Pan African International Conference on Science, Computing and Telecommunications

Proceedings PACT 2019 Swaziland

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Chair's Report

"Anything noble is as difficult as it is rare," say Baruch Spinoza. PACT 2019 has been a tremendous conference. It was held in the beautiful country - the Kingdom of eSwatini. The conference was brought back to Southern Africa after the successful hosting of it at the Strathmore University, Kenya in 2017. We received a huge support from the management of the University of Swaziland, and many thanks to the various committees that made conference a success. While the conference was held at the University premises, the accommodation of delegates was provided at the Esibayeni Lodge, the Sibane Hotel and the Royal Swazi Sun Hotel.

For this edition of the conference, we received 52 quality papers. These papers were rigorously peer-reviewed. And at the end of the process, the recorded paper acceptance ratio was 0.53. The pre-conference workshop and tutorial featured presentation on an emerging Pan-African Strategic Studies Initiative. And the conference had three world-renowned professors delivering keynote speeches on hot topics, such as Cybercourt, ICT Policies and Artificial Intelligence for Humanity.

I am pleased with the planning and execution of the conference activities, and deeply honoured to invite you to read this book of proceedings.

Call for Papers

The conference accepted papers submitted, but not limited to, in the following areas:

1. Computational Intelligence
2. Cyber security & Forensics
3. Wireless Mobile Communications(3G, 4G and 5G)
4. GIS and Remote Sensing
5. Deep Learning
6. Machine Learning
7. Telecommunications
8. Data Communications
9. Cloud Computing
10. Computer Science Education on learning and teaching
11. Health Informatics
12. Food Security(Policies & Technical aspects)
13. ICT for development
14. Applied Mathematics
15. Internet of Things(IoT)
16. Nanotechnology
17. Information Science
18. Biotechnology

Deadline for submission of Full papers:	Jan. 7, 2019
Notification of Acceptance/Rejection:	Jan. 31, 2019
Final Revised paper Submission:	Feb. 11, 2019
Deadline for Notification of Pre-Conference Workshops:	Sept. 15, 2018
Deadline for expression of interest in Pre-Conference Workshops:	Sept. 5, 2018
Launching of IEEE Chapter in Swaziland:	Mar. 8, 2019
Pre-Conference Workshop:	Mar. 9, 2019
Conference	Mar. 10-13, 2019

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Conference Programme

PRE-CONFERENCE WORKSHOP

8 MARCH 2019

VENUE: SCIENCE EDUCATION CENTRE
UNIVERSITY OF ESWATINI
MATSAPHA, KWALUSENI
ESWATINI

CHAIRPERSON: DR S. G FASHOTO

11:30 -12:00	ARRIVAL OF PARTICIPANTS AND REGISTRATION
12:00 – 12:15	OPENING AND WELCOME REMARKS : DR S. G. FASHOTO
12:15 –14:30	PRESENTATION: TOPIC: PAN AFRICAN INSTITUTE OF STRATEGIC STUDIES (AFRICAN ACADEMIC RESEARCH & RESOURCE CENTRE) FACILITATORS: REV. CANON BENEDICT KOLEDOYE & PROF. MICHAEL ADEYEYE OSHIN ABSTRACT: PAISS (PAN African Institute of Strategic Studies) is an institute proposed to address some of the challenges confronting Africa. These challenges are changing faces as occasioned by proliferating liberalisation of markets and international trade and democratic deficits to mention a few. AARRC (African Academic Research & Resource Centre) is an arm of PAISS commissioned to drive some technical processes aimed at combating the challenges. The workshop will feature some of the ongoing efforts of the institute.
14:30 –15:00	CLOSING REMARKS AND VOTE OF THANKS: DR A. S. METFULA
	TEA *TEA* *TEA*

PROGRAMME OF PROCEEDINGS

11-13 MARCH 2019
UNIVERSITY OF ESWATINI
MATSAPHA, KWALUSENI
ESWATINI

	MONDAY, 11 MARCH 2019:
7:30-8:30	**ARRIVAL OF PARTICIPANTS AND CONFERENCE REGISTRATION** **VENUE:** IDE SEMINAR ROOM
8:30-11:00	**OPENING CEREMONY:** IDE LECTURE THEATRE **DIRECTOR OF CEREMONIES:** DR. P.M. MASHWAMA **WELCOMING REMARKS:** PROF. S.S. MOTSA (DEAN, FACULTY OF SCIENCE & ENGINEERING) **REMARKS & INTRODUCTION OF MIN OF ICT:** PROFESSOR. J.M. THWALA (VC) **MINISTER OF ICT:** HRH PRINCESS SIKHANYISO **PERFORMANCE:** UNESWA CULTURAL GROUP **KEYNOTE ADDRESS:** EXTERNAL ACTORS IN NATIONAL ICT POLICIES FORMULATION IN DEVELOPING COUNTRIES PROFESSOR WALLACE CHIGONA, UNIVERSITY OF CAPE TOWN, SOUTH AFRICA
	TEA ***TEA*** ***TEA***
11:30-1:00	**PLENARY SESSION 1:** IDE LECTURE THEATRE **SESSION CHAIR:** PROF. JOHNSON AGBINYA 1. **TOPIC:** ADOPTION OF FREE AND OPEN SOURCE SOFTWARE IN TEACHING AND LEARNING OF STEM SUBJECTS IN HIGH SCHOOLS USING R-PROGRAMMING IN DEVELOPING COUNTRIES: A CASE OF THE KINGDOM OF ESWATINI **PRESENTERS:** ELLIOT MBUNGE, STEPHEN FASHOTO AND ANDILE METFULA UNIVERSITY OF ESWATINI, KWALUSENI, ESWATINI **REFLECTIONS, COMMENTS & QUESTIONS**

	2. **Topic:** Machine-Learned Bayesian Networks Reveal Invasion Dynamics Of Chromolaena Odorata In Eswatini **Presenters:** Wisdom Dlamini University Of Eswatini, Kwaluseni, Eswatini Willem Nel &Jimmy Hendrick University Of South Africa, South Africa **Reflections, Comments & Questions**
1:00-2:00	**LUNCH** **LUNCH** **LUNCH**
2:00-6:00	**Parallel Sessions** **Venues:** IDE Lecture Theatre----------IDE Seminar Room----------Commerce Conference Room
	End of Day 1
	TUESDAY, 12 MARCH 2019:
8:30-10:30	**Keynote address:** Cyber Court Professor Atsushi Ito Utsunomiya University, Japan **Plenary Session 2:** IDE lecture theatre **Session Chair: Prof.** Michael Adeyeye Oshin 1. **Topic:** Application of Gaussian Primes in 5G QAM Modulation Using Lattice Power Allocation Scheme **Presenter:** Johnson Ihhey Agbinya Melbourne Institute of Technology, Australia **Reflections, Comments & Questions** 2. **Topic:** An Information Delivery System on Disaster for Hearing Impaired People Using LED Display -To Extend to Universal Usage **Presenters:** Yuko Hiramatsu , Chuo University, Japan Atsushi Ito, Utsunomiya University, Japan Akira Sasaki, GClue Inc., Japan Naoto KawasakiUtsunomiya University, Japan Koichi Tsunoda, Tokyo Medical Center, Japan Sotaro Sekimoto, Tokyo Medical Center, Japan Fumihiro Sato Chuo University, Japan **Reflections, Comments & Questions**
10:30-11:00	***TEA*** ***TEA*** ***TEA***
11:00-1:00	**Parallel Sessions** **Venues:** IDE Lecture Theatre----------IDE Seminar Room----------Commerce Conference Room
1:00-2:00	**LUNCH** **LUNCH** **LUNCH**
2:00-4:00	**Plenary Session 3:** IDE Lecture Theatre **Session Chair:** Dr. Z. Makukula 1. **Topic:** A Systematic Review Of Soft Computing Techniques For Software Testing **Presenters:** Boluwaji Akinnuwesi And Gboyega Adenaike Lagos State University, Ojo, Nigeria **Reflections, Comments & Questions**

	2. **Topic:** Automated Testing Of Real-Time Gis Applications In An Agile Development Environment Using Open Source Tools **Presenter:** Laurie Butgereit Nelson Mandela University, South Africa **Reflections, Comments & Questions**
4:00-6:00	Audience Getting Ready For The Conference Gala Dinner
6:30	**Gala Dinner** **Venue: Ligcabho LemaSwati (Sports Emporium)**
	End of Day 2
	WEDNESDAY, 13 MARCH 2019
8:30-10:00	**Plenary Session 4:** IDE Lecture Theatre **Session Chair:** Dr. M.A. Mulatu 1. Improved Trivariate Spectral Collocation Method Of Solution For Two-Dimensional Nonlinear Initial-Boundary Value Problems Via Domain Decomposition **Presenters:** Mutua Samuel Felex University Of Kwazulu-Natal, Durban, South Africa Sandile Motsa University Of Eswatini, Kwaluseni, Eswatini **Reflections, Comments & Questions** 2. Application Of Cloud Computing To Improve Library Services: A Study **Presenter:** Satyabati Sorokhaibam University Of Eswatini, Kwaluseni, Eswatini **Reflections, Comments & Questions** 3. Bayesian Geostatistical Modeling To Assess Spatio-Temporal Variations And Elapsing Time For Malaria Incidence Risk In Swaziland **Presenters:** Sabelo Dlamini And Sizwe Mabaso University Of Eswatini, Kwaluseni, Eswatini **Reflections, Comments & Questions**
10:00-10:30	***Tea*** ***Tea*** ***Tea***
10:30-12:00	**Closing**
	Reflections, Resolutions, Vote Of Thanks & Closure Prof. Johnson Agbinya **Venue:** IDE Lecture Theatre **Performance:** UNESWA CULTURAL GROUP
12:00-1:00	**Lunch** **Lunch** **Lunch**
1:00	**Excursion**
	End of Conference
	Bon Voyage

Keynotes and Workshops/Tutorials

Keynotes

- Title: Cyber Court

  Speaker(s): Prof. Atsushi Ito

  Abstract: Because the business world is increasingly recognizing the Internet as a place where commercial dealings can take place, the legal system needs to be equipped to not only understand the Internet but also to use it as a tool to successfully exchange and use information. The Internet now provides a wide range of legal information, and one of the benefits of information being provided in this way is that it can be kept up-to-date as the law changes. Not only can the Internet assist in legal research but it can also assist in court processes in general, that is, in trial preparation and in the courtroom throughout the hearing. Reasons that courts should embrace such technology lie in the constantly increasing caseloads, the complexity of cases and jurisdictions, resource constraints, the pressure to improve access to justice, expectations of improvements in performance, and the pressure to improve efficiency and effectiveness in the court's administration and the delivery of justice. Therefore, jurisdictions of many countries aim to follow economic growth and political changes to allow anyone to easily access judiciary documents by introducing ICT (information and communications technology). Such a justice system empowered by ICT is called a "cyber court". In this keynote address, I would like to mention the idea of the Cyber Court, explain some examples of it in some countries and introduce researches to support it.

  Biography: Atsushi Ito received B.S. and M.S. degrees from Nagoya University in 1981 and 1983, respectively. He also received a Ph.D. degree from Hiroshima City University in 2007. From 1983 to 2014, he was with Research and Development Laboratories of KDDI Corporation. He is now a Professor of the Graduate School of Engineering of Utsunomiya University from 2014. During 1991-1992, he was a visiting scholar at the Center for the Study of Language and Information (CSLI) of Stanford University. His current research interests include open platform for mobile communications, ad hoc networking, user interface design, cyber court and IoT for agriculture.

- Title: External Actors in National ICT Policies Formulation in Developing Countries

  Speaker(s): Prof. Wallace Chigona

  Abstract: National Information and Communication Technology (ICT) policies are vital towards shaping how the technology contributes towards the attainment of socio-economic development goals of respective countries. Recent international events have nudged most of African countries to formulate national ICT policies. The low success rate of the policies in Africa could be, to an extent, attributed to the dearth of research focusing on ICT policies on the continent. In this talk we shine the lime light on an important aspect which needs to be critically researched: the role of policy formulation actors who are from outside to the country. The involvement of external actors in formulation of policies affects the look and feel of public ICT policies and consequently their acceptability and their impact. This presentation explores the nature and effects of external actors in the formulation of national ICT policies in Africa. Research in this area has the potential to contribute towards empowering custodians of ICT policies to manage the engagement between internal and external policy formulation actors.

  Biography: Wallace Chigona is a Professor in Information Systems at the University of Cape Town, South Africa. His research focuses on the use of ICTs for human development and ICT policy. He has researched on the use and impact of ICTs amongst the disadvantaged communities in different African Countries. Prof Chigona is currently on the editorial boards of Electronic Journal of Information Systems in Developing Countries (EJISDC) and previously served on the board of the African Journal of Information Systems. Prof Chigona is rated as an Established Researcher by the South African National Research Foundation (NRF). Prof Chigona is member of (i) UNESCO/Netexplo Advisory Board; (ii) the Communication Policy Research for the global South. He previously served as the IFIP 9.4 Africa and the Middle East representative.

- Title: Artificial Intelligence for Humanity

  Speaker(s): Prof. Christian W. Omlin

  Abstract: The revolution of AI is fueled by ever larger available data, advancement in AI algorithms and the relatively cheap computational power that outperforms most supercomputer of the recent past. While these advances hold the promise of improving the quality of life and may even help

tackling some of the pressing issues facing humanity, these opportunities also come with uncertainties and society is facing important challenges with AI. This talk presents both opportunities and challenges as we examine the present and the future of AI.

Biography: Christian Omlin joined the Center for Artificial AI Research (CAIR) at the University of Agder in Norway in September 2018. His previous academic appointments include the University of South Africa, University of the Witwatersrand, Middle East Technical University, University of the South Pacific, University of the Western Cape and University of Stellenbosch. He served as the founding director of the Telkom/Cisco Center of Excellence for IP and Internet Computing at the University of the Western Cape. He did his graduate work while at the NEC Research Institute in Princeton (USA). Much of his research focuses on architectures, learning algorithms, hybrid systems and knowledge representation in neural networks for time series modelling with applications in eHealth, security, safety, human-computer interaction, astronomy, and bioconservation. Beyond his immediate technical interests in AI, he is fascinated by deeper questions of (universal) consciousness and being. He received his Ph.D. from Rensselaer Polytechnic Institute (USA) and his M.Eng. from the Swiss Federal Institute of Technology in 1995 and 1987, respectively

Workshops/Tutorials

- Title: PAN African Institute of Strategic Studies (African Academic Research & Resource Centre

  Facilitator(s): Rev. Canon Benedict Koledoye & Prof. Michael Adeyeye Oshin

  Abstract: PAISS (PAN African Institute of Strategic Studies) is an institute proposed to address some of the challenges confronting Africa. These challenges are changing faces as occasioned by proliferating liberalisation of markets and international trade and democratic deficits to mention a few. AARRC (African Academic Research & Resource Centre) is an arm of PAISS commissioned to drive some technical processes aimed at combating the challenges. The workshop will feature some of the ongoing efforts of the institute.

  Biography: Benedict Koledoye obtained his first degrees in Philosophy (Ibadan) and Theology (Rome). He attended University of Bradford, United Kingdom where he received a Master's Degree in Peace Studies. He thereafter obtained a PhD from University of Swansea. His areas of expertise are; politics, governance, and development.

  Michael Adeyeye Oshin earned his first Master's degree in Information and Communication Technology. He earned his second Master's degree and a PhD degree in Electrical Engineering at the University of Cape Town. Among other professional obligations, he holds various fellowships in Europe (Erasmus Mundus@University of Montpellier) and Africa (University of Zululand) and became a Professor at the School of Computing, University of Namibia.

BOOK OF PROCEEDINGS

Machine-learned Bayesian Networks Reveal the Invasion Dynamics of *Chromolaena odorata* in Eswatini

Wisdom M. Dlamini*[1], ORCID ID: 0000-0002-0397-4404, Willem A.J. Nel[2], Jimmy Hendrick[2]

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Abstract. The ecological and socio-economic impacts of invasive alien species make them significant drivers of ecosystem change. The control of such species requires knowledge on their invasion dynamics including how they interact with the invaded environment. In the Kingdom of Eswatini (formerly Swaziland), such information has been very scarce for one highly invasive alien plant, *Chromolaena odorata*, more so on the drivers of its spread. Species distribution models provide vital insights into species ecology although there are limitations with conventional approaches. Bayesian networks (BNs) are emerging techniques for solving complex problems due their ability to model stochastic, non-linear inter-causal relationships and uncertainty. However, most of the previous BN-based studies have used knowledge-based approaches which have documented limitations on their development and parameterization. In this study, machine-learned BN models are integrated with geographic information system (GIS) to explore the invasion patterns and pathways of *C. odorata* in Eswatini. Various BN structure learning algorithms coupled with feature selection were used to build and test models from a set of 170 variables. All the BN models produced very accurate predictions of *C. odorata* occurrence (log loss: 1.121 to 0.92 bits/instance, mean = 1.02 bits/instance). The models graphically reveal new insights on the complex interplay of factors which influence the species' geographic distribution patterns. The proportion of people with access to electricity in an area is found to be a key driver of the distribution of the *C. odorata* in addition to minimum temperature of the coldest month and other topographic and biotic factors. The derived occurrence probability maps show different levels of invasion risk with high risk areas concentrated in ruderal and human-disturbed areas with suitable climates. This study highlights the importance of machine-learned BN models and geospatial technology in predicting and explaining complex contemporary problems such as alien species invasion.

Keywords. Bayesian network, Eswatini, invasive plant, geographic information system, machine learning

1 INTRODUCTION

The questions of what makes an invader successful is central in the study of invasion (Latombe et al. 2017). The identification of the key and relevant factors that constrain the range of species is one of the most important goals in ecology, biogeography and species distribution modelling (González-Salazar et al., 2013). Discovery of ecologically meaningful species-environment relationships embedded within existing distribution data requires the choice of relevant factors or variables that effectively describe each species' ecology. Species-environment relationships are of critical importance in understanding the distribution and abundance of species. The unravelling of the complex biotic and abiotic interactions and relationships is one of the fundamental challenges in ecology. Understanding the networks that form ecosystems is also of growing importance in predicting how species will respond to climate change. Like many biological systems, species-environment relationships are inherently complex, stochastic and non-linear which complicates the task of untangling of the underlying interactions and relationships. This complexity is further exacerbated by the fact that environmental data are typically polymorph (variable), incomplete (missing), noisy (difficult to observe) and, therefore, can be the source of errors (Gibert et al. 2008). Furthermore, species interact through various mechanisms such as competition, predation, facilitation and mutualism, amongst others (Milns, Beale, & Smith, 2010; Wisz et al., 2013). The relationships amongst biotic and abiotic factors that influence a species' distribution are themselves rarely deterministic and are often fuzzy in nature. Hence, the unravelling of the complex interactions and relationships is one of the fundamental challenges in ecology (Boulangeat et al. 2012; Jordano 2016).

Understanding the networks that form the systems is of growing importance for predicting and managing the potential spread of invasive alien organisms (Faisal et al. 2010). Nevertheless, underlying all the modelling approaches is the need to uncover, describe, understand and predict the biogeographic and ecological relationships between species and the environments in which they are or likely to be found. McMahon (2005) suggests that researchers must better quantify these inter-dependencies of the community into which a species invades in order to quantitatively describe the way components of a community interact with that species. Identifying these underlying patterns and processes requires novel approaches and methods that are capable of efficiently recovering and inferring the structure of these complex networks and acquiring, integrating and modelling massive quantities of diverse field data (Birkhofer et al. 2015; Hochachka et al. 2012; Milns et al. 2010).

This study applies machine-learned Bayesian networks (BNs) (Pearl 1988) to study one of the highly invasive species in the Kingdom of Eswatini (formerly Swaziland), *Chromolaena odorata* (L.) R.M. King & H. Rob. This invasive plant species is a Category 1 species and is included in Henderson's (2007) list of prominent invaders of southern African forest, grassland and savanna biomes. The key objectives are to identify the key drivers of this species geographical occurrence and to predict its potential spread in the country.

2 METHODS

2.1 Species distribution data and explanatory variables

Alien plant observation datasets were obtained from plot-based field surveys (Loffler & Loffler, 2005) and a detailed aerial surveys (Kotzé et al., 2010) conducted over Eswatini. From these, a total of 18,066 points were extracted from the aerial survey dataset whilst the tree atlas data comprised of 585 data points derived from sampling plots. The two datasets were merged, creating a database which was recoded into presence-absence format within 1km grids covering Eswatini. The datasets were then cleaned, a process that involved removal of double allocation cases. This also included verification of misspelling and checking for inconsistent species nomenclature in cases where elements of both common and scientific names were simultaneously used for the same species.

Suitable explanatory variables for generating important hypotheses in the invasion biology of the species under investigation were identified. In this study we used proximal (and to a lesser extent distal) 170 predictor variables consisting of biotic and abiotic variables to develop the models. All the datasets were collated and converted to $1km^2$ raster data formats within a geographic information system (GIS) for spatial analysis. Furthermore, the collated raster datasets were re-formatted for processing and analysis using the open-source data mining software, Waikato Environment for Knowledge Analysis (WEKA) version 3.7.12 (Hall *et a*l., 2009).

2.2 Data preprocessing and feature selection

One of the main tasks of this study was to select those variables which influence *C. odorata* occurrence. A hybrid approach which iteratively alternates between filter ranking and wrapper feature subset selection was used in order to speed up the computation process. This method also uses an evaluation heuristic which prefers subsets of features that are highly correlated with the class while having low inter-correlation. A filter ranking technique, the re-ranking-based feature subset selection method (Bermejo et al. 2012), was implemented together with the correlation-based feature selection (CFS) filter method (Hall, 1998) for feature evaluation. Attribute space searching was optimized using the evolutionary particle swarm optimization (PSO) algorithm (Kennedy & Eberhart, 2001).

Using this approach, the subsets of candidate features or variables were selected and each variable scored using a metric function which measures a feature's ability to discriminate the presence and absence of *C. odorata*. For this purpose, Peng, Long, & Ding's (2005) maximum relevance - minimum redundancy (mRmR) algorithm was used because it has the dual optimization goal of maximizing relevance and minimizing redundancy. The symmetric uncertainty metric (Seiler and Seiler 1989) was used as a measure of the appropriate metric of correlations and of the mutual dependence between two features because it compensates for the information gain's bias toward features with more values and normalizes its values to the range 0 – 1.

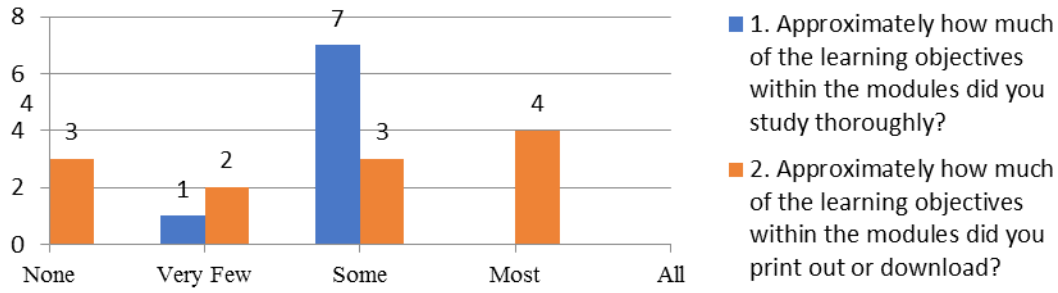
2.3 Bayesian network learning

The BN structure and parameter learning processes were performed using the WEKA software. For structure learning, a total of 16 algorithms were used. In addition to the naïve Bayes - NB (Duda and Hart 1973), the score-based BN structures which were machine-learned were the Tree-Augmented Naive Bayes – TAN (Nir Friedman et al. 1997), General Bayesian networks (GBNs) and Bayesian Augmented Naïve (BANs) networks. The BANs were learned with different search strategies namely Greedy Hill Climber (Buntine 1996), K2 (Cooper and Herskovits 1992), Look ahead in good directions hill climber (Holland et al. 2008), Repeated Hill Climber (Buntine 1996), Simulated Annealing (Kirkpatrick et al. 1983) and Tabu Search (Glover 2008). The search strategies were implemented for both the local and global search-based strategies except for the LAGD hill climber, which was only available for the local search implementation. The conditional independence (CI) algorithm and Inferred-Causation (ICS) algorithms (Verma and Pearl 1992) were the constraint-based approaches used. All the network topologies and search strategies differ in the trade-offs made between network structure, computational complexity and structural richness.

A Markov blanket (Chen et al. 2015) was then applied over the prediction node or target variable (i.e. *C. odorata* occurrence) to ensure that every node or variable in the network is its parent or child of sibling. In order to guarantee impartiality of the structure learning process, the number of parents for any node was set to a value of 100,000 which imposes no restrictions on the number of parents a node could have. After learning the structure, the parameters or probabilities were estimated based on the learned structure and the data. Parameters were estimated using the Bayesian estimator (Bouckaert 1994) which directly computes the relative frequencies of the associated combinations of the attribute values in the training data. The Bayesian estimator also assumes that the conditional probability of each node corresponding to its parent instantiation conforms to the Dirichlet distribution with local parameter independence (Chen et al. 2015). The alpha parameter, which is the initial count on each value, was used in the estimation of the conditional probability table for each of the BN models (except for the NB). This parameter was set to 0.5 to avoid bias and preliminary analysis showed that this performed best across all the algorithms.

2.4 Variable importance analysis

Each of the selected variable's connectivity strength was estimated by measuring its relative influence on the occurrence of *C. odorata*. This was done through calculating and ranking the mutual information or entropy reduction (Laskey 1995) between the target (*C. odorata* occurrence) node and the environmental variables. Given a probability distribution p defined over two sets of variables X and Y, the mutual information between X and Y, which is measured in bits, is:



, (1)

where $p(x)$ and $p(y)$ are the probability densities of x and y, and $p(x, y)$ is the joint density; which can also be expressed in terms of entropy as:

$$I(X;Y) = H(X) + H(Y) - H(X,Y), \quad (2)$$

H(X) and H(Y), are the entropies of X and Y, respectively, and H(X,Y) is the joint entropy of X and Y. Given a joint distribution Q(Y,X) of two variables X and Y, the symmetric mutual information attempts to extract the relevant information that Y contains about X and is a very good measure of the average number of bits needed to convey the information X contains about Y and vice versa. As such, the mutual information can detect additional non-linear dependencies and correlations among variables that are undetectable using the conventional measures (Guyon and Elisseeff, 2003). The minimum possible value is zero when the variables are independent and attains a maximum when one variable is a deterministic function of the other.

2.5 Performance evaluation

Ten (10) runs of 10-fold cross-validation were performed on each BN model to obtain its prediction accuracy, thereby ensuring that the final calibration of every model used all the data available in making predictions. The interest was on assessing the ability of each of the machine-learned BN models to predict or correctly reproduce the observed spatial patterns in the geographic distribution of *C. odorata*. Discrimination capacity and reliability were the preferred criteria for assessing model performance and hence a metric that focused on both was used. The performance of the different BN learning algorithms was tested using the logarithmic loss (Marcot 2012). This metric was preferred because of its suitability and reliability for tasks where the posterior probability values are an important consideration.

3 RESULTS

Despite the differences in BN structures, all the learned BNs seem to model the data almost equally well, which can be gathered from their predictive accuracies (Table 1). Generally, there were few statistically significant differences ($p < 0.01$) in the performance of the BN learning algorithms. Hence, the best performing algorithm was chosen solely based on having the lowest logarithmic loss.

Table 1. Performance comparison for all the BN learning algorithms (best score is indicated in bold letters).

Algorithm	Log loss (bits/instance)
naïve Bayes	1.121
Global search algorithm	
hill climb	1.053
k2	1.115
simulated annealing	1.008
tree-augmented naive	1.08
tabu search	1.097
Local search algorithms	
hill climb	**0.92**
k2	1.004
look ahead in good directions	0.931
repeated hill climb	0.923
simulated annealing	0.935
tree-augmented naive	0.999
tabu search	1.002
Constraint-based algorithms	
inductive causation	0.966
conditional independence	1.119

The hill-climbing algorithm learned with local scoring outperformed all other algorithms. This algorithm produced a general BN (GBN) structure comprising 6 interacting variables with direct arcs to the target variable (Fig. 1). Of the 170 variables initially used, only 6 variables were selected, implying that 164 predictor variables were redundant and least relevant, i.e. they had weak influence on *C. odorata* geographic distribution.

According to the best performing model, the distribution of *C. odorata* in Eswatini is primarily determined by the minimum temperature of the coldest month, land surface curvature, land surface form, percentage of population with access to electricity and possible interactions with *Caesalpinia decapetala* and *Lantana camara*.

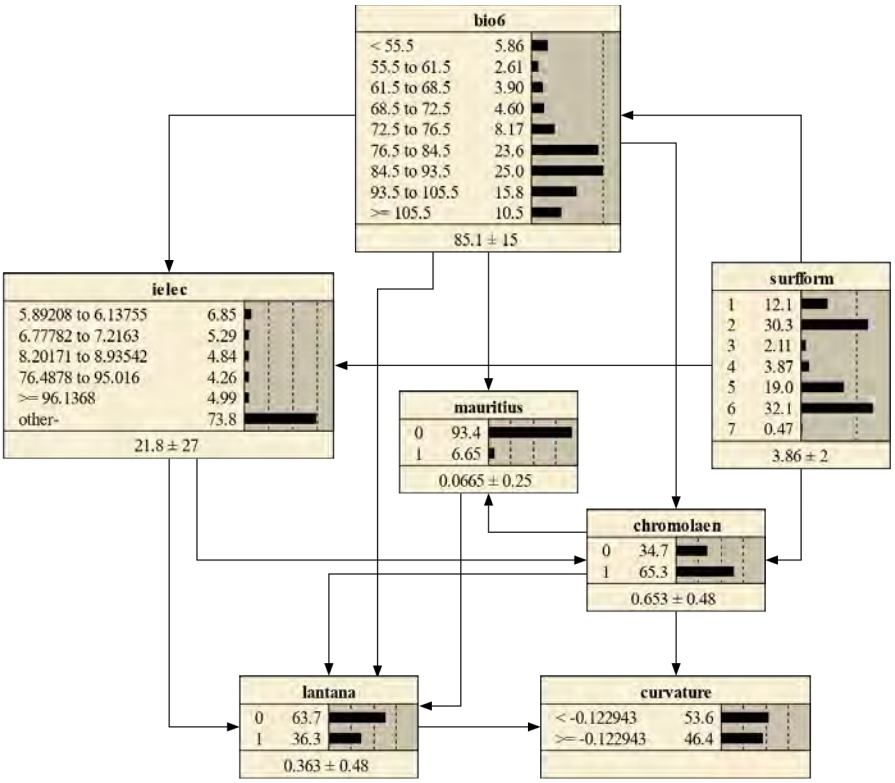


Fig. 1. The Bayesian network of *Chromolaena odorata* distribution derived from the hill climbing algorithm with local search.

A minimum temperature of the coldest month of 7.2˚C was found to be western threshold for the *C. odorata* distribution. Areas with a high percentage of people with access to electricity were found to be highly invaded by the species although the relationship is non-linear. Hills or low mountains and breaks (drainage lines) are similarly prone to invasion as equally elucidated by the species' occurrence relationship with surface form and land surface curvature.

The percentage of people with access to electricity and the minimum temperature of the coldest month are the strongest predictors of *C. odorata* occurrence whilst land surface form has the least influence of the six variables (Table 2). Hence, the socioeconomic conditions of an area, which likely determine the extent and nature of human use of environmental resources, are a key determinant of *C. odorata* invasion. The spread of the species is constrained by low temperature conditions, resource availability, and biotic (probably facilitative/mutualistic) interactions with *L. camara* and *C. decapetala*.

Table 2. Mutual information for selected *Chromolaena odorata* predictor variables.

Variable	Mutual information
ielec - % of people with access to electricity	0.15692
bio6 - minimum temperature of coldest month	0.09207
lantana - presence of *L. camara*	0.01074
curvature - surface curvature	0.00532
mauritius - presence of *C. decapetala*	0.00545
surfform - surface form	0.00194

The strong influence of the interacting and dominant factors shown in Fig. 1 and Table 2 result in the predicted spatial distribution in Fig. 2.

Fig. 2. Predicted posterior probability of *C. odorata* occurrence in Eswatini (predicted by the best-forming local hill-climbing BN model in Fig. 1). The actual occurrence points are shown in black dots (aerial survey) and triangles (tree atlas survey).

4 DISCUSSION

The findings indicate that general Bayesian networks (GBNs) and Bayesian augmented networks (BANs) structures perform no better than that of the NB, CI and TAN when the same parameter estimation procedure is used. This suggests that the joint probability distributions (JPD) for *C. odorata* could be represented with equal validity by an equivalence class, i.e. the collection of BN structures representing the same JPD with differences only in the direction of (some of) their arcs. However, the more flexible structure of GBNs and BANs endows them with not only the capacity to express approximate cause and effect relationships, e.g. among *C. odorata* occurrence and the explanatory variables, but also between the explanatory variables themselves (Lee and Cho 2012; Milns et al. 2010). Aguilera, Fernández, Reche, & Rumí (2010) and Lorena *et a*l. (2011) noted that the limitations and relative poor performance of the NB might be attributed to its independence assumption which is not useful for ecological applications where interactions between variables are important. The NB also tends to retain spatial autocorrelation among the predictor variables (Ibrahim et al. 2015)

Based on the BN models used in this study, the prediction of the species' distribution depends only on the variables of its Markov blanket. If the observation of the Markov blanket variables is incomplete, i.e. not all the variables are observed at inference time, information from outside the Markov blanket flows into the prediction by indirectly marginalizing (summing) missing variables out (Vogel et al. 2014). This means that including many variables is desirable and provides additional knowledge, which is one of the advantages of BNs. Markov blankets have been shown to produce effective probabilistic models (Aliferis et al. 2010).

The machine learning application of the Markov blanket, coupled with the automatic discretization and feature selection processes, resulted in BN structures that had more arcs connecting the variables to each other and direct connections from some of the explanatory variables to the target (*C. odorata* occurrence) node. The direct arcs to the target variable intuitively indicate that factors such as surface form, percentage of people with access to electricity and minimum temperature of the coldest month have a large informative effect and are thus assumed to have an important influence on the distribution of this invasive plant. Most importantly, complex non-linear relationships between *C. odorata* occurrence and predictor variables were uncovered. Furthermore, the directed acyclic graphs show which variables are the most relevant for the prediction of *C. odorata* distribution and graphically decipher the probabilistic dependence and conditional relationships between those variables.

C. odorata is vigorous in its invasion and as a result, it is invading many disturbed areas in many parts of the country. The species seems less tolerant of frost or very low temperatures as evidenced by low temperatures of the coldest month restricting its westward expansion to high altitude grasslands. However, incursions along warmer river valleys can be observed. Binggeli (1999) also observed this intolerance to frost as well as drought. The intolerance to drought perhaps explains low probabilities in the south-eastern parts of the country, an area characterized by very low rainfall and frequent drought conditions (Goodall and Erasmus 1996). Goodall, Zimmermann, & Zeller (1994) and Goodall & Erasmus (1996) provided the first detailed account of the species invasion in South Africa and Eswatini wherein they highlighted that the species may have first invaded Eswatini in the mid- to late 1980s through the warmer south-eastern parts of the country. As predicted by Goodall et al. (1994), the species has since spread to most of the areas that were uninvaded more than two decades ago.

The influence of land surface curvature and surface form highlights the importance of topography on the establishment of the plant. Although the species establishes itself

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in most terrain types, the BN model indicates that hillsides and drainage lines are particularly vulnerable to invasion. Another notable factor is the percentage of people with access to electricity. This compound variable is a measure of human welfare whilst also an indirect indicator of the proportion of people who may be using other alternative sources of energy especially firewood and facilitating the invasion of *C. odorata*. This finding highlights the potential effects of human welfare on patterns of spatial development and hence alien plant invasion on the landscape. Socio-economic variables are known to be indicative drivers of land use and land cover changes including forest fragmentation which create gaps that can facilitate invasion (Mandal & Joshi, 2014).

Another important finding was the association of *C. odorata* with *L. camara* and *C. decapetala*. Ramaswami & Sukumar (2013) observed this co-occurrence with *L. camara* whereby there was a general increase in the abundance of *C. odorata* in areas where *L. camara* occurred. However, this increase was truncated by a further increase in the density of *L. camara*. *C. odorata* populations have also been observed to increase soil fertility through enhancing the nutrient and organic matter content and reducing soil bulk density, thereby facilitating the invasion of species such as *L. camara* (Mandal and Joshi 2014) and probably *C. decapetala*. This affirms the classification of this species as a transformer species (Henderson 2001) through allelopathy, amongst other mechanisms (Sahid et al. 2011; Zachariades and Goodall 2002). There is, therefore, a need to focus on *C. odorata* as a priority species particularly in the high probability areas. Its control should also minimize new incursions into new areas primarily those that are disturbed by human activities.

5 CONCLUSION

The data-driven BN models provided further insight into the factors that result in the observed *C. odorata* geographic distribution patterns and further elucidated the underlying ecological processes. A combination of high climatic and topographic heterogeneity coupled with intense anthropogenic activity results in complex invasion patterns, which the BNs were able to reveal. It is interesting to note that the machine-learned BN models uncovered both known and novel complex interplays of bioclimatic, topographic and anthropogenic factors.

The strong association of *C. odorata* with topography is apparent, as is the effect of human activities. This implies that increasing human activities will increase propagule pressure and facilitate further invasions, only to be constrained by low temperatures and limiting topography. The derived BN models provide very important knowledge on one of the highly invasive species which had not been studied at this level of spatial detail or scale before in the country. Most importantly, the importance of integrating machine learning, BNs and geographic information systems in elucidating a complex environmental problem is demonstrated.

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Afrimesh: A Framework for Management and Monitoring of Wireless Mesh Networks

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Abstract. VoIP over mesh networks could be a potential solution to the high cost of making phone calls in most parts of Africa. The VillageTelco is an easy-to-use and scalable VoIP over WLAN telephone infrastructure. The VillageTelco infrastructure runs a Network Management System (NMS) built on the BATMAN routing protocol. The NMS, which is called Afrimesh, uses both Simple Network Management Protocol (SNMP) and Internet Control Message Protocol (ICMP) as the network management protocols. It provides a thorough report on network health, such as interference, noise level and latency. In addition, it displays the current network topology and can run at a node thereby making it efficient to identify compromised or isolated node(s). This article presents the Afrimesh architecture. The performance of a typical mesh network is also reported here. The performance metrics include signalling overhead, network latency, jitter and bandwidth of a small-scale mesh network with few nodes. Experiments showed that an additional hop in a network increases the network latency by averagely 35ms. In addition, the signalling overhead of a network using the NMS increases with time at every node. However, the footprint is small and would not impede the performance of a network in a large-scale deployment. Results also showed that the villagetelco equipment has a high throughput of 15Mbps with minimal jitter. These results make the equipment with its NMS a reliable wireless telecommunication infrastructure for quality voice and data services.

Keywords: Afrimesh, Wireless Mesh Networks, Network Management

1 Introduction

Although most WMN (Wireless Mesh Networks) projects can be classified into community and commercial projects, intra-campus wireless networks now exist in several universities and research centres. The wireless networks are used for ubiquitous communication. Examples are RoofNet at MIT, VMesh in Greece, MeshNet at UCSB and CUWIN in Urbana. Some of the commercial solutions already in the market are FON, Meraki, Nortel and Cisco WMN solutions. They all provide specific hardware for use in sharing broadband, though they operate based on different business approaches. FON's objective, as an example, is to develop community-centric alternatives to existing broadband infrastructure. FON sells equipment to create hotspots, provides an infrastructure to aggregate information on hotspot locations, and manage authentication and billing for hotspot use. By providing the infrastructure, they facilitate the creation of many hotspots in many locations and their members enjoy global roaming use of this network of hotspots.

A WMN can provide network capacity for community activities, such as content distribution, education, health care, games, file sharing, peer-to-peer applications and services and resource

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sharing. VillageTelco (VT) is another WMN project. It is a local and wireless infrastructure that can provide a local telephone network and Internet services for personal use and make a sustainable business for interested parties. Its wireless nodes, called Mesh Potatoes (MPs), form a WMN with nearby wireless nodes to provide wireless links. An MP (Mesh Potato) includes the Afrimesh Network Management System (NMS). An NMS is a service that employs a variety of tools, applications and devices to assist human network managers in monitoring and maintaining networks. Its concepts in wireless mobile network include mobility management, power management and network monitoring and profiling.

Data used in NMSs (Network Management Systems) include metrics from the MAC and the PHY layers of the 802.11, routing and network topology [1]. Diagnosis and analysis often require a complete trace of the packets in many network faults. As bandwidth requirements can be prohibitive, the capture and remote analysis of all data packets is often infeasible in a mesh network [1]. However, network monitoring has helped in (i) providing statistics to determine the causes of network failure, (ii) verifying performance of routing protocols, applications and middleware, (iii) locating potential bottlenecks in order to re-adjust a network.
Traditional solutions for monitoring wireline networks provide poor performance in mesh networks due to several reasons. First, the network is being maintained by combined effort of the hosts that make the wireless network. Second, the hosts often operate under severe constraints, such as limited bandwidth. Third, mesh networks experience significant signal quality fluctuation, such as interferences, hidden hosts and unreliable physical medium. While the previous paper [2] reported the power consumption, antenna gain and the hardware and software architecture of an MP (Mesh Potato), this paper presents the Afrimesh architecture and its implementation.

Network Management tools are required for network monitoring and profiling. MPs, Afrimesh and other related WMNs are discussed in this paper. The paper is arranged as follows: Section II presents a background of WMNs; section III presents related WMN works; section IV presents the VT project, which includes Afrimesh protocols and architecture; section V presents experiments that were carried out; and section VI discusses the results of the experiments and presents some information on the deployment of the VT. The conclusion and future work are presented in sections VII and section VIII, respectively.

2 Background

WMNs can be achieved using Layer 2 or Layer 3 of the IEEE 802.11. The difference between the two is shown in Table 1. The three design issues in mobility management of Layer 3 WMN are: IP address resolution, location management and MAC address resolution. Systematic management of IP and MAC addresses of each Mobile Host (MH) in a WMN can be realized using centralized, home, replication or distributed management. Mobility management is however difficult in layer three.

NMS and its tools are required to speed up development and testing of novel protocols and architectures. Functions of the tools include initial network planning, frequency allocation, fault management, performance management, bandwidth management and accounting [1]. One of the tools used in NMS is Captive Portals, which provide access control and bandwidth sharing between clients. An example of a captive portal solution is the Nocat system [2]. The WiFiDog system is another popular captive portal system. Another project dedicated to developing software for WMNs is CUWIN, which is used to create new solutions and protocols. Open source software programs used to manage user authentication for multiple wireless hotspots include NoCatAuth. Groups, such as freifunk, CUWIN and Open Mesh, have focused on developing open source software that enables meshing. An example of the software is CUWiNware. As an

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alternative to proprietary solutions, Wi-Fi (Wireless Fidelity) equipment can be used with modified firmware using a Linux distribution, such as OpenWRT and DD-WRT. The solution is aimed for embedded devices and enables the easy sharing of network resources. In addition, it reduces the total cost of deploying a WMN [3].

Network Management in WMNs (Wireless Mesh Networks) offers additional complexity, when compared to network management in WLANs (Wireless Local Area Networks). The reason is that its monitoring system addresses problems in both mesh routers and client devices. As a result, problems associated with the design of NMSs for WMNs are enormous. A WMN needs to be managed and troubleshot in real-time. In addition, the multi-hop architecture of a mesh network and inherent wireless-related properties of 802.11-based devices make the design a non-trivial task [4]. Interference from surrounding devices could contribute to the challenges of effective monitoring and management of a mesh network.

Table 1: WMN USING LAYERS 2 AND 3

Layer 2	Layer 3
Uses MAC address and	Uses IP address and does
does frame relaying	routing (delivery of
-	packets using IP address)
Standardization in on-going	Already standardized
Broadcasts ARP request frames	No ARP request frame broadcast
that consumes bandwidth	-
Less Scalable	Highly Scalable

Problems encountered in WMN solutions include bandwidth degradation, radio interference and network latency. Owing to this, the inherent multi-hop mesh networks only offer limited scalability and could be unsuitable for large-scale network deployments. Some of the challenges faced during deployment are ad-hoc partitioning, DNS route maintenance, link quality variability and inconsistent transmit power. There are also problems associated with the routing protocols. Routing protocols used byWMNsolutions vary from one product to the other. Cisco solutions use a proprietary routing protocol named Adaptive Wireless Path (AWP), Nortel solutions use the traditional Open Shortest Path First (OSPF) wired routing protocol and VMesh uses Optimized Link State Routing (OLSR), which is a standard pro-active routing protocol. RoofNet uses a hybrid approach called Srcr, which combines link state and DSR-style on-demand querying. Other protocols used in WMN solutions include Ad-hoc On-Demand Distance Vector (AODV) and Hazy Sighted Link State (HSLS) routing.

There are also various protocols used in NMSs. Network Management protocols include SNMP [5], ICMP [6], and netconf [7]. They are used to support network and network devices management. An easy way to manage WMNs would be to extend the application layer protocol called Simple Network Management Protocol (SNMP) [8].

3 Related Works

The related WMN projects include Meshman [1], Meshmon [2], Abare [3] and Mobimesh [4]. Other WMN frameworks are DAMON [5], MobileMon, Scuba [6], MTV [7] and Maya [8]. This section presents MeshMan and MeshMon, and the other WMNs are briefly discussed.

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3.1 MeshMan

In Meshman, a lightweight query response mechanism was designed in place of SNMP using simplified encoding rules. The mechanism used simplified encoding rules as the network management protocol. The Optimal Link State Routing protocol (OLSR) [7] was used as the default mesh network routing protocol. Two considerations that motivated the design of Mesh- Man are WMNs intricacies, which include volatility of wireless channels, dynamic routes and limited bandwidth, and interoperability of wireless and wired networks [1].

Each mesh router in MeshMan is identified by a mesh ID, which is automatically configured in a hierarchical fashion. Mesh IDs are stored at a central location called a mesh manager. A mesh manager serves as routing directives for queries generated from the mesh manager to mesh routers. Unicast queries are routed using source routes encoded in the mesh ID and delivered over the OSI link layer. The layer eliminates the dependency on mesh routing protocols in use. Broadcast queries are flooded in the network for maximal resilience to packet losses. In events of missing or mismatched information at the mesh manager, MeshMan provides ARP-style resolution over multiple hops for mappings between MAC addresses and mesh IDs as fail-safe [1].

In the work, temporary unavailability of nodes in Meshman due to misconfiguration and/or slow convergence of routing table in the Meshman testbed were observed. In the case of networklevel disconnection of a physically connected network, node state information (e.g. routing table entries) becomes unavailable when it is most needed. As a result, the design and implementation required that the solution be robust to network layer failure for the purpose of diagnosing and correcting network layer faults. In addition, it must be self-reconfigurable during failure of nodes and addition of new nodes.

3.2 MeshMon

Meshmon is a framework proposed and implemented in [2]. It performs network monitoring to help an administrator with his tasks. However, the framework is reduced to simply monitoring the network. It takes some actions automatically if the network behavior is different from a standard set statically by the administrator. Meshmon requires two sets of metrics.

The first sets of metrics, called baseline metrics, are sufficient when the network performance is satisfactory and can be used for coarse identification of potential problems. A comprehensive metric collection is however required when there are problems in the network. The speed of metric collection/generation is often the computational bottleneck. As a result, visual rendering of the data could be slow. Owing to this shortcoming, there is a need for a methodology of monitoring and metric collection that is bandwidth-efficient and scalable with respect to the number of devices in the network.

3.3 Other WMN frameworks

Distributed Ad-hoc Network Monitoring (DAMON) is a system to monitor distributed and adhoc sensor networks. It was proposed by Ramachandran et al [5]. It is worth emphasizing that the DAMON algorithm is dependent on the Ad-hoc On-Demand Distance Vector (AODV) routing protocol for its operation. DAMON requires agents, which are used to collect information from the network and send data to repositories. The agents are used to actively monitor network behavior. DAMON's generic architecture supported the monitoring of any protocol, device or network parameter.

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Another WMN solution is MobiMesh. It is an implementation that provides a comprehensive framework of analysis for the behaviour of a WMN in real environments. The analysis of behavior includes advanced routing support in WMNs, and it also considers multiple radios, channel allocation, and managing, monitoring and security platforms in a WMN [4].

The SCUBA framework [6] was designed for interactive visualization and reporting on problems in large scale mesh networks. The framework had several metrics gathered in a database through a gateway node. Although the process of collecting information may cause overload in a WMN [9], a solution that uses the management tools of the framework was proposed. It was implemented at an application level of the OSI. SCUBA allows a network manager to view the network at three contexts, namely the Route, Link and Client contexts. Its display is capable of indicating the level of external interference around a router.
In MobileMAN, information collected at different layers of the networking stack are shared in a common local memory structure and exploited to adapt the behaviour of a node depending on the particular circumstance the node operates in. The approach satisfies the layer separation principle. That is, protocols belonging to different layers can be added or removed from the protocol stack without modifying the protocols operating at the other layers.

The MTV (Mesh Topology Viewer) is a visualization tool developed specifically for WMNs and used in the ReMesh project [7]. It is a web based tool developed using the Scalable Vector Graphics language. It generates a topology map of the WMN and shows the positions of routers. In addition, it shows the quality of the links between them using a colour scale. Its display is similar to the VT's [10]. It however uses the OLSR routing protocol.

MAYA is a tool designed for management and configuration of WMN. The OpenWRT firmware was used to extend MAYA's functionality so that wireless routers can meet the needs of WMN. An administrator is able to configure wireless mesh routers when he is within the signal range of the network. The changing of network configuration parameters is only reserved for the network administrator. The configuration on the mesh routers are done through SSH. The method is considered secure since it makes use of a public key and the transmitted information is encrypted. A security mechanism is integrated into the implementation to avoid clients performing administrative tasks.

4 The VillageTelco (VT) Project

The VillageTelco (VT) project is a broad wireless network communications project. It is a cooperative engagement of a collection of mobile nodes (MPs) without the required intervention of any centralized access point or existing infrastructure. It involves building hardware called Mesh Potato (MP), a network management system called Afrimesh and extending a charging system called A2Billing. All mesh nodes communicate on a single Wi-Fi channel, and each node operates its Wi-Fi interface in two modes simultaneously: (1) ad-hoc mode, which connects with nearby MPs, and (2) infrastructure mode, which allows MPs to operate as backhaul network. Every MP acts either as a client to obtain Internet access or as an access point to allow ordinary Wi-Fi devices to obtain network access. This choice helps to design the system without any specialized software on Wi-Fi enabled cellphones. MPs support both BATMAN and BATMAN-adv. BATMAN-adv was recently introduced in order to easily and effortlessly use a mesh network for data services. Since BATMAN-adv operates at the data layer, it avoids the routing problem often faced with BATMAN, which operates at layer three. Users can choose their preferred protocol for a network by using the appropriate firmware. This process requires flashing the MPs with the appropriate firmware image files (".squashfs" and ".lzma" files).

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4.1 Afrimesh Routing and Network Management Protocols

Afrimesh makes it easy to create an IP network and is built on top of the BATMAN (Better Approach To Mobile Ad-hoc Networking) project to provide a simple network management dashboard. The dashboard enables network operators to create and sustain a resilient communications network. Afrimesh is a web application that provides node/client management, network maps maintenance, and network monitoring and bandwidth management.

The protocols supported by Afrimesh are SNMP (Simple Network Management Protocol), ICMP (Internet Control Message Protocol) and BATMAN. They report topology information and are responsible for route selection. All other management traffic utilizes TCP and is routed by the mesh network. BATMAN does have elements of classical routing protocols: It detects other BATMAN nodes and finds the best way (route) to deliver packets. It also keeps track of new nodes and informs their neighbours about their existence.

SNMP, as an application layer protocol, operates on top of the UDP (User Datagram Protocol) or TCP (Transmission Control Protocol) transport protocol. It relies on a functioning IP layer to route information. In SNMP, each managed node owns a Management Information Base (MIB), which is a collection of information that is hierarchically organized. MIBs are accessed using SNMP. The protocol is designed to work over heterogeneous link layer technologies, where network bandwidth and storage space are relatively abundant. Mesh routers are embedded devices with limited storage capacities, and their networks experience routing flaps and instability. Running SNMP in mesh networks can be heavyweight in bandwidth consumption. As a result, it can be resource-intensive if the network layer has not been configured properly. The reason is that SNMP relies on a functioning network layer to reach nodes that are more than one hop away.

The Internet Control Message Protocol (ICMP) provides a mechanism to send error messages, when services on routers and hosts are not available. The UDP protocol lacks the reliability and data ordering that TCP has. Hence, datagrams may be out of order or lost in transit. However, it introduces no extra overhead to offer complex functionalities. It is faster and lightweight. Owing to this, it is optimally used in time-sensitive applications (e.g. network management). While BATMAN is used as the routing protocol, ICMP and SNMP are used as the network management protocols. Both ICMP and SNMP gather required network data, which are sampled and displayed by the visualization server. The protocols are selectively used based on network conditions.

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4.2 The Afrimesh Network Management Architecture

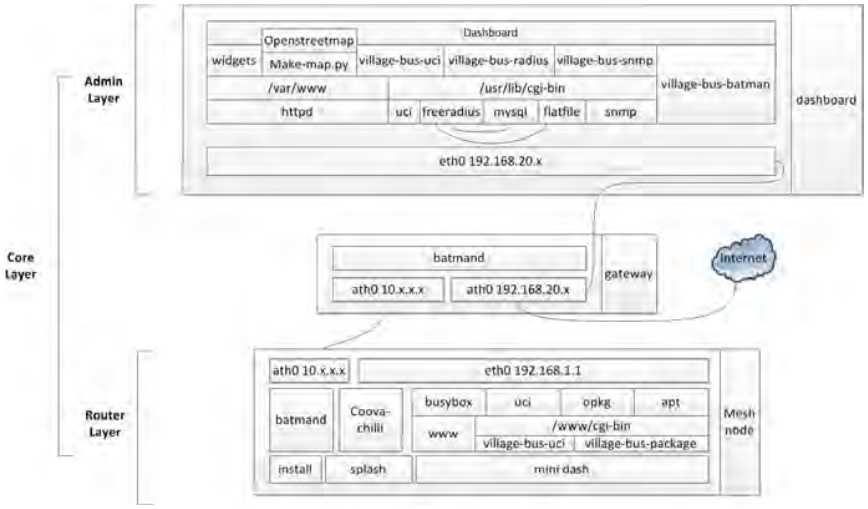

Fig. 1 The Afrimesh Architecture

Figure 1 shows the Afrimesh NMS architecture. The architecture is made up of three layers, namely the admin layer, the router layer and the core layer. The core layer overlaps both the router and admin layers. The management application is a web-based application, which was developed using technologies and projects, such as JSON, IPtables, Node.js, Redis, jQuery and LuCI. Afrimesh messages are in JSON format and are sent over HTTP. Node.js is a server-side javascript implementation and is used with JSON (JavaScript Object Notation) and Redis. Redis is an advanced key-value store and is also referred to as a data structure server. IPtables is a utility used to set up, maintain, and inspect the tables of IPv4 packet filter rules in the Linux kernel. Both the admin and router layers show the services and components required to deploy Afrimesh. They include an HTTP service, MYSQL service, Batmand service, SNMP, a package manager (opkg), busybox (which provides several Unix tools in a single executable), coova-chilli (an access controller that provides a captive portal environment and uses RADIUS or a HTTP protocol for access provisioning and accounting) and Unified Configuration Interface (UCI), which centralizes the whole configuration of OpenWrt. The architecture shows how the components interact with one another, network interfaces of a device and how the system connects to the Internet or a mesh network.

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Fig. 2 The Afrimesh Network Management Interface.

The deployment and management of a network requires a number of steps. Although Afrimesh runs on every MP, it is also recommended the management application (same as Afrimesh) runs on a PC (Personal Computer), which is connected to the same network with the MPs. The MPs are required to have a visualization deamon running on them in order to see them on the management interface. The PC is also required to run similar services, such as the visualization and batmand services. In addition, the PC needs to be configured to join the network ESSID (Extended Service Set ID) of the MPs. Other settings required in the network management server include the ad-hoc network mode, the MPs' BSSID (Basic Service Set IDentifier) and the wireless channel.

Afrimesh look-and-feel on a PC and an MP are the same. Figure 2 shows a dashboard at the admin layer and a mini dashboard (mini dash) at the router layer. While the former refers to the interface on a PC, the latter refers to the interface on an MP. The settings page, which can be found in both an MP and a PC running Afrimesh, enables an administrator to set the coordinates of the device and the IP addresses of the visualization and accounting servers. Other pages that can be found in the Afrimesh NMI include the people, the network health and the network logs pages. The people page shows the names of people with MPs, their email addresses and the IP addresses of the MPs. The network health page reports the overall signal strength, interference and noise level for the network. And lastly, the network log page gathers information about various activities taking place in the network, such as mesh nodes and nanostations joining and leaving the network. Critical tasks, such as change in ESSID, channel and BSSID, can be performed without rebooting a node.

5 Experiments

For experimental purposes [18, 19], the simplified testbed shown in Figure 3 uses three MPs (nodes 1, 2 and 4), one Ubiquiti nanostation as a SuperNode (SN) and the Afrimesh network management server (node 3). Nanostations are repeaters, which are typically used to bridge two or more mesh clouds to form a large network. In peer-to-peer networking, a supernode is any node that acts as a network relayer, which handles data flow and connections for other users. Hence, a nanostation functions as a supernode. Ideally, a supernode would contain three nanostations mounted on a single pole, each covering a 120 degree sector.

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The directional antenna of the nanostations typically offers a 2 km radius of coverage to the VT. The management system is a PC with a 2.5GHz Intel processor, 2GB of RAM and an IEEE 802.11g Zyxel wireless USB card. It uses the Ubuntu 11.04 operating system. The MPs and nanostations were distributed in a linear topology, where each MP only reaches the other MPs in the same building with it. The management server (node 3) is located in one of the buildings. While it is one hop away from node 1, it is two hops away from nodes 2 and 4. The nanostation in the testbed links the two autonomous networks to form one big network.

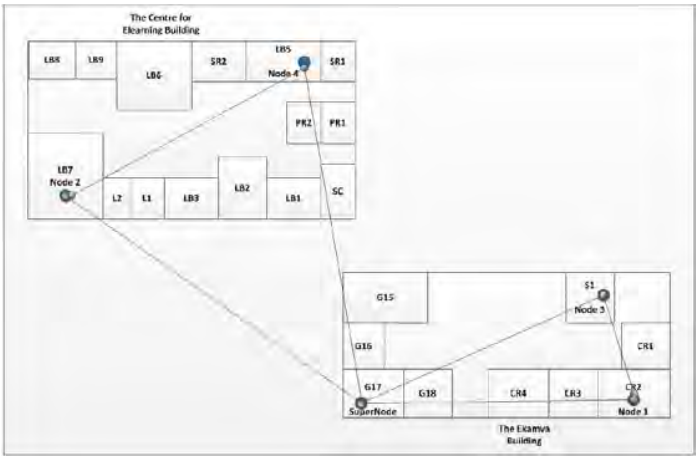

Fig. 3 The VT Testbed at Cape Peninsula University of Technology, Cape Town.

Two different cases were evaluated: (1) an unloaded scenario, where only traffic due to the BATMAN routing protocol is considered, and (2) a loaded scenario, where the traffic generated by an MP has to compete with several bandwidth-hungry TCP flows. The first experiment required gathering the UDP traffic at a node, when the network was idle. The experiment was repeated over varying times, and the tcpdump utility was used to listen to the UDP traffic at the node. The traffic represents the routing protocol (BATMAN) signalling overhead. The second experiment required determining the delay in transmission of data between nodes. In addition, the delay in transmission of data when packets traverse a supernode was determined. While the former was a one-hop transmission i.e. between node 3 and the SN, the latter was a two-hop transmission i.e. between node 2 and the SN and between the SN and node 3.

A graph of data bytes sent against the elapsed time was plotted as shown in Figure 4. The graph shows that the routing protocol overhead increases with time at a node; hence, there will be a gradual drop in throughput at every node with time. Figure 5 shows delays in the transmissions. The data set used in the figures represent average values from three iterations of each test. Figure 4 represents the unloaded scenario, and Figure 5 represents the loaded scenario. Figure 4 shows that the routing protocol overhead increases with time when data flow from one node to another.

Results showed that latency is higher when transferring data over two hops and would increase as number of hops increases. It appeared in some cases that the RTT (Round Trip Time) in the two-hop graph was less than the RTT in the one-hop. It would likely be as a result of interference of other Access Points (APs) within the range of the experiment. However, the delay caused by an additional hop is averagely 35ms.

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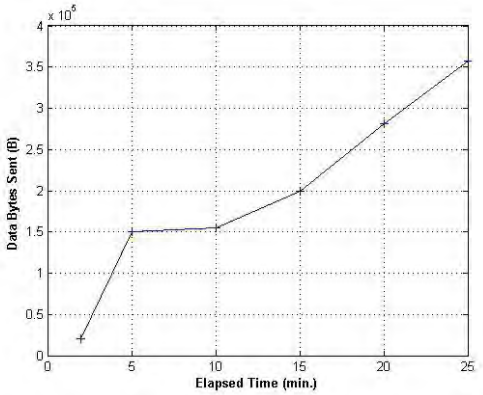

Fig. 4 The Routing Protocol (Batman) Overhead

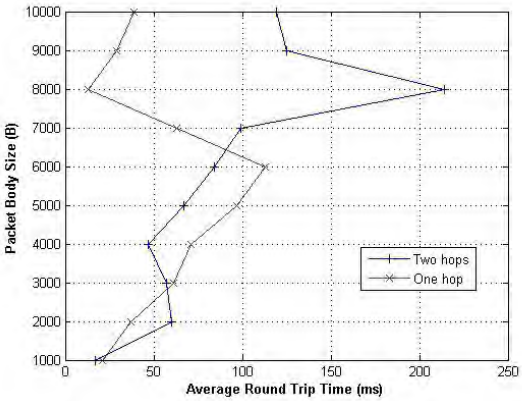

Fig. 5 Transmission Delays for One and Two Hops.

The amount in bytes in the Y-axis for Figures 4 and 5 are absolute counts; the packet sizes were generated by hping3. On one hand, Figure 5 shows that the routing protocol overhead increases with time a node. On the other hand, Figure 5 shows that latency is higher when transferring data over two hops and would increase as number of hops increases. It appeared in some cases that the RTTs (Round Trip Times) in the two-hop graph were less than the RTTs in the one-hop. The reasons are either that the packets get delayed or are routed to another node before reaching the node they were intended for. It would likely be as a result of interference from other Access Points (APs) within the range of the experiment. The anomalies are possible since the network is susceptible to interference. The spikes (i.e. the abrupt drop in average RTT) can also be attributed to large packets that were sent in a single hop.

The increase in the average RTT for large packets sent in two hops could however be acceptable as its reasons are the large file sizes and the number of hops in the transmission. On the other hand, the extremely large rise in RTT for two hops is likely a delay caused by a node scanning for best route. Considering both graphs and neglecting the sudden rise/fall in the RTT, the delay caused by an additional hop is averagely 35ms. An average change in RTT over change in packet size for each graph was calculated. The difference between the two values was determined, which gave the delay value. Although Afrimesh is not self-healing, it does not make the system unreliable. In addition, there is no evidence of lack of reliability in the comparison between both hops. A simulation of the experiments using OMNET++ produced non-increasing delay, despite change in packet sizes and number of hops. Hence, the simulation results are not presented

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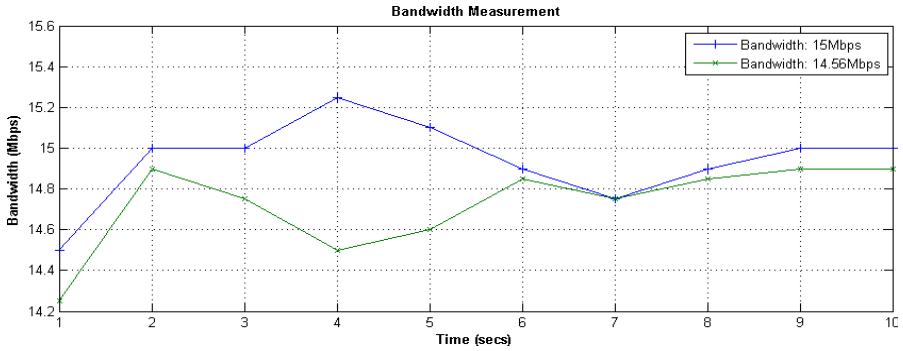

Fig. 6 Bandwidth Measurement.

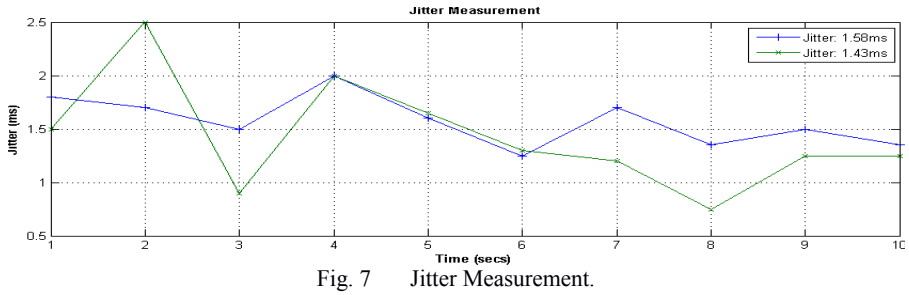

Fig. 7 Jitter Measurement.

Figures 6 and 7 show bandwidth and jitter measurements, respectively. The experiment was between nodes 2 and 4, which can directly connect to each other. The JPREF performance tool were used to measure bandwidth and jitter at each node [18]. With a minimal jitter of 1.51ms, an MP can transmit data at 15Mbps [20, 21]. Given the high throughput, the latency and signaling overhead introduced at each node would not negatively impact a large scale deployment from providing reliable data and voice services.

Table II shows the comparison between Afrimesh and two other WMNs. The WMNs are compared based on their architecture, visualization, supported routing protocol and ability to repair network/node failure. Afrimesh has an autonomous architecture; that is, each node could function with little or no support from the other. It architectural principles are that (1) every metric for the network performance must be subservient to the goal of the network, (2) all nodes exhibit a wide variety of topological schemas, and only connected nodes continue to scale once they have reached an equilibrium in their energy distribution, (3) and lastly, any component in a node can only enforce policy for the components whose continued operation it is directly responsible for. Owing to these principles, Afrimesh provides baseline and comprehensive metrics compared to Damon and Meshman. It uses BATMAN as its mesh routing protocol. However, it is not self-healing unlike Meshman, which has a fail-safe feature. Nodes in Afrimesh requires human intervention to make them visible on the dashboard during setup, addition of new node(s) and network/node failure.

Table II Evaluation of Afrimesh with other Wireless Mesh Networks.

-	**Damon**	**Meshman**	**Afrimesh**
Architecture	Generic	Hierarchical	Autonomous
Visualization	Limited (via agents)	Limited	Baseline/Comprehensive
Routing Protocol	AODV	OLSR	BATMAN
Node Failure	Non Self-healing	Fail-safe	Non Self-healing

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There are several guidelines that should be followed to ensure a successful VT mesh deployment. They include the gateway-to-repeater ratio, the maximum mesh hops and the multi-path fail-overs. Gateway-to-Nanostation Ratio: It is desirable to have as many Internet gateway routers as possible to maximize overall network performance. In general, it is advised to plan for no more than five nanostations for each gateway router.

Maximum Mesh Hops: As reported in section VI, there will always be a throughput reduction with each hop in a mesh. As a result, it is advised that a mesh network be designed for no more than three hops from the gateway to a node. Multi-Path Fail-overs: Regarding multiple failover paths, it is recommended that a node has at least three strong neighbours connected to it. The node and its neighbours should be visible on the Afrimesh mini-dash or dashboard.

The visualisation of information in Afrimesh is done through gathering data from the mesh network at various frequencies. The mesh topology and the link quality is obtained from BATMAN via a daemon at every three seconds. Effective network latency information is obtained from each node when it sends an ICMP echo request packet to its neighbours and any gateways on the network. This data is sampled and reported every ten minutes. For each node the radio signal level, noise level, radio rate, network traffic counters and gateway failure counts are also sampled and reported at the 10-minute interval.

The topology information can be sampled from a mesh node attached to the dashboard via a separate wired Ethernet thereby allowing the collection of data without interfering with the function of the network. Afrimesh sponteneously detects change in a network routing topology, though there is a latency in reporting the change in a visual form. The bottleneck is in the speed at which BATMAN vis deamon update its information. Baseline metrics vary for all network management solutions. With regards to Afrimesh, it tries to limit metrics to the absolute minumum required for an untrained human operator to take corrective action in case of mesh performance problems. From experience in managing community mesh networks, the following metrics, in decreasing order of importance, have proven to be the most widely used: Effective Network Latency, Radio Signal Level, Radio Noise Level & Radio LQ value. These metrics are used in Afrimesh like a number of other WMN solutions did.

The mesh nodes are addressed by their IP addresses thereby allowing for the tracking of how packets move on the network. Where packet loss occurs, it cannot be measured directly on the network. However, nodes that drop off the network are marked on the network visualisation along with the length of time they have been down.

6 Conclusions

Afrimesh is a tool for managing and configuring wireless mesh networks. It extends the OpenWRT platform, which offers a fully configurable firmware for wireless routers. It simplifies the WMN monitoring and management processes by allowing critical changes to be made in a simple and efficient manner. Its building blocks were present for interested developers. Afrimesh's core layer contains the admin and the router layers. Various experiments were carried out to provide additional performance metrics and information for the Villagetelco and Afrimesh projects. The experiments include determining the signalling overhead, latency bandwidth and jitter in a network. Afrimesh makes each node report at 10-minute unsynchronised interval, and the message sizes are within maximum transmission unit limits. In addition, information on how the network could scale without degrading in performance was discussed. While providing comprehensive reports on a network state, Afrimesh limits metrics so that users can take correc-

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tive actions on a node or network. Its metrics include network latency, radio signal, radio noise level and route link quality value. Lastly, it uses both SNMP and ICMP as the network management protocols thereby offering support for heterogeneous link layer technologies with small overhead for its complex functionalities.

7 Future Work

Future work includes reporting performance of the new firware, which runs batmand-adv and comparison of its overhead with the overhead discussed in this paper. In addition, it will include reporting routing delay, when a node is no longer reachable. In the current implementation, there is a tweak that needs to be fixed. The tweak requires refreshing the web interface in order to see changes in the topology of the nodes. Afrimesh, which can now run on a mobile device [4], will also be extended for use in the Fabfi project.

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Automated Testing of Real-Time GIS Applications in an Agile Development Environment Using Open Source Tools

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Abstract. The Agile Manifesto emphasizes that *working software* should be delivered to the customer in multiple iterations of short intervals of time. The expression *working software* is used in both the values portion of the manifesto and the principles portion of the manifesto. In order to prove that software is, in fact, working, tests must be written to fully exercise the software. The tests should be automated to enable short durations of time for the iterations. In the case of real time GIS applications, however, there appears to be no well documented open source tools for testing such applications. This paper investigates a combined use of Selenium, Rest-assured, and Sikulix in order to completely exercise real time GIS applications which are tracking the physical location of devices in the real world.

Keywords: GIS, Agile, Selenium, Rest Assured, Sikulix

1 Introduction

The second value of the Agile Manifesto is that proponents of Agility consider working software to be more important than comprehensive documentation. In addition, the third and seventh principles of the manifesto also center around the concept of *working software* with the third principle being that working software should be delivered frequently and the seventh principle being that working software should be the primary measurement of progress [1]. In order to satisfy these characteristics of agility, comprehensive automated tests need to be written in order to ensure that the software is always working. In addition, an extensive suite of automated tests ensures that software can be delivered more frequently than if the application were being tested by human testers.

This paper looks at a strategy for automated testing of a real-time GIS application using open source tools. The GIS application places remote devices on a map within ten seconds of a commercial transaction happening on the remote device. The GIS application under test monitors tens of thousands of remote point-of-sale devices situated throughout South Africa. These point-of-sale devices sell various digital products such as airtime, data, and electricity. In addition to providing a wide variety of geographical information, the GIS application under test provides a live sales map based on Google Maps with pins appearing and disappearing within ten seconds of the sales happening.

The testing strategy uses a combination of Selenium (for the web interface), Rest Assured (for the Restful communication) and Sikulix (for the GUI component).

Section 2 explains that there is a dearth of published articles about automated testing of real time GUI applications using open source tools. Section 3 describes the environment in which this strategy is used. Section 4 describes the architecture of the

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application. The actual testing strategy is described in Section 5. Results and Conclusions are found in Sections 6 and 7 respectfully.

2 Previous Work

An initial search for previous research indexed by Google Scholar [2] in the area of open source automated testing tools for real time GIS applications did not provide any peer reviewed publications. The Jstore digital library [3] did not report any publications on the topic of open source automated testing tools for real time GIS applications. In addition, the IEEE Explore digital library [4] also did not provide any publications on open source automated testing tools for real time GIS applications. In the more non-academic realm such as queries on StackOverflow [5], it is clear that the testing of GIS applications, especially real time GIS applications, using open source testing tools is problematic and there appears to be no clear solution to the problem.

This is not to say that testing tools for GIS applications don't exist. Many open source GIS applications come with associated testing tools. Many closed source GIS applications do the same. It is just the gap of open source GIS testing tools unbundled from any GIS framework which is problematic.

The lack of published academic research indicates that new research can be done in this area and that new knowledge can be created in the area of automated testing of real time GIS applications using open source tools.

Having said that, however, there is good literature on automated testing of individual aspects of a real time GIS application.

Selenium is a well respected and documented open source testing utility for web applications [6], [7]. It provides an API which processes HTML and Java Script and simulates a browser. Authors of automated Selenium tests can search for HTML elements, click buttons, wait for results, etc. Selenium supports a generic headless browser and also supports specific browsers such as Chrome, Firefox, Safari, etc.

Rest-assured is an open source testing framework specifically for restful interfaces [8], [9]. The API provides easy testing for rest calls and responses.

Sikulix (some portions of which are called Sikuli) can be used for automated testing (and other screen oriented applications) by looking for specific images which are displayed on the screen [10], [11]. Besides doing image recognition, Sikulix can also click buttons and click and drag the screen.

So, although there is no published research on automated tests using open source tools of real time GIS applications, the author maintains that these individual utilities which are well documented can be combined in innovative ways to do such testing.

3 Environment

This testing strategy was deployed at Blue Label Telecoms. Blue Label Telecoms is a South African company listed on the Johannesburg Stock Exchange. It is one of the largest vendors of secure tokens which can be redeemed for airtime, data, electricity, and other non-tangible products. In addition, Blue Label Telecoms offers a number of other facilities and services such as bill payment facilitation, traffic fine payment facilitation, purchase of metered electricity, purchase of event tickets, and purchase of bus tickets.

This is facilitated by a proprietary switch which was developed by the company and is owned and operated by the company. This switch connects to the various cell service providers, electricity providers, ticketing agencies, etc. On the other side of the switch, Blue Label Telecoms provides devices to merchants which allow these

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merchants to on-sell these services to the end consumer. At the point of writing this paper, the company does not deal directly with the end consumer. Blue Label Telecoms provides these services to merchants and the merchants on-sell the services.

There are two types of devices which are offered to merchants – Windows based devices and Android based devices. The Windows based devices are more suited to large franchise chains. The Android based devices are more suited to smaller independent merchants. There are tens of thousands of the Android devices deployed in South Africa. During office hours, at any one time, a couple hundred of those devices are transacting.

The application which is being tested displays a live map of sales on these Android devices within ten seconds of the sale actually happening on the device as can be seen in Figure 1.

Figure 3: Screen grab of GIS application

4 Application

Architecture

In order to understand the testing strategy, it is first necessary to describe the architecture and flow of information from the remote Android devices supported by Blue Label Telecoms to the actual mapping application under test. As can be seen in Figure 2, the Android devices communicated with the proprietary switch operated by the company. Embedded in the messages from the Android device was either the longitude and latitude of the device as provided by Android Location Services or nearby cell tower information provided by the Android telephony libraries. The non-geo portion in the messages was transferred to the various service providers such as cell service company, electricity companies, etc, and those results were returned to the Android device. In addition, the entire transaction was sent to the Mapping application. The Mapping application then placed this information as pins on a Google Map and provided a web interface for employees of Blue Label Telecoms so they could visually monitor sales.

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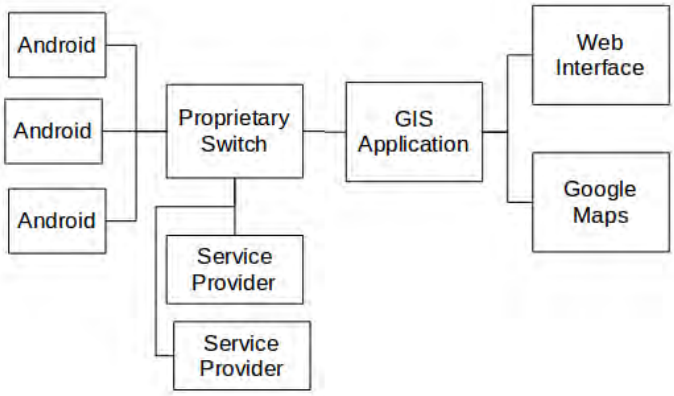

Figure 4: Architecture of application

5 Testing Strategy

The testing of the Mapping application was complicated due to the following issues

1. There were web interactions between the user and the web interface such as logging into the mapping application, navigating to various pages, etc.
2. There were Restful interactions between the proprietary switch and the mapping application
3. There were AJAX interactions between the web interface and the mapping application
4. There were Google map interactions with pins dropping on the map
5. There were timing issues to ensure that the pins appeared on the map within ten seconds of the sale of the product on the device

Each of these five types of interactions needed to be tested individually and in collaboration with each other.

To cater for web-interactions described in #1, a full suite of Selenium based tests were written to test functionality such as logging in, setting up profiles, etc. To cater for the restful interactions described in #2, Rest-assured was used to simulated data coming from the proprietary switch. The AJAX interactions between the browser and the server described in #3 could be simulated by using Rest-assured to communicate with the server and by using the Javascript facilities of Selenium to communicate with the browser. The Google map could be searched to look for specific images such as a yellow pin in Cape Town to see if the data was properly displayed by the use of Sikulix. And finally timestamps were put on the data as it moved through the test system so that the latency could be measured.

Existing test programs following the following steps:

1. Login to appropriate page using Selenium
2. Use Sikulix to see if the Google Map template looks ok
3. Simulate the push of data from the proprietary switch using Rest-assured
4. Simulate the browser asking for locations via AJAX by also using Rest-assured
5. Check the numeric values of longitudes and latitudes of the pins received by #4 comparing with the pushed data of #3 using textual comparisons

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6. Using the Javascript facility of Selenium, push these numerical values to the browser map
7. Compare the images on the map with the expected pins and their locations
8. Check the various timestamps on the messages

6 Results

The results of this combination of Selenium-Rest-assured-Sikulix tests were extremely positive. There was only one problematic issue. The image recognition facilities of Sikulix were not good enough to differentiate similar positions on the Google map. For example, Sikulix could not reliably differentiate between similar looking map locations such as Kimberley and Vryburg as seen in Table 1.

Table 3: Kimberley / Vryburg comparison

Table 4: Cape Town / Port Elizabeth comparison

For this reason, all testing was placed around coastal cities where the ocean provided easily recognizable images as can be seen in Table 2. Once this minor issue was resolved, the tests ran quickly and accurately.

Another iritating problem that was encountered was that the image recognition facilities of Sikulix did not cater for different resolution screens or monitors. For this reason, once specific workstation was dedicated to be the test work station.

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Measuring the latency of the data flow was done by comparing timestamps on the data. The originating Android devices did not send timestamps with their data although they did store timestamps on local log files if there were problems. The devices were point-of-sale devices with human operators. If a delay of more than a few seconds was routinely encountered, the human operators could call a contact centre for help in solving the problems. Once the data left the Android devices, however, each server added a timestamp to the message. This enabled the latency to be measured up to the point where it was ready to be queried by the browser.

The entire test suite currently consists of 103 test programs and runs for approximately 30 minutes. Besides testing the geo-locations, the tests also check that the correctly coloured pin is dropped for cell phone type purchases with the pins being coloured with the corporate colours of the cell company involved. Products such as electricity, bill payment facilities, and ticket purchases also have their own pin types. Some additional pie charts are also displayed in the margins giving quick visual percentages of high selling service providers.

7 Conclusion

The Agile manifest emphasizes the importance of *working software* being made available to the client within short iterations. One way to prove that software is working is by writing automated tests that exercise the different facilities of the application. There are a number of different open source testing frameworks and utilities available for different types of tests.

However for real time GIS applications, there appears to be no published research on how to adequately test such applications using open source tools. This paper describes research in using a combination of three different complementary open source tools to test real time GIS applications:. Selenium (for the web component), Rest-assured (for the data comms component), and Sikulix (for the GUI component) to write tests of real time GIS applications. The results were extremely positive.

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Effect of Stratification and Cross-diffusion in Magnetohydrodynamics Micropolar Fluid Flow Over an Inclined Stretching Cylinder

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Abstract. In this paper an analysis has been made to study heat and mass transfer in two-dimensional magnetohydrodynamics (MHD) micropolar fluid flow over an inclined stretching cylinder examining effect of stratification and cross-diffusion. The governing equations are non-dimensionlized and then linearized using a quasilinearization method. The resulting linearized equations are solved by Chebyshev spectral local linearization method. The effects of various physical parameters on the boundary layer velocity, microrotation, temperature and concentration profiles are discussed in detail for both micropolar and viscous fluids. The computed values of the skin friction coefficient, local Nusselt number and Sherwood number are discussed for various values of physical parameters. The tabulated results show that angle of inclination, thermal stratification parameter, solutal stratification parameter and Hartmann number increases the skin friction whereas decreases Nusselt number and Sherwood number.

Keywords: Stratification, Micropolar fluid, Dufour and Soret, Stretching cylinder.

1 Introduction

Stratification plays a dynamic role in many industrial and natural phenomena. Extensive studies of heat and mass transfer have been investigated in the past decades and various extensions of the problem have been reported in the literature. When the fluid is electrically conducting double stratified medium on the mixed convection boundary layer flow under the influence of an external magnetic field not only is fascinating theoretically but also finds applications in mathematical modeling of several industrial and biological systems. A possible practical application of the theory we envisage is in the geophysical flows, heat rejection into the environment such as seas, lakes and rivers, storage systems for thermal energy like solar ponds. Another area in which the theoretical study may be of interest is in the closed containers, environmental chambers with heated walls are supported by double diffusion occurrence. Stratification of medium appears due to temperature differences, variation of concentration or mixture of different fluids of distinct densities. Several analytical and experimental attempts have been made for heated surface flows in a stable stratified medium [1-4].

In practical situations when heat and mass transfer mechanism run simultaneously, it becomes essential to analyze the convective mode of transportation in fluids under the influence of double stratification. It has been also observed that an energy flux can be generated not only by temperature gradients but also by concentration gradients. The energy flux caused by a concentration gradient is termed the diffusion thermo (Dufour) effect. On the other hand, mass flux can also be created by temperature gradients

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and this embodies the thermal-diffusion (Soret) effect. In most of the studies related to heat and mass transfer process, Soret and Dufour effects are neglected on the basis that they are of a smaller order of magnitude than the effects described by Fouriers and Ficks laws. But these effects are considered as second order phenomena and may become significant in areas such as hydrology, petrology, geosciences, etc. The Soret effect, for instance, has been utilized for isotope separation and in mixture between gases with very light molecular weight and of medium molecular weight. The Dufour effect was recently found to be of order of considerable magnitude so that it cannot be neglected [5]. Several researchers studied the effect of Dufor and Soret for different flow geometries, to mention a few [6-10].

A large amount of literature is available on the viscous theory. However, only a limited study of non-Newtonian fluids available. Additional nonlinear terms arising in the equation of motion rendering the problem more difficult to solve in the case of non-Newtonian fluids. The study of non-Newtonian fluids has many applications in various industries, such as nuclear paints, physiology, bio-mechanics, chemical engineering, and technology. There are many non-Newtonian fluid models. The theory of fluids with micro structures has been the subject of a large number of investigations. These are realistic and important from a technological point of view. The classical theories of continuum mechanics are inadequate to explain the microscopic manifestations of complex hydrodynamic behavior. Microcontinuum theory or generalized continuum theories incorporates independent deformations of the microstructure inside of a material point. There are a number of microcontinuum theories, namely couple stress, micropolar, microstretch and micromorphic Eringen [11, 12]. Micropolar fluids constitute an important branch of non-Newtonian fluid dynamics where microrotation effects as well as microinertia are exhibited. Traditional Newtonian fluids cannot precisely describe the characteristic of fluid with suspended particles. Micropolar fluids formulated by Eringen [13] includes certain microscopic effects arising from the local structure and micromotions of the fluid elements, and provides a mathematical model for the non-Newtonian fluid flow behavior such as exotic lubricants, polymers, animal bloods and real fluids with suspensions. Eringen [14] extended the micropolar fluid theory and developed the theory of thermo-micropolar fluids. An excellent review of micropolar fluids and their applications was given by Ariman *et al* [15]. Extensive review of foundations of the micropolar continuum mechanics found in the book by Eremeyev [16].
The intent of the article is to present a stratification effects together with temperature and concentration gradients (Dufour and Soret effects) on MHD micropolar fluid flow along an inclined stretching cylinder in the presence of mixed convection phenomena and heat generation process comparing micropolar and viscous fluids. Spectral local linearization method (SLLM) used to find solutions of the nondimensional coupled nonlinear equations that govern the flow. Results are verified with Successive relaxation method (SRM). To reveal the tendency of the solutions, selected results for the velocity components, temperature, and concentration are graphically depicted.

6 Flow Analysis

Let us consider MHD steady incompressible and electrically conducting micropolar fluid over an incline stretching cylinder with inclination Φ. The axial axis of cylinder is supposed as x-axis and r-axis is perpendicular to it. The fluid properties are assumed to be constant except for density variations in the buoyancy force term. In addition, the Soret and Dufour effects are considered. Further the temperature and concentration are supposed to be higher than ambient fluid across the surface of cylinder.

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Based on these assumptions, the governing equations of micropolar fluid flow and heat transfer are as follows.

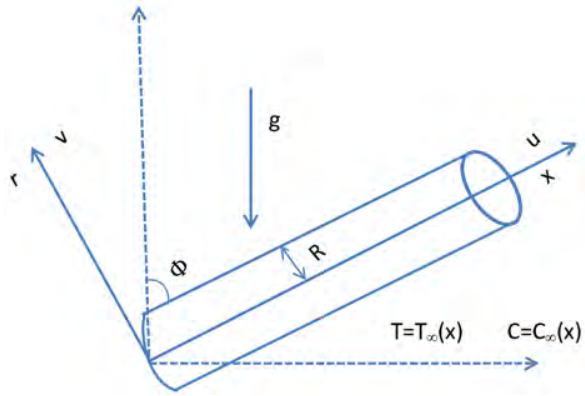

Fig. 1 Flow Geometry

$$\frac{\partial(ru)}{\partial x}+\frac{\partial(rv)}{\partial r}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial r}=\frac{K}{\rho}\frac{\partial(r\Gamma)}{\partial r}+\frac{\mu+\kappa}{\rho}\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u}{\partial r}\right)+g[\beta_T(T-T_\infty)+\beta_C(C-C_\infty)]\cos\Phi-\frac{\sigma B_0^2}{\rho}u \tag{2}$$

$$\rho j\left(u\frac{\partial\Gamma}{\partial x}+v\frac{\partial\Gamma}{\partial r}\right)=-2\kappa\Gamma-\kappa\frac{\partial\Gamma}{\partial r}+\gamma\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial(r\Gamma)}{\partial r}\right) \tag{3}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial r}=\frac{k}{\rho C_P}\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)+\frac{DK_T}{C_S C_P}\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial C}{\partial r}\right) \tag{4}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial r}=D\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial C}{\partial r}\right)+\frac{DK_T}{T_m}\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) \tag{5}$$

The boundary conditions are given by

$$u=U(x),\quad \Gamma=n\frac{\partial u}{\partial r},\quad T=T_\infty(x),\quad C=C_\infty(x)\quad at\quad r=R \tag{6a}$$

$$u\longrightarrow 0,\quad \Gamma\longrightarrow 0,\quad T\longrightarrow T_\infty(x),\quad C\longrightarrow C_\infty(x)\quad as\ r\longrightarrow\infty \tag{6b}$$

where R is radius of the cylinder, $U(x)\frac{U_0 x}{L}$, $T_w(x)=T_0(x)+\frac{bx}{L}$, $T_\infty(x)=T_0(x)+\frac{cx}{L}$, $C_w(x)=C_0(x)+\frac{dx}{L}$, $C_\infty(x)=C_0(x)+\frac{ex}{L}$. It should be noted that *b, c, d* and *e* are positive constants *u, v* are flow velocities, *L* is the reference length, Γ is components of microrotation, *T* is the temperature, ρ fluid density, μ dynamic coefficient of viscosity, κ is vortex viscosity, γ is material constants (the spin, gradient, viscosity), *g* is the acceleration due to gravity, β_T is the coefficient of thermal expansion, β_C is the coefficient of solution expansion, B_0 is magnetic induction,

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σ is electric conductivity of the fluid, D is the mass diffusivity, C_P is the specific heat of fluid, C_s is the concentration susceptibility, T_m is the mean fluid temperature, and K_T is the thermal diffusion ratio. Where $n = 0$ the case micro-elements close to the boundary stick to the wall and $n = 1$ correspond the turbulent boundary layer. Introducing the following similarity variables

$$\eta = \frac{(r^2 - R^2)}{2R}\sqrt{\frac{U_0}{\nu L}}, \qquad u = \frac{U_0}{L}f'(\eta), \qquad v = -\frac{R}{\nu}\sqrt{\frac{U_0\nu}{L}}f(\eta),$$

$$\Gamma = \left(\frac{U_0}{L}\right)^{\frac{3}{2}}\frac{x\,r}{R\sqrt{\nu}}g(\eta), \qquad \theta(\eta) = \frac{T - T_\infty}{T_W - T_0}, \qquad \phi(\eta) = \frac{C - C_\infty}{C_W - C_0}$$

and applying the transformations on equations (1) - (5)

$$\frac{((1+2\delta\eta)+f'''+2\delta f'')}{(1-N)} + \frac{((2\delta g+(1+2\delta\eta)g'}{(1-N)} + ff' - f^2 + \lambda(\theta + S\phi)\cos\Phi - \frac{Ha^2}{Re_x}f' = 0 \tag{7}$$

$$\frac{(2-N)}{m^2}Re\big((1+2\delta\eta)g'' + 4\delta g'\big) - \frac{N}{(1-N)}f'' + \frac{2Ng}{(1-N)} ajRe_x(f'g - \delta fg - fg') = 0 \tag{8}$$

$$\frac{1}{Pr}\big((1+2\delta\eta)\theta'' + 2\delta\eta\theta'\big) + Df(2\delta\phi' + (1+2\delta\eta)\Phi'') + f\theta' - (\theta + \epsilon_1)f' = 0 \tag{9}$$

$$\frac{1}{Sc}\big((1+2\delta\eta)\phi'' + 2\delta\eta\Phi'\big) + Df(2\delta\theta' + (1+2\delta\eta)\theta'') + f\phi' - (\Phi + \epsilon_1)f' = 0 \tag{10}$$

where

$$Ha^2 = \frac{\sigma B_0^2 L^2}{\mu}, \quad Pr = \frac{\nu}{\alpha}, \quad \delta = \frac{1}{R}\sqrt{\frac{\nu}{\alpha}}, \quad aj = \frac{j}{L^2}, \quad m^2 = \frac{L^2\kappa(2\mu+\kappa)}{\gamma(\mu+\kappa)}$$

$$N = \frac{\kappa}{\mu+\kappa}, \qquad G_r = \frac{g\beta_T(T_W - T_0)}{\nu^2}, \qquad G_c = \frac{g\beta_C(C_W - C_0)x^3}{\nu^2},$$

$$Re_x = \frac{U_0 x^2}{\mu L}, \quad a = \frac{U_0}{L}, \quad S = \frac{G_C}{G_r}, \quad Df = \frac{DK_T d}{C_S C_p b\nu}, \quad Sr = \frac{DK_T(T_W - T_0)b}{T_m(C_W - C_0)d\nu}$$

The non-dimensional boundary conditions are

$$f' = 1, \ f(0) = 0, \ g(0) = nf'', \ \theta(0) = 1 - \epsilon_1, \ \phi(0) = 1 - \epsilon_2 \tag{11}$$

$$f'(\infty) \to 0, \quad g(\infty) \to 0, \quad \theta(\infty) \to 0, \quad \phi(\infty) \to 0 \tag{12}$$

where

$\epsilon_1 = \frac{c}{b}$ and $\epsilon_2 = \frac{e}{d}$ and *b, c, d, e* are constants. The shearing stress on the surface of a body, skin friction, is defined as:

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$$\tau = \left[(\mu + \kappa)\frac{du}{dr} + \kappa\Gamma\right]_{r=R} \tag{13}$$

The shearing stress at the wall can be calculated in non-dimensional form as:

$$(1 - N)Re_x^{1/2}Cf = 2(f'' + nN\,g) \tag{14}$$

The local mass flux and the local Sherwood number are respectively given by

$$Nu_x = \frac{x\,q_r}{k(T_w - T_\infty)}, \qquad q_w = -k\left(\frac{\partial T}{\partial r}\right)_{r=R} \tag{15}$$

$$Sh_x = \frac{x q_r^*}{D(C_w - C_\infty)}, \qquad q_r^* = -D\left(\frac{\partial C}{\partial r}\right)_{r=R} \tag{16}$$

We have the dimenssionles form

$$\begin{aligned} Nu_x Re_x^{-\frac{1}{2}}(1 - \epsilon_1) &= \theta'(0) \\ Sh_x Re_x^{-\frac{1}{2}}(1 - \epsilon_2) &= \phi'(0) \end{aligned} \tag{17}$$

7 Method of Solution

In this subsection, we present the numerical method that was used to generate the results. We shall present the Spectral Local Linearisation Method (SLLM) in general and apply it to solve our system of equations (7) – (10). We develop the spectral local linearization method for a general system of n nonlinear ordinary differential equations. Without loss of generality, we consider system of n nonlinear ordinary differential
equations of the form,

$$\begin{aligned} &\Gamma_1[G_1, G_2, \cdots, G_n] = 0, \\ &\Gamma_2[G_1, G_2, \cdots, G_n] = 0, \\ &\quad\vdots \\ &\Gamma_n[G_1, G_2, \cdots, G_n] = 0, \end{aligned} \tag{18}$$

where

$$\begin{aligned} G_1 &= \left\{f_1, \frac{df_1}{d\eta}, \frac{d^2 f_1}{d\eta^2}, \cdots, \frac{d^p f_1}{d\eta^p}\right\}, \\ G_2 &= \left\{f_2, \frac{df_2}{d\eta}, \frac{d^2 f_2}{d\eta^2}, \cdots, \frac{d^p f_2}{d\eta^p}\right\}, \\ &\quad\vdots \\ G_n &= \left\{f_n, \frac{df_n}{d\eta}, \frac{d^2 f_n}{d\eta^2}, \cdots, \frac{d^p f_n}{d\eta^p}\right\}. \end{aligned} \tag{19}$$

The solution procedure assumes that the solution can be approximated by a Lagrange interpolation polynomial of the form

$$f_k(\eta) \approx \sum_{i=0}^{N_\eta} f_k(\eta_i) L_i(\eta), \tag{20}$$

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for $k = 1, 2, \cdots, n$. The grid points are given by (η_i) in the η direction, for $i = 1, 2, \cdots, N_n$. These selected grid points are called Chebyshev-Gauss-Lobatto points Trefethen [17] and are given by

$$\{\eta\} = \left\{\cos\left(\frac{\pi i}{N_\eta}\right)\right\}_{i=0}^{N_\eta} \tag{21}$$

$$L_i(\eta) = \prod_{\substack{i=0 \\ i \neq k}}^{N_\eta} \frac{\eta - \eta_k}{\eta_i - \eta_k} \tag{22}$$

where

$$L_i(\eta) = \delta_{ij} = \begin{cases} 0 & if \quad i \neq k \\ 1 & if \quad i = k \end{cases} \tag{23}$$

Applying the quasilinearisation method independently in each equation, we get a system of *n* decoupled linear differential equations of the form:

$$\begin{aligned} \textstyle\sum_{s=0}^{p} \alpha_{s,r}^{(1)}(\eta) f_{1,r+1}^{(s)} &= R_1(\eta), \\ \textstyle\sum_{s=0}^{p} \alpha_{s,r}^{(2)}(\eta) f_{2,r+1}^{(s)} &= R_2(\eta), \\ &\vdots \\ \textstyle\sum_{s=0}^{p} \alpha_{s,r}^{(n)}(\eta) f_{n,r+1}^{(s)} &= R_n(\eta), \end{aligned} \tag{24}$$

where $\alpha_{s,r}^{k}(\eta)$, are the variable coefficients of $f_{n,r+1}^{(s)}(\eta)$ respectively, for $k = 1,2, \cdots, n$ and $s = 0,1,2, \cdots, p$. These coefficients correspond to the k^{th} equation, for $k = 1,2, \cdots, n$. Since constant *p* denotes the order of differentiation, then

$$\alpha_{s,r}^{k}(\eta) = \frac{d\Gamma_k}{df_{k,r}^{(s)}} \tag{25}$$

In general, the k^{th} right hand side is given by

$$R_k(\eta) = \textstyle\sum_{s=0}^{p} \alpha_{s,r}^{(k)}(\eta) f_{k,r}^{(s)} - \Gamma_n(\eta). \tag{26}$$

Equations (24), are evaluated at the Chebyshev-Gauss-Lobbatto grid points η_i ($i = 0,1,2, \cdots \eta_N$). Substituting equations (20) into equations (24) yields

$$\begin{aligned} A_{1,1} F_{1,i} &= R_{1,i}, \\ A_{2,2} F_{2,i} &= R_{2,i}, \\ &\vdots \\ A_{n,n} F_{n,i} &= R_{n,i}, \end{aligned} \tag{27}$$

where $A_{1,1} = \sum_{s=0}^{p} \alpha_{s,r}^{(1)} D^{(s)}, A_{2,2} = \sum_{s=0}^{p} \alpha_{s,r}^{(2)} D^{(s)}, \cdots, A_{n,n} = \sum_{s=0}^{p} \alpha_{s,r}^{(n)} D^{(s)}.$ (28)

The diagonal matrices of the corresponding variable coefficients are

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$$\alpha_{s,r}^{(k)} = \begin{bmatrix} \alpha_{s,r}^{(k)}(\eta_0) & & & \\ & \alpha_{s,r}^{(k)}(\eta_1) & & \\ & & \ddots & \\ & & & \alpha_{s,r}^{(k)}(\eta_{N_\eta}) \end{bmatrix} \tag{29}$$

Imposing boundary conditions for $i = 1,2,\cdots N_\eta - 1$, equations (27) can be expressed as the following $(N_\eta + 1)X(N_\eta + 1)$ matrix system

$$\begin{bmatrix} B_{0,0}^{(k)} & B_{0,1}^{(k)} & \cdots & B_{0,N_\eta}^{(k)} \\ B_{1,0}^{(k)} & B_{1,1}^{(k)} & \cdots & B_{1,N_\eta}^{(k)} \\ & \ddots & & \\ B_{N_\eta,0}^{(k)} & B_{N_\eta,1}^{(k)} & \cdots & B_{N_\eta,N_\eta}^{(k)} \end{bmatrix} \begin{bmatrix} F_k \\ F_k \\ \vdots \\ F_k \end{bmatrix} = \begin{bmatrix} \mathcal{R}_k \\ \mathcal{R}_k \\ \vdots \\ \mathcal{R}_k \end{bmatrix} \tag{30}$$

where

$$B_{(i,j)}^{(k)} = \sum_{s=0}^{p} \alpha_{s,r}^{(k)} D^{(s)}, \text{ for } k = 1,2,\cdots n.$$

The vector $\mathcal{R}_k$ is defined as

$$\mathcal{R}_{k,i} = R_k \text{ for } k = 1,2,\cdots n.$$

4 Results and Discussion

Equations (7) - (10) subject to the boundary conditions (11) have been solved by SLLM for some values of the governing parameters. Results are validated using the Spectral relaxation method (SRM). From Table 1 it is seen the outcomes of this comparison are found to be in excellent agreement. Throughout the study we used these values of the parameters $\delta = 1,\ N = 0.5,\ \lambda = 2,\ S = 0.9,\ Ha = 3,\ Re_x = 1,\ \epsilon_1 = 0.5,$ Df=0.3 $Pr = 0.71,\ \epsilon_2 = 0.1,\ Sc = 0.2,\ Sr = 0.2,\ n = 0,\ m = 0.1,\ aj = 0.01,$ and $\Phi = 30^0$ unless stated otherwise.

Table 1. Comparison of local mass flux $-\theta'(\eta)$ generated using the SLLM, SRM when $N = 0.5,\ \lambda = 1, S = 0.9,\ Ha = 2,$ $Re_x = 1,\ \epsilon_1 = 0.4,\ \epsilon_2 = 0.6\ Df = 0.3,\ Sr = 0.2,\ \Phi = \frac{\pi}{6},$ $aj = 0.01,$ and $m = 0.1.$

Pr	SRM	SLLM
1	0.92881916	0.92881916
0.5	0.66204232	0.66204232

The nondimensional parameter *N* satisfy the thermodynamic restrictions given by Eringen [14]. For a given shape of the microelements *N* directly gives a measure of concentration of the microelements. The coupling number *N* characterizes the cou-

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pling of linear and rotational motion arising from the micromotion of the fluid molecules. Hence *N* signifies the coupling between the Newtonian ( ) and rotational viscosities (κ) and hence $0 \leq N < 1$. To study effects of various parameters, we sketch the graphs for both viscus fluid (*N=0*) and micropolar (*N=0.9*) fluid. The case *N=0*, micropolarity is lost, there is no microrotation component velocity (i.e. *g*=0) and this is evident in Fig. 2(b), Fig. 3(b)} and Fig 4(b). Temperature and concentration profile for micropolar fluid is greater than that of viscous fluid whereas the opposite behavior is found in the case of for velocity profile as seen in the graphs.

The effects of thermal stratification parameter $\epsilon_1$on the dimensionless velocity, microrotation, temperature and concentration are depicted in Fig. 2(a) - 2(d). It can be seen from Fig. 2(a) that the velocity reduces as thermal stratification parameter ϵ_1 increases. This is because a lighter fluid from upper layers may be dragged by the particle to lower denser layers and hence the velocity of settling particle is reduced due to the increase in buoyancy imposed by lighter fluid attached to the particle. Similarly, reduction in microrotation is observed with the increase in stratification parameter as shown in Fig. 2(b). Fig. 2(c) elaborates the influence of thermal stratification parameter on temperature distribution. It is observed that increasing ϵ_1 decreases the temperature profile. Physically the presence of thermal stratification effect reduces the effective temperature difference between the surface and the ambient fluid which leads to a weaker temperature profile. Impact of thermal stratification parameter ϵ_1 on the concentration profile is plotted in Fig. 2(d).

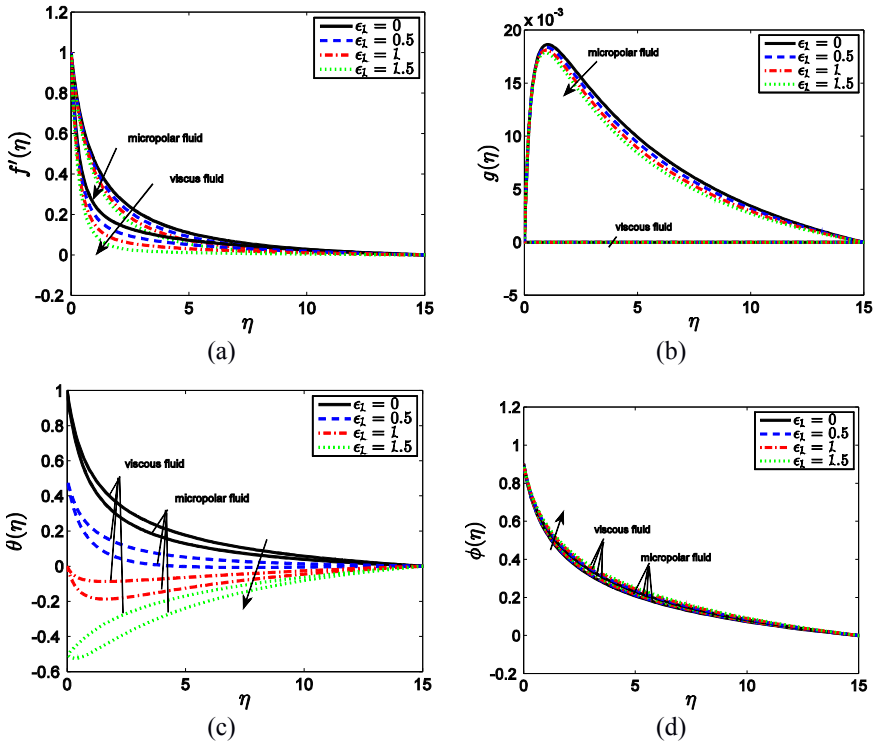

Fig. 2 Effect of ϵ_1 on (a) , (b) (c) $\theta(\eta)$ and (d)

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Fig. 3(a) - 3(d) display the effect of solutal stratification on velocity, microrotation, temperature and concentration. Solutal stratification effect on velocity and microrotaion is similar to that of the thermal stratification effect and presented on Fig. 3(a) and 3(b) whereas the opposite effect is observed for temperature and concentration as seen from Fig. 3(c) and Fig. 3(d). It is interesting to see unlike the thermal stratification parameter the solutal stratification parameter enhance the temperature.

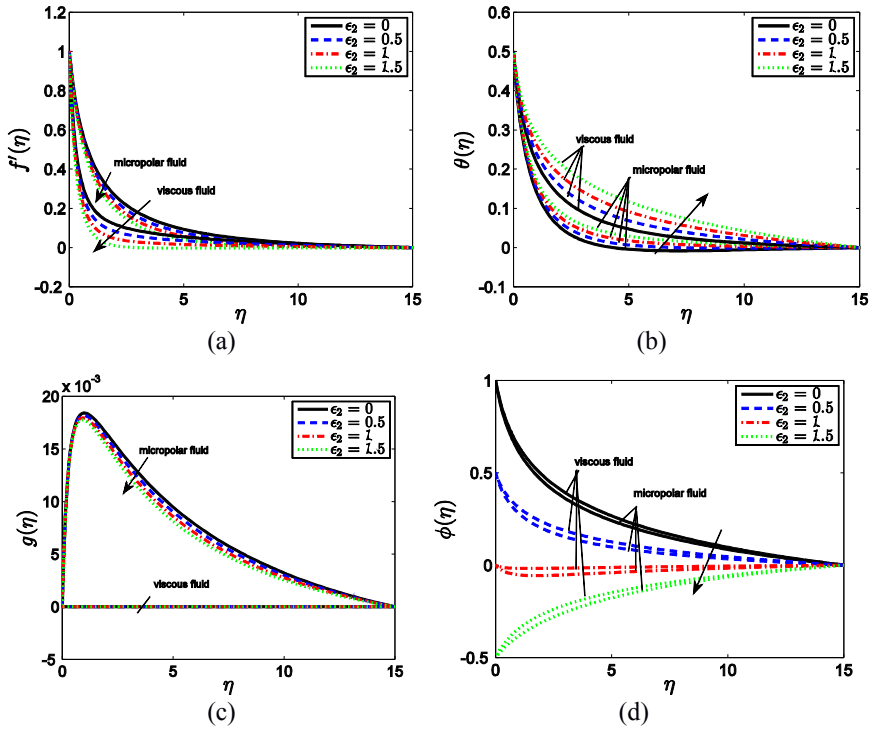

Fig. 3 Effect of on (a) , (b) (c) and (d)

The effects of Dufour and Soret numbers are significant when density difference exist in the flow regime. The species are introduced at a surface in fluid domain with different density compare to the surrounding fluid, both soret and dufour effects shows significant effect. The combined Soret and Dufour effects analyzed through velocity microrotation, temperature and concentration profiles in Fig. 4(a) - 4(d). Fig. 4(a) displays the non-dimensional velocity for different values of Soret number *Sr* and Dufour number *Df*. It is observed that the velocity of the fluid decreases with smaller values *Df* and increases with larger values of *Df* (or a decrease of Soret number *Sr*) is seen from Fig. 4(a). From Fig. 4(b) it is seen that the values of microrotation are initially increases near the boundary layer and decrease outside the boundary layer, showing a reverse rotation in the flow medium. The reason is that the microrotation field in this region is dominated by a small number of particles spins that are generated by collisions with the boundary. Dufour parameter affects the energy transport to a greater extent as seen in Fig. 4(c), decreasing the Dufour parameter (increasing the soret parameter) decreases the velocity profile. The reverse effect is observed on concentration profile when Dufour number decreases as seen in Fig. 4(d).

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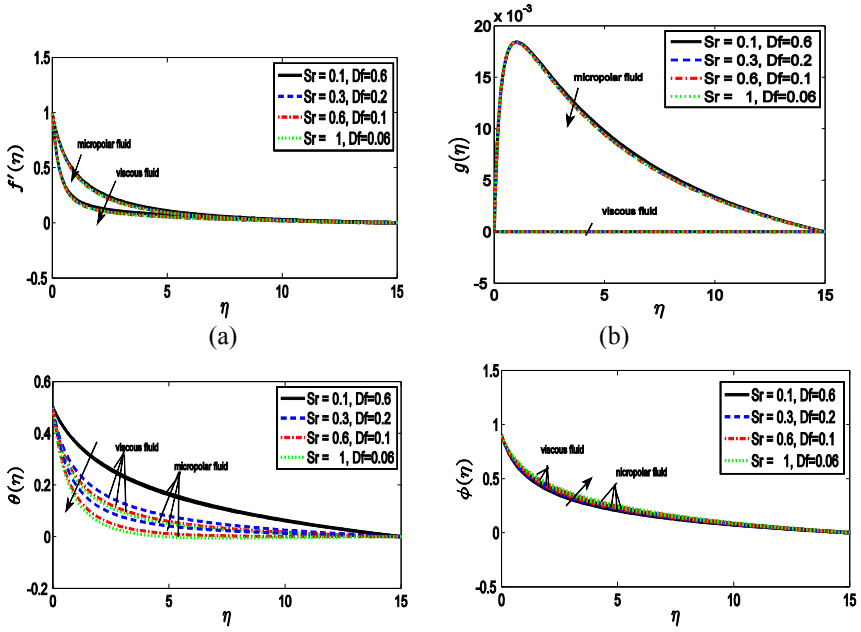

Fig. 4 Effect of Df and Sr on (a) $f'(\eta)$, (b) $g(\eta)$, (c) $\theta(\eta)$ and (d) $\phi(\eta)$

Table 2. Skin friction, wall shear stress, local mass flux and concentration gradient for various parameter values when *N=0.5, Pr=0.71,* $\lambda = 0.5, m = 0.1, \delta = 1, Re_x = 1, Df = 0.3, Sr = 0.2, Sc = 0.2n = 0, \wedge aj = 0.01$

Φ	ϵ_1	ϵ_1	Ha	$f''(0)$	$\theta'(0)$	$\phi'(0)$
π /12	0.4	0.6	3	2.5989	0.685 9	0.320 3
π /6	0.4	0.6	3	2.6080	0.683 5	0.319 5
π /4	0.4	0.6	3	2.6224	0.679 7	0.311 8
π /3	0.4	0.6	3	2.6414	0.674 5	0.316 6
π /6	0.0	0.6	3	2.5720	0.949 0	0.322 0
π /6	0.5	0.6	3	2.6169	0.616 7	0.318 9
π /6	0.7	0/6	3	2.6348	0.482 4	0.317 7
π /6	1.0	0.6	3	2.6616	0.279 5	0.316 0
π /6	0.4	0.0	3	2.5586	0.696 2	0.683 2
π /6	0.4	0.5	3	2.5997	0.685 6	0.380 2
π /6	0.4	0.7	3	2.6162	0.681 4	0.258 7
π /6	0.4	1.0	3	2.6409	0.675 1	0.076 0
π	0.4	0.6	0	0.9459	0.990	0.438

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/6				0	8	
π /6	0.4	0.6	1	1.2756 2	0.907 8	0.399
π /6	0.4	0.6	3	2.6080 5	0.683 5	0.319
π /6	0.4	0.6	4	3.3131 7	0.618 6	0.300

5 Conclusion

In the present work the Computational Fluid Dynamics models have been developed for steady incompressible and electrically conducting micropolar fluid over an incline stretching cylinder.

The governing nondimensional equations were solved numerically using the SLLM method. The effect of velocity, microrotation, temperature, concentration fields for different parameters are studied both for viscous and micropolar fluids. The thermal stratification parameter increases with decrease in velocity, microrotation, and temperature. Velocity of the micropolar fluid is greater than the viscous fluid whereas the temperature and concentration are in the opposite. The microrotation shows reversing flow in the flow medium and significantly affected by the thermal and stratified parameters. Temperature decreases with thermal stratification increase and increases with solutal stratification parameter increases. The temperature profile is highly affected by the Dufour and Soret parameters. Increasing the Soret parameter (decreasing the Dufour parameter) decreases velocity microrotation and temperature profiles are decreasing whereas the concentration increases. Skin friction increases with increase in the angle of inclination of the cylinder, thermal and solutal stratification parameters and Hartmann. It is also seen that both Nusselt and Sherwood numbers decreases with these parameters. This problem can be extended to address cases like the stretching cylinder with porous boundary and the magnetic effect to include the effect of Hall.

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Delivery System on Disaster for Hearing Impaired People Using LED Display -To Extend to Universal Usage-

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Abstract. There is a sudden blackout on the big disaster. Under such circumstances, people get information verbally by voice, megaphone, and radio instead of looking at some screen on PC, smartphone screen or on TV by their eyes. After the big disasters, people have to find the safety place using voice announcements. However, hearing impaired people cannot get information from voice announcement. In addition, it is difficult to distinguish hearing impaired people from others by their appearances. Therefore, they have little chance for helf by others. We have researched and created a system for hearing impaired people get information on the disaster using LED display. Also, we found such a system is useful for elders and foreigners, too. People cannot use their smartphone as usual because of shortage of their battery under disinters. Our system was designed to save battery using Bluetooth Low Energy (BLE) and small CPU. Besides, people will co-operate looking at one same screen under the disaster situation.

Keywords: BLE, Advertisement, Ad hoc network, LED display, Disaster information delivery system

1 Introduction

Information Technology makes our daily lives convenient. However, the big disaster sudden breaks such circumstances in a moment. We have many disasters in Japan. 15,893 persons were dead, and 2,553 persons were missing by the big earthquake in 2011. Especially hearing impaired people got little information and were postponed to be rescued. They sometimes didn't get relief supplies.

In Africa there are a lot of disasters, too. Loss by earthquakes in Africa was 12,218,000,000 (estimation) in 1980-2003 according to the research by the World Bank [1]. African's current urban population is increasing and it is said to become 1 billion on 2040. In addition, African cities have few 40% neighbors to interact with compared to Asia and Latin America [3]. Cities will be crowded and can be disconnected on disasters.

Using a mobile ad hoc network, we developed an information delivery system for hearing impaired people based on such reports of disasters in Japan. The rest of this paper is structured as follows. Section 2 discusses related works. Section 3 sets out our information delivery system. In section 4, we propose our experiments. Finally, in section 5, we summarize this research and discuss about future studies.

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1 Related Works

There are several research papers about the situation of hearing impaired people under the blackout. “Giving and Receiving of Information by Hearing-Impaired Persons after the Earthquake Disaster: From an Interpersonal Communication Point of View” (Kawauchi, 2011) told “the Symposium of Earthquake Communication clearly show the need to examine the giving and receiving of information after a disaster. We need to reconsider the use of "Mieru-radio/ Teletext broadcasting [4]”. However, the service named "Mieru-radio" has already closed. Because visible contents on the websites using smartphones are increasing day by day, and many people inclosing hearing impaired ones use them instead of special Teletext broadcasting [5]. Those smartphone applications are useful for normal lives. Communication traffics apt to occur in a disaster, and it would be hard to get information by smartphones. “Eye Dragon 4” [6] is a subtitles system of TV for hearing impaired people. However, if electricity fails on the disaster, TV does not work at all.

The daily lives of people including hearing impaired people have been more convenient. However, the situation for hearing impaired people on disasters has been worse. We have studied the information system for 12 years [7-9] and have to continue our project under such circumstances.

2 Our Information Delivery System on Disaster

2.1 *Outline of Our System Using LED Display*

The outline of our information delivery system is described in Fig.1. LED displays are connected by ad hoc network using BLE advertising message. An operator input information (text) from the application on Android phone by Wi-Fi. The message is transferred to the next LED display by the ad hoc network. There is the limitation of packet size so that a long message is broken down into some advertisement messages. We also implemented a simple routing protocol that meets the limitation of the packet size of the BLE advertisement [10]. Table 1. shows the primary functions of the application to control the information delivery system. Users can change colors of texts, also can register some frequently used texts, and change displaying speed. In addition, there are buzzers. Hearing impaired people cannot hear sounds, however, someone near them who can listen, notices the information on a LED display. Such behaviors of other persons will be some signs to look at the LED display for hearing-impaired people, too.

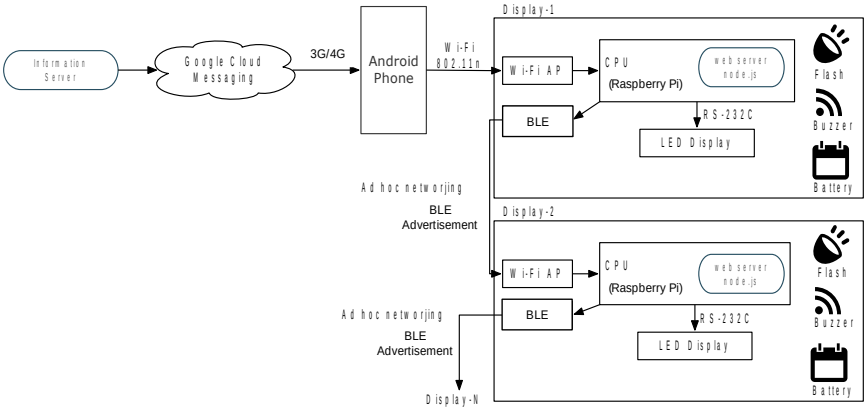

Fig. 5. Block diagram of disaster information delivery system

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Table 1. Functions to control the LED display

Function	Outline
Input message	Input message to display
Send message	Send message to LED
Register message	Register frequently used message (10 messages)
Set color	Red/Yellow/Green/Blue
Set display speed	Min 0.5 sec for 8 characters
Set the number of repetitions	Min 1
Stop display message	

3 Experiments and the Results

3.1 Outlines of the Experiments

After the tests of ad hoc connection, we had several experiments at different use scenes in order to research effective use scenes (see Table 2, n=238). Main target was hearing impaired people. In addition, families, and people with hearing impaired ones answered questionnaires. Because they are in the same scene as hearing impaired people. People help each other under the disaster. We asked them for the evaluation of our system and also asked to choose color, speed, contents that they would like to use their ordinary lives. How they use this display in their dairy life is essential for emergency use. People do not look at the LED display if they are not accustomed to looking at the display in their daily lives.

Table 2. Outline of Our Experiments Using LED display

Phase	Year	Numbers	Instrument	Function	Use Scene
1	2007～2008	130	Feature phone	Bluetooth	Events(inside and outside)
2	2009	15	Feature phone	Bluetooth/Internet	Office/House
3	2010	46	Feature phone	Bluetooth	Hospital(ENT)
4	2016	47	Smartphone	Bluetooth	School of hearing impaired

3.2 Results of the Experiments

Our system evaluated high not only by hearing-impaired people but also by hearing ones. (See Fig.2.) In addition, they chose as followings.

- The color of letters: [ordinary green/emergency red] has garnered high acclaim.
- Scroll speed: The distance between the display and people was important how they felt the speed. Scroll speed adjustment function was evaluated.
- Use scene: (Daily life) news, clock, information / (Emergency) Evacuation route

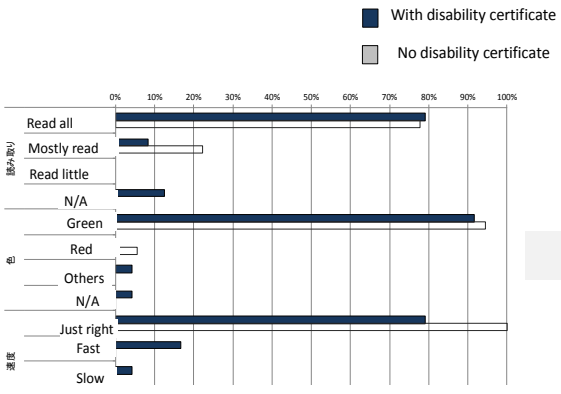

Fig.6 Evaluation in 2016

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- Comments and requests: It will be useful at the shelter not only for hearing impaired people but also for elders.

3.3 For School of hearing impaired children

According to the request of teachers at the school of hearing impaired children, we had another experiment in 2018. They urged us to sent messages speedy among 3 floors. After a test in Utsunomiya University, we had an experiment of multi-hop communication using 1 transmitter and 5 receivers. We set them for 5 routes and determined packet loss. In addition, we measured performance of the communication devices. Data receptions were 50~70%. It was presumed that the height of the devices and some materials of the building involved the results.

4 Conclusion of experiments and new developments for practical use

4.1 Extension for the universal use

According to the experiments, our system was recognized that it was useful not only for hearing impaired people but also for hearing ones. For example, this system should be helpful as a signboard for outdoor events such as concerts and fireworks. For that purpose, we should consider the capacity of a battery. A waterproof function is also crucial if we use it outside. In 2020, the Olympic games will be held in Tokyo. Many foreigners will come to Japan, who do not understand the Japanese language. Using this system and some application for translation, sponsors will show infomation easily by several languages. If it does not spread on people's daily lives, it will not be used at the emergency scene. Therefore, we consider how many usages and how many people can use this system conveniently.

In addition, it is difficult to use a keyboard in the urgent cases, hence voice input should be required. Because of the progress of voice recognition technology and machine translation technology, we can use voice recognition now.

ICT provides people to convenience lives and diversity. Hearing impaired people use the same device as hearing ones in daily life. However, once the big disaster occurs, they would not have any information. We will continue this project to bring words speedy and certainly.

It will be useful for elders, foreigners and hearing people on disasters. Just after the big disaster, people are at the panic station. An otolaryngologist told to us that elders who are hard to hear tend to hear less than usual after the disasters. In addition, it was reported that foreign residents in Japan could not understand Japanese words for the emergency at the Great East Japan earthquake by Kahoku Ninpo, a newspaper at Tohoku area in Japan [11]. The words for emergency call are different from daily ones. If there were letters at the display, it would be helpful for them, too. According to our research, people hearing well also answered that this display would be useful for their safety lives. Everyone needs the reliable information of his or her living area at the great disaster.

4.2 New role of Smartphone after the disaster in our system

At the end of this paper, we mention about smart-

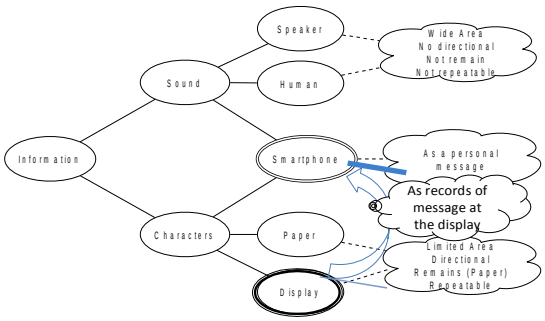

Fig.3. Classification of media for disaster information

phone use. According to the following consideration, we would like to extend our model [9] to describe the relation of disaster information and media as illustrated in Fig. 3. We added in this figure to smartphone part; it is the third eye and ear in ICT society. At the disaster in the acute stage, people do not have enough time to see their smartphones. But if smartphones can receive information that is transmitted between LED displays, the smartphones can store the information, and the users can review it at the shelter. The message by voice and display is gone immediately in the evacuation place. However, they can check the information on their own smartphone screens. There are small disasters or fire after the big one. Officers or some staffs can send such messages. Fortunately, the recent smartphone has a function of BLE, so that it may be useful media to convey and store the disaster information. It is also possible to send information to smartphones through BLE as another path. We will continue researches in order to improve our system for information at disasters.

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E-voting System for National Elections Using a Blockchain Architecture

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Abstract. Due to many challenges that are associated with elections in Africa, the need for the adoption of electronic voting (e-voting) in order to possibly improve the quality of elections has been advocated. However, many of the existing e-voting systems are based on a centralised software architecture design which makes them vulnerable to Distributed Denial of Service (DDoS) attacks, as well as other cyber-attacks which may disrupt voting proceedings of elections. The decentralized architecture of a blockchain and its inherent quality attributes of transparency, autonomy, immutability, and anonymity presents new opportunities to overcome some of the known challenges of existing e-voting systems. This paper proposes a national e-voting system for South Africa that is based on a blockchain architecture. A preliminary assessment of the e-voting system from an architectural point of view was conducted by using the Architecture Tradeoff Analysis Method (ATAM). The evaluation revealed that the proposed e-voting system is feasible, credible, and has the potential to be functionally suitable for national elections. The results of the ATAM evaluation also identified weaknesses that must be addressed in subsequent stages of software development in order to give impetus to future adoption of a blockchain e-voting system for national elections.

Keywords: Blockchain, Electronic Voting (e-voting), Architecture Tradeoff Analysis Method (ATAM).

1 Introduction

Political elections in Africa are generally substandard due to challenges such as lack of transparency, fraudulent manipulations, violence, insecurity, and other vices, which limits their credibility, which has led to increased voter apathy [1, 2]. Although, the legitimacy of an electoral outcome depends on maximum voter participation, yet a decline in voter participation has been observed since South Africa's first democratic election in 1994 [3].

Currently South Africa uses the traditional paper-based voting system. The paper-based system suffers from many problems that are associated with i) printing of ballot papers in many languages for over 26 million voters (considering that South Africa has eleven official languages); ii) logistic issues that relate to transporting of ballots to and from voting stations in a secure manner; iii) manual counting of voting totals which require huge amount of time and resources; iv) human errors and fraudulent manipulations; v) difficulty of voters with disabilities such as visual impairment to be able to vote without having their confidentiality rights violated [3, 4]. As in other countries, the need to migrate to a national electronic voting (e-voting) system that is capable of solving some of these identified challenges had been advocated [2, 5].

Many countries have introduced e-voting in an attempt to offer a more secure and efficient voting process, as well as increased voter participation [5]. Estonia, Switzer-

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land, and Norway were among the first to introduce e-voting systems for national, state and council elections [5]. However, despite the many advantages of e-voting, many of the existing national e-voting systems are based on the traditional centralised designs which makes them vulnerable to Distributed Denial of Service (DDoS) attacks, as well as other cyber-attacks which may disrupt voting proceedings during elections. There is also the issue of lack of process transparency for which most of these e-voting systems have been criticized [5, 6]. As a result of these, several countries including Australia, Finland, Netherlands, and Germany have reverted back to a paper ballot system due to various security vulnerabilities, privacy, and transparency concerns of the e-voting system. The e-voting systems currently implemented in Brazil, India, Estonia, and America have also come under criticism, after verified reports of elections being compromised in some forms [5, 7].

The advent of blockchain technology presents new opportunities to overcome some of the challenges of existing e-voting systems [7]. The inherent attributes of a blockchain architecture in terms of security (encryption), anonymity, data integrity, immutability, decentralization, and transparency make it viable for the implementation of more efficient, secure, and transparent e-voting systems [7].

This paper presents the conceptual design of an e-voting system for national election in South Africa that is based on a blockchain architecture. A stakeholder-centric approach was adopted to elicit the core e-voting requirements that pertain to South Africa, and evolve a blockchain architecture for e-voting. A preliminary evaluation of the proposed e-voting system from an architectural point of view was performed by using the Architecture Tradeoff Analysis Method (ATAM) in order to ascertain its plausibility and determine the merits or demerits of further investments. As a contribution, this paper presents the conceptual design of a blockchain architecture of an e-voting system that is contextually relevant to South Africa. It also offers insights on the application of blockchain technology in strategic areas of national development in developing countries.

The rest of this paper is as follows. Section 2 presents background and related work. In Section 3, we report the methodology adopted for the study, and the key activities that were undertaken in the study. Section 4 describes the proposed blockchain architecture for e-voting, while Section 5 presents details of the evaluation of the architecture. The paper is concluded in Section 6 with a brief discussion and a closing summary.

2 Background and Related Work

In this section, we present an overview of blockchain technology and related work in the area of e-voting blockchain.

2.1 Blockchain Technology

Blockchain technology is founded on a peer-to-peer electronic transaction system, called Bitcoin [8]. The Bitcoin blockchain allows users to transfer bitcoin, a digital cryptocurrency, between users, without the need for a trusted central authority [8]. A blockchain is an immutable append-only ledger of transactions replicated across the blockchain network. A copy of the ledger is maintained by each node that makes up the bitcoin blockchain system [8]. Nodes also referred to as miners, are responsible for appending new sets, blocks, of transactions onto the blockchain. Transactions are broadcast to the blockchain network, where each node listens for transactions to include into a block. The blockchain protocol uses a cryptographic hashing algorithm to produce a unique hash from the transactions included in that a block, each block contains the hash of the previous block forming a chain of inter-linked blocks [8, 9].

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Private key cryptography, peer to peer network and a blockchain protocol are the three fundamental parts of blockchain technology [10]. The combination of these technologies enables blockchain's transparency, autonomy, immutability, and anonymity capabilities, whilst ensuring data integrity and security [10, 11]. The blockchain technology can be divided into three main types, which are:

- *Permissionless (Public) Blockchain*: this allows anyone to read, download or become a node in the blockchain network [1, 12]. It does not require any verification from a central authority. Bitcoin and Ethereum are two popular examples of permissionless blockchains [1].
- *Permissioned (Private) Blockchain*: this belongs to an individual or organisation. It has strict authority management controls that determine which nodes may participate or access the data ([2, 10].
- *Consortium Blockchain*: this has the characteristics of both public and private blockchains. It is partly decentralised, which could include read-only access for the public, but the ability to run the consensus protocol is limited to preselected nodes [10].

Around the world, blockchain technology is gaining a lot of traction. In February 2018, the European Commission (EC) launched a blockchain partnership declaration, which so far includes signatures from 23 European Union (EU) countries [13]. Also, IBM is one of over 90 companies supporting the Hyperledger Project, which is dedicated to advancing blockchain technology [14]. The Hyperledger Project is an umbrella containing various open source blockchains tools and frameworks, founded by the Linux Foundation in December 2015. Its aim is to support cross-industry collaborative development of blockchain technologies capable of supporting global business requirements [14].

2.2 Related Work

Significant efforts have been made in the area of applying blockchain technology for e-voting. In [15] an e-voting design by adapting the Bitcoin's e-payment protocol was proposed. The paper describes a protocol whereby eligible voters send their private keys to be authenticated as valid voters by an authentication server. One major drawback of the system is the possibility to link a transaction to the voter via the voters' private key, which compromises a voter's confidentiality. The authors in [16] describe an e-voting system that addresses the issue of anonymity by introducing a blind signature scheme for authorities to authorize registered voters with no way of knowing the contents of the vote. The blind signature scheme uses cryptography to enable authorities to validate the sender of a message (voter), but not the message content (the vote). In [17], authors argue that a blind signature scheme in e-voting affords too much power to a single entity. A single authorising entity may have the ability to introduce dummy votes for registered voters who have chosen to abstain. In response to this concern, the authors incorporated a blind multi-signature scheme in their proposed design.

Ethereum is also a public blockchain with its own cryptocurrency, but a set of the development tools for decentralized applications included on Ethereum's platform sets it apart from the Bitcoin [1]. In [18] authors, argue that Ethereum's platform is better suited for an e-voting protocol due to its broader range of use cases with the power of smart contracts, whereas Bitcoin's platform is only intended for transaction correctness. Hence, [19] propose a self-tallying e-voting solution for boardroom voting using smart contracts built on Ethereum's development platform. The limitation of Ethereum-based implementation is that it cannot be scaled for use in larger use cases such as national elections [18, 19]. The drawbacks of using a public blockchain for e-

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voting include high processing cost of each transaction in terms of computational power [8, 15, 16, 19] and slow transaction processing speeds [20].

Wang et al. [20] propose a large-scale e-voting design using a permission-based protocol called Delegated Proof of Stake (DPOS). DPOS protocol can be a small network of nodes that have obtained permission from an administration authority [20]. The paper addressed the issue of anonymity and voter privacy by using a one-time ring signature protocol. It makes use of smart contracts for recording, managing, calculating and checking votes.

The blockchain architecture of our proposed national e-voting system is based on a state-of-the-art design that is permission-based, uses smart contracts, and founded on the zero-knowledge proof, which is one of the best cryptographic protocols for information exchange. Compared to other existing e-voting blockchains, it is unique because it has the potential to cater for large-scale elections in the specific context of South Africa by ensuring the integrity of votes cast, and auditability of votes, without comprising voters' privacy.

3 Methodology

A design science research approach was adopted for the execution of this study. This involves problem identification, defining the solution objectives, design and development, and critical evaluation [21]. The outline of activities of the adopted DSR approach is presented in Table 1.

Table 5. Outline of Activities of the Adopted Design Science Research of Study

Step	Activity	Activities
1	Problem identification and motivation	• In-depth interview with the IEC officials was conducted to discover and understand current issues and concerns within the context of e-voting in South Africa. • Review of IEC documentations on e-voting • Interaction with different types of stakeholders (voters - young, middle-age, elderly, disabled, technical experts)
2	Define the objectives of a solution	• Requirements analysis, requirements modelling, and requirements prioritization in order to identify core and non-core requirements. • Requirements specification for the e-voting system.
3	Design and Development	• Theoretical analysis of existing blockchain architectures for e-voting • Architecture modelling and design based on Kruchten's 4+1 model view of architecture [22] • Create an architectural framework for e-voting based on blockchain
4	Evaluation	• Assessment of the proposed architecture by using the Architectural Tradeoff Analysis Method (ATAM) • Evaluation of feedback and observations from the ATAM process.

3.1 Requirements Identification and Architecture Modelling

In order to understand the key issues that relate to the implementation of e-voting in South Africa, an in-depth semi-structured interview was conducted with some of the top staff of Independent Electoral Commission (IEC) of South Africa. The key member that was interviewed is someone who has been involved in feasibility studies of e-voting in South Africa. Also, there were interactions with persons who had partic-

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ipated in the voting process in South Africa. Some of the documentations on e-voting such as the report of the IEC Seminar on E-voting that was conducted in 2013 were also reviewed [23]. The analysis of the interaction with the different relevant stakeholders revealed a number of key issues that are crucial for the success of e-voting in South Africa and its adoption. These are:

Trust: the e-voting design needs to possess qualities that advocate trust and confidence among all stakeholders.

Transparency: the need to ensure that no manipulation of votes, or tallying can occur and to do this in a way that is visible and transparent to all.

Verifiability: voters should be able to verify that their votes were correctly cast and counted without compromising the security of the system.

Auditability: ensures that the system allows rechecking and recounting if there is a dispute over the outcome of the election.

Availability: ensures that the system does not suffer a downtime during critical moments during the election.

Performance: ensures that system perform efficiently in terms of speed of processing, and response time.

Socio-economic Factors: It is essential to ensure that the risk of coercibility is addressed by providing a safe method of voting, free of intimidation or manipulation. It should also ensure that a voter's vote remains anonymous.

Socio-political factors: It is important to identify what problems e-voting seek to address and the associated advantages. The e-voting should also not introduce any risks of vulnerabilities in the voting process.

Thus, the software architecture of the proposed national e-voting system must satisfy these identified requirements.

4 The Blockchain Architecture for National E-Voting System

The Blockchain Architecture for National E-voting System (BANES) is proposed as a solution to the identified e-voting requirements. It is a layered architecture that consists of four layers (See Fig 1). The layers of the architecture are described as below.

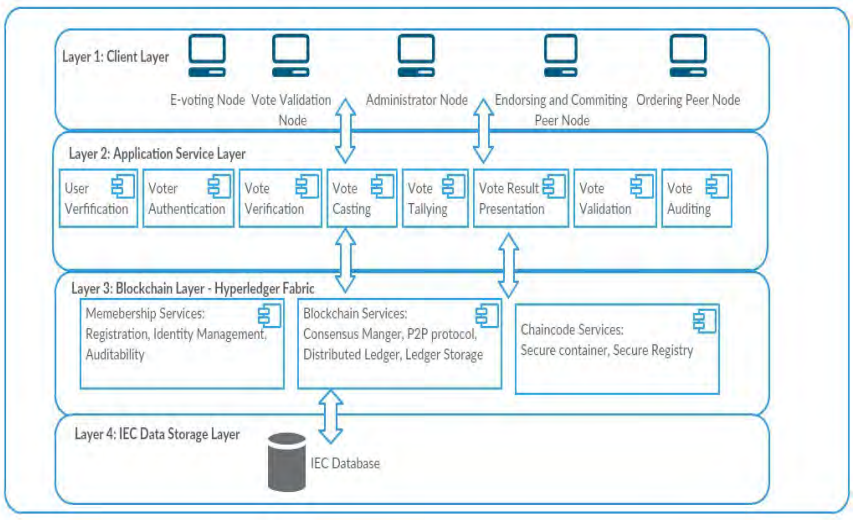

Fig. 1. Overview of the Blockchain Architecture for National e-voting System (BANES)

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Client layer: this consists of the physical devices that are used to interact with the e-voting system. These devices correspond to peer nodes of the e-voting blockchain. The peer nodes will execute smart contracts, referred to as "chaincode" in Hyperledger; access ledger data, endorse transactions and interface with applications [24]. The proposed e-voting system will accommodate several types of peer nodes, each with their own responsibilities, access controls and permissions as enabled by the Hyperledger Fabric (Layer 3). These different types of peer nodes as categorized by responsibility are:

i) *Voting Nodes*: These nodes are for the primary purpose of authenticating of voters and casting of votes, which is recorded on the blockchain.
ii) *Administration Nodes*: These nodes are used to configure blockchain network channels and administer permissions, roles and access control.
iii) *Public Nodes*: Provides view-only access to the system for the purpose of results report, vote validation, and auditing.
iv) *Validating and Endorsing Nodes*: Validates, and endorses the authenticity of transactions included in a block.
v) *Committing Nodes*: Validates and commits new blocks to the blockchain ledger

Application Service Layer: consist of all services within the e-voting system. Access to services is governed through access control and permissions determined by the responsibilities of each node type.

Blockchain Layer: is the foundation which makes the e-voting solution possible, with the use of Hyperledger Fabric. Hyperledger Fabric is a blockchain framework implementation which enables the development of blockchain information system solutions by using a modular architecture approach. The Hyperledger Fabric enables the creation of permissioned blockchain networks, which inherit the security, and privacy properties of underlying blockchain [24]. In addition to peer nodes, Hyperledger Fabric network uses "Ordering nodes" which are used to ensure the consistency of the blockchain by delivering ordered blocks of an endorsed transaction to the committing peer nodes to add to the blockchain [24].

IEC Database Layer: includes details of registered voters as well as political candidates. This database will be used to authenticate and authorise voters to vote.

4.1 Key Enablers of the Blockchain E-voting System

Two important concepts that will enable the BANES for efficient operations are discussed below.

Smart Card Technology. This offers increased privacy protection, security in identification [25]. The smart card, which shall be given to voter during the voters' registration phase, will hold the voters public key for identification, in conjunction with a personal identification number (PIN) for authentication and authorisation. A private key will also be stored on the smart card which will be used for digital sign in and will use password-based encryption to ensure that only a valid holder of a smart voter's card can vote.

Implementation of a Zero-knowledge Protocol. A zero-knowledge protocol allows a party to verify that something is true without revealing any other information to the other party [26]. A zero-knowledge protocol works in a way that ensures that when a voter casts a vote, their public key in conjunction with their private pin is used for identification and authentication through the IEC's registered voter database. The IEC authenticates the voter and generates a digital ballot which is not linked to the voter. The unique ID of the digital ballot then forms part of the voting asset, which will be recorded on the blockchain. By this, the integrity of the vote is achieved with voters signing their vote with their private key. In this way, the IEC is able to verify that a vote belongs to a valid voter but does not know who the voter is. A zero-knowledge

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protocol was included in the design of the e-voting system to ensure the integrity of votes cast and auditability.

4.2 Operational Workflow of the Proposed BANES

The design of the system is premised on the assumption that voting will still occur at polling stations in order to protect voters from the risks of coercibility – being forced to vote in a certain way. Communication between the IEC database and the blockchain network will be secured using Hyper Text Transfer Protocol Secure (HTTPS) and encryption. The proposed e-voting procedure entails the following:

i. A voter logs into a voting terminal by scanning the voting smart card and enters his password.
ii. The voter's public key is sent to the IEC for authentication and authorisation.
iii. If authorised, the IEC system generates and returns a digital ballot, which includes a list of candidate public keys, and a unique ballot ID
iv. The voter casts his vote by selecting the candidate of his choice.
v. The ballot ID, which acts as the asset, gets assigned to the selected candidate via their public key, the transaction is authenticated with the digital signature of the private key embedded in the voting smart card.
vi. The transaction is broadcast and recorded on the blockchain network.

5 Evaluation

This section reports the evaluation of the BANES by using the Architecture Tradeoff Analysis Method (ATAM).

5.1 Evaluation Using Tradeoff Analysis Method (ATAM)

ATAM is a scenario-based method for evaluating the software architectures in order to assess its potential to satisfy the expected quality attributes of a system and identify possible areas of improvement from the architectural point of view. ATAM helps with the identification of the risks, sensitivity points and tradeoffs points that pertain to a system [27, 28]. In ATAM, risks refer to potentially problematic architectural decisions; a sensitivity point is a property of one or more components that are critical for achieving a particular quality attribute response; and a trade-off point is a property that affects more than one attribute which is also a sensitivity point for more than one attribute [28].

We conducted the ATAM in two phases using a small number of stakeholders. The first phase, which is architecture-centric involved a panel of 3 experts. The panel of experts includes i) an information system (IS) solutions architect, that has 14 years of IS architecture experience; ii) a doctoral degree holder in mathematics and encryption, with experience in blockchain development for business use; and iii) a software engineering research with over 15 year experience in software development. Phase 2 of the ATAM included additional 3 participants who are non-experts, but end-users and voting stakeholders to verify the outcome of the first phase. The summary of the results of the ATAM process is presented in the next section.

5.2 Assessment of Business Drivers and Quality Attributes by Using Scenarios

From the interaction with key stakeholders during the requirements identification phase, the main business drivers of e-voting for national elections in South Africa are to i) increase transparency in the electoral process; ii) reduce ballot paper and logistical distribution challenges; iii) enable faster, more efficient voting and counting; iv) to ensure more reliable results; v) increase accessibility to voting; vi) reduce carbon foot-

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print; vii) reduce costs of running elections; viii) increase voter participation. Based on the identified core business drivers, the panel of experts rated three attributes as having the highest priority. These are security, performance, and functional suitability (in terms of transparency, verifiability, auditability, and availability). The scenarios that were used to evaluate each of these attributes are presented in Table 2.

Table 2. Attributes and Scenarios used for the ATAM

Attributes	Scenarios
Security	A voter's vote remains a secret in all circumstances
	Only a valid voter is allowed to vote
	The system's response to a Man-in-the-middle attack during voting
Performance	System's response to a high volume of transactions in terms of speed of processing and reliability
Functional Suitability (Transparency, verifiability, Auditability)	Stakeholders want to view the process to be sure of transparency
	Stakeholders want to verify election result after vote cast
	A voter wants to verify vote without the risk of coercion

5.3 Identification of Risks, Sensitivity Points and Tradeoffs based on Scenarios

Based on the quality attributes that were adjudged to be of the highest priority and the associated scenarios presented in Table 2, the panel of experts analysed the architecture (see Fig.1) of the proposed BANES with the aim of identifying risks, non-risks, sensitivity points, and trade-off points. In order to foster a deeper understanding, other perspectives of the proposed architecture based on the Kruchten's 4+1 Views of Architecture were presented to the panel of experts in order to engender a basis for thorough analysis of the proposed architecture.

In terms of security, the analysis revealed that use of smart card technology that requires a voter to login with a personal identification number (pin) and a combination of public key and private key makes it very difficult for an invalid voter to gain access to the voting system. The implementation of the zero-knowledge protocol (see Section 4.2) allows the validity of a vote cast to be established without allowing access to the real identity of the voter. Thus, a voter's identity will always be anonymous even when an audit of votes cast is undertaken. In a scenario of a Man-in-the-middle attack of connections outside of the blockchain network, this can be mitigated by adding another private key encryption component for communication between the components that are external to the blockchain network. The e-voting smart card for identification, authorization, and authentication would cater for the additional procedure. There are no risks associated with this change, and no sensitivities points were identified.

Definitely, a scenario of high volumes of traffic of transactions could affect accessibility, performance, availability, and reliability of an e-voting system. However, the risk associated with this scenario is mitigated by the Hyperledger Fabrics blockchain that supports modular functionality that is both decentralised and distributed according to permission, roles and blockchain channel (see Section 4.1).

The issues of transparency, verifiability, confidentiality, and auditability are very important in e-voting. The implementation of a zero-knowledge protocol provides confidentiality and auditability, but together with the verifiability requirement, introduces a risk of coercion (where persons are forced/influenced to vote in a certain way) which affects the integrity of the voting process. This issue can be mitigated by creating an additional peer node role type that is purely for validating. The nodes can be limited to controlled access points, such as IEC outlets, which can offer the security to

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avoid coercion. The trade-off point that was identified is the need to ensure that verification of votes can only take place at designated nodes and not on just any node.

In summary, the results of the ATAM evaluation indicate that the only major trade-off associated with the proposed architecture was the need to limit access to vote validating nodes to secure locations in order to mitigate any risk of coercibility.

6 Discussion and Conclusion

Interactions with relevant stakeholders reveal that South Africa is not outrightly opposed to e-voting for the national election, but there must be a convincing assurance that the technology can deliver according to expectations. The expectation relates to meeting the core requirements such as usability, reliability, performance, availability, and essential aspects of functional suitability such as transparency, auditability, transparency, and verifiability. Our ATAM evaluation revealed that the proposed BANES could be a good starting point towards the realisation of e-voting for national elections. The conceptual design of the BANES reasonably addresses the concerns of security, performance, and function suitability that are particularly important in the South African context. Also, unlike many of the existing e-voting systems that are based on a centralised design, which makes them vulnerable to Distributed Denial of Service (DDoS) attacks, the proposed BANES will be relatively more secure. It will promote more transparent elections and less prone the risk of internal corruption and vote manipulation by leveraging key aspects such as the Hyperledger Fabric, and zero-knowledge protocol that have been integrated into its design. The result of the ATAM evaluation also revealed some sensitivity points and tradeoff points in the aspects of vote validation. This appears manageable, and it is one that could be handled effectively in the subsequent stages of software development, which gives impetus to further investment in the future towards the realization of blockchain e-voting for South Africa.

In conclusion, this paper presents the application of blockchain technology for national elections in South Africa. By adopting a stakeholder-centric approach for requirements identification, the blockchain architecture for national e-voting system (BANES) was proposed. An evaluation of BANES from the architectural point of view revealed that it has the potential to satisfy all important quality attributes that relate to e-voting. Areas of improvement that should receive attention in subsequent stages of development were also discovered. These observations support the need for further engagements and investment in e-voting, albeit as a supplementary approach to traditional paper-based voting, which will still be more accessible for many persons.

In future work, we shall produce a more elaborate design of the BANES as a basis for engagement with a wider sphere of stakeholders in order to understand the requirements, drivers, and factors that are critical for successful e-voting implementation in South Africa in a better way.

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Critical reflection on Instant Messaging as an e-mentoring platform in rural high schools

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Abstract. This paper reports the findings of a qualitative case study of critical reflection on the use of Instant Messaging (IM) for e-mentoring purposes. The researchers reflect on its potential and challenges of an e-mentoring programme implemented in a rural high school in Limpopo Province, South Africa. The majority of schools in rural areas are associated with a high school dropout rate which is influenced by various social issues. In addition, learners in rural areas are characterised by lack of self-motivation and self-actualisation. This is often exacerbated by the lack of mentoring, lack of information to encourage academic success and sometimes lack of role models. IM technologies such as WhatsApp provide an excellent platform for e-mentoring in rural settings. The paper discusses the potential of an e-mentoring programme on improving academic success in rural South Africa. It also reflects on the challenges experienced by mentors, mentees and the developers of the e-mentoring intervention during the programme. The study makes an interesting contribution to information communication technology (ICT) for development research by using critical reflection as a methodology to assess the use of IM technologies as an e-mentoring platform. In addition to mobile data challenges, the study finds learners in rural areas to be reluctant to participate in an e-mentoring relationship for a long period.

Keywords: E-Mentoring, Educational Technologies, Instant Messaging, Rural High Schools, Self-actualisation, Mentorship.

1 Introduction and background

Nationally, South Africa is battling high levels of dropout in schools. Of the 1,155,629 learners who enrolled for Grade 1 in 2006, only 34.7% of them made it to matric [1]. In 2016, the South African Department of Basic Education revealed that rural provinces have had increased levels of high school dropout [2]. For the 1,100,877 learners who enrolled for Grade 10 in 2014, only 610,178 enrolled for Grade 12 in 2016 [2]. Nationally, this counted as a 44.6% dropout rate for learners between Grades 10 and 11 during the years 2014-2016 [2]. The dropout rate was severe in rural provinces: the Northern Cape had 54.4%, North West 52.7%, Limpopo and Eastern Cape had 46.2% [2]. Lack of role models in rural schools plays a significant role in discouraging learners to stay in school [3]. Learners in rural areas, due to socio-economic challenges, drop out of school more often than their counterparts in urban areas. Mentorship would be instrumental in providing role models and guidance in rural learners to stay in school [4].

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Mentoring is a relationship in which a well-versed or knowledgeable individual (mentor) guides a less exposed or less knowledgeable individual (mentee). The South African College of Applied Psychology sees mentoring as a crucial psychological process that improves the mentees self-worth and accelerates self-actualisation [5]. Traditional mentoring involves a one-on-one meeting between a mentor and a mentee in a particular setting where they are able to converse about the developmental areas of the mentee [6]. Researchers globally acknowledge the significance of mentoring in human development, ie, for education and career development purposes [7]. For decades, most educational institutions have depended on mentoring to enhance the learning process [7]–[9].The advent of Web 2.0 has introduced e-mentoring (also known as online mentoring) – mentoring that takes place through computer-mediated communication (CMC) systems [10]. Moreover, as advances on social media continue to transform online communication, e-mentoring has gained popularity in the field of mentoring [11].

As IM continues to enhance human communication, it becomes essential to explore its potential on mentoring rural high-school learners. While mentoring has been largely recognised as a pillar of professional development globally, in most rural communities the mentoring phenomenon as an effective approach to accelerate academic success is still relatively novel [12]. In the South African context, educational psychologists acknowledge that mentoring is a successful intervention in the learning environment. However, it has mostly been used in urban schools, especially those that are close to universities. For example, the University of Stellenbosch established a mentoring programme in which psychology students provide mentoring services to the nearby impoverished township of Kayamandi [13]. However, this initiative still follows traditional mentoring – one-on-one meetings between a mentor and mentee.

Although the concept 'e-mentoring' has been widely explored, little research has been done to critically reflect on the dynamics of an e-mentoring programme in rural settings. The current study espouses an academic debate into the use of IM as a tool for e-mentoring for learners in rural high schools. It takes a reflective approach to present benefits and challenges of an e-mentoring programme in rural settings.

This study follows a critical reflection qualitative research methodology [14]. This methodology allow participants to generate knowledge from the hands-on experience of the project [15]. This methodology sees both researchers and respondents as participants and acknowledges that complexities from them influence the outcome of the research. [16, p. 10] assert that:

… 'Participants find that critical reflection provides a way of "standing back" and seeing the issues from a different perspective. The critical reflection process encourages participants to name the influence of uncertainty and complexities of power, including their assumptions about the place of power'…

Critical reflection is useful for Information and Communications Technologies for Development (ICT4D) research because it allows researchers to reflect upon the entire development process. ICT4D research projects are usually emancipatory in nature – and are prone to complexities associated with a transformative environment. More information about the methodology will be discussed later.

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8 Literature review

8.1 E-Mentoring in education

E-mentoring can be defined as the use of an information communication technology (ICT) tool to facilitate a mentoring relationship between a mentor and a mentee [10]. Most e-mentoring programmes take place in a dedicated platform which allows individuals to log on and exchange ideas with regard to personal development [10]. An example in the African context is Mara Mentor, an e-mentoring platform that connects young entrepreneurs with professionals across 30 African countries [17]. This e-mentoring platform came as a result of the partnership between the National Youth Development Agency (NYDA) and the Mara Foundation to accelerate youth entrepreneurship through mentorship [17]. The primary objective of this paper is to reflect on the potential and challenges of using an Instant Messaging (IM) technology such as WhatsApp as an e-mentoring platform in rural settings.

The majority of mentoring in education is done to equip teachers with skills to teach the current generation of learners who have been born into a digital world [8]. Most scholars acknowledge that e-mentoring in schools has gained popularity as educational technologists continue to look for tools to enhance the learning experience beyond the classroom [11]. Moreover, e-mentoring has the potential to cover the lost instructional time due to strikes, natural disasters or any disturbance during the academic calendar [18]. Similar to most educational technologies, e-mentoring may accommodate learners with different learning styles, because it is a more personal method of sharing information [19]. If the learner struggles with certain concepts in the classroom, they can chat with their mentor to clarify the concepts. The mentor might even explain the concept in layman's terms, or even in a vernacular language to elaborate further.

8.2 Challenges of e-Mentoring

One of the challenges of mentoring in a virtual environment is the lack of body language [6]. In e-mentoring, non-verbal cues are replaced by emojis, but do not successfully perform the relational function of non-verbal cues in the communication process. Considering that mentoring is a psychological process, e-mentoring may fail to facilitate the psychological process that is involved in improving academic success for learners [11], [20].

Although e-mentoring has the potential to transform the learning experience for learners, it has some pitfalls. Because it is run on an online platform which often requires data, it might not be used by everyone [6]. Thus, in the African context where data is expensive, learners in rural areas may have affordability issues [21]. Moreover, in terms of generations, generation X may find being constantly online time-consuming, while millennials would enjoy chatting online for a longer period [10].

With regard to establishing an e-mentoring relationship, people must establish a mutual agreement with about to how the engagement would work [10], for example, online time and response time during the virtual conversation. In addition, this mutual agreement must highlight expectations for both parties, and problem areas which the mentees wish to be addressed [10].

8.3 Instant messaging as an e-Mentoring platform

Previous studies have looked at IM in the schooling environment with emphasis on its advantage of improving the learning experience [22]–[24]. WeChat and WhatsApp

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are the most popular IM technologies in the world, but the latter has seen an increase in users since it was acquired by Facebook [24]. In South Africa, WhatsApp became popular around 2012 [25]. WhatsApp is useful in creating a collaborative learning environment between lecturer and students at university level[26]. As an e-mentoring platform, IM creates a personalised environment which allows mentees to be free to discuss deeper issues which affect their academic performance [25].

For [26], IM technologies such as WhatsApp should be used in conjunction with learning management systems (LMSs) such as Blackboard. Considering that LMSs run on a complex framework and network systems, WhatsApp can be useful for information sharing, especially during assessments. A study by [22] WhatsApp groups were primarily used for harnessing the social atmosphere in the class, interacting, creating dialogue and encouraging information sharing. However, WhatsApp groups sometimes become challenging to manage as students may discuss information which is irrelevant to the concerned subject[22]. Apart from a conducive social environment, [22] conclude that IM technologies offer numerous teaching pedagogies which educators can benefit from – for example, differential learning.

WhatsApp is a solution to bridging the information gap that exists in rural South Africa [27]. Because of its file-sharing capability, people in rural areas can share information about various economic opportunities, for example, jobs, bursaries etcetera. In most developing countries, WhatsApp has proved to be imperative for facilitating the growth of informal businesses[27]. However, in addition to the lack of sufficient equipment and infrastructure to encourage learners, rural schools have been modest in adopting technologies which can enhance the learning experience [28]. While there is an increase in the use of mobile phones for educational purposes in South Africa, this has not been the case in the rural areas [26].

9 Research context and case description

This qualitative case study was conducted in the Limpopo province, in a high school called Tshiemuemu Limpopo remains one of the poorest provinces after the Eastern Cape. Of its 5,726,800 population, 78.9% are living below the poverty line [29]. As a result, most villagers live in high levels of poverty [30]. The school is in Tshakhuma village which falls under the Vhembe district. The village has a population of 17,371 people[31]. The school used to be the best out of three high schools in the village. However, the early 2000s saw the school falling through the ranks as it started having a poor pass rate. As a result, villagers started taking their children to other schools, even as far as Thohoyandou – the largest town in the Vhembe district, located approximately 20km away from Tshakhuma. To improve academic access for the learners, the principal turned to mentoring. The principal started contacting some of the alumni directly to request starting mentoring learners in Grade 12. The researchers, as part of the alumni, saw it as an opportunity to implement a development initiative that would contribute towards academic success for the learners across all grades.

Both researchers were past students at the school and had long left the village to study in Cape Town. The older researcher is pursuing a Doctor of Philosophy' (PhD) in Information Systems (IS), while the younger one is pursuing a Bachelor of Science (BSc) in Computer Science. Before they became co-researchers, they had been in an e-mentoring relationship for the previous five years. The younger researcher ended up at the University of Western Cape as a result of an e-mentoring relationship. Moreover, while in Cape Town, the researchers were involved in various successful ICT for development (ICT4D) projects. As a result, the two researchers were convinced that the e-mentoring programme would be a success

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At the beginning of 2018, the researchers developed an e-mentoring initiative and approached the school to identify people who could be involved. A Facebook post was created to recruit e-mentors. This was supplemented by word of mouth to other alumni to ask them to become part of the programme. A total of 16 mentors volunteered, from whom two head mentors were identified. Head mentors would be responsible for attending to, and reporting about, challenges faced by mentors. Moreover, they were also primary liaisons between teachers and mentors. For example, should mentees start bunking school or show indications of stress, the teachers would alert the head mentors. Most mentors were from the University of Venda – a local university located in Thohoyandou.

The programme was announced to the learners across all grades. It was introduced as a programme to help learners improve their marks and, where possible, to provide information about career paths. Seventy-three learners signed up for the programme and were paired with the 16 mentors. Moreover, some mentors were matched with learners regardless of their understanding of career aspirations. These mentors were given contracts in which they agreed to be there for their mentees and to buy their own data to facilitate the e-mentoring process. Thereafter, three WhatsApp groups were created. The first group were the implementers. The second group consisted of the 16 mentors, and the third one was for the head mentors and the implementers. Each mentor communicated directly with each of their mentees – these conversations could not be done in groups for mentor-mentee confidentiality purposes. The researchers were part of all the WhatsApp groups for the purpose of observation and feedback.

10 Methodology

10.1 Sample and unit of analysis

The research employed a non-probabilistic convenience sampling strategy which consisted of 16 mentors, 73 mentees and two head mentors. In academic research, scholars use convenience sampling because the members of the population are accessible and are available at a specific given time [32]. In addition, to achieve the goals of a critical reflection methodology, the researchers were also included as part of the sample. The study analysed the activities of the sample on WhatsApp as an e-mentoring platform. Therefore, the unit of analysis is the actual e-mentoring programme implementation and the activities by both the researchers and the sample.

10.2 Data collection and analysis

For data collection, the research largely employed observation into the activities of the three WhatsApp groups that were created for feedback purposes. In addition, the researchers also conducted a reflection session where they critically reflected on the implementation of the entire e-mentoring programme to identify its potential and challenges on improving academic success for learners in rural areas.

The research employed thematic analysis where the themes emanating from the observations and reflections inform the final findings [33]. The conversations during the reflections were coded through an open code to identify emerging themes. The researchers employed an inductive approach which was guided by the available data to facilitate the thematic analysis process[34].

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10.3 Critical reflection as a qualitative research method

Critical reflection is 'a way of learning from and reworking experience'[16, p. 56]. As a methodology, critical reflection is used in professional settings where practitioners need to improve their practices [15]. In the technology environment, this method is commonly used to identify what went wrong after the final release of a platform which failed or had multiple 'bugs'. While it is still in its early stages as a research methodology, critical reflection has been useful in environments which need deeper introspection to improve the efficacy of certain practices and processes. This methodology allows researchers to capture the richness of complex social dynamics during IS and ICT for development projects [35]. In the ICT4D research, this methodology is useful for reflecting upon the implementation of the development intervention. As research in IS and ICT4D continues to seek a deeper understanding of social dynamics involved in implementation, an inquiry methodology such as critical reflection becomes essential [35], [36](Eden, Jirotka, & Stahl, 2013; Kelder & Turner, 2007). While most qualitative methods allow scrutiny from a participants' perspective, critical reflection is holistic in that it also scrutinises the researcher.

These are [37]four steps for critical reflection according to [37]:

- Assumption analysis – here researchers challenge their initial beliefs and social structure to determine their impact on a project, programme or practice.
- Contextual awareness – in this step, researchers determine social and cultural contexts that influence their assumptions.
- Imaginative speculation – this involves imagining ways of thinking in order to challenge researchers' current ways of thinking.
- Reflective scepticism – entails questioning universal claims by suspending or temporarily rejecting previous knowledge about the subject.

These four steps are instrumental in facilitating collecting data. To obtain answers for the reflective process above, researchers must ask themselves questions such as[38];

- Why did we do what we did?
- What else could we have done?
- Does the entire experience, prior to, during and post-implementation tell us anything about ourselves and our involvement in the development process?
- What new knowledge do we have about the entire development process?
- In future, what should researchers consider in a similar context?

While the steps above were used to guide the reflection process, they were also used as a framework for the challenges and potential for using WhatsApp for mentoring purposes.

11 Results

11.1 Challenges of e-Mentoring in rural high schools

The technology v/s human capacity

The prior assumption of how this programme would work was based on the capabilities of the technology (WhatsApp) as opposed to humans (mentors). While the chosen technology proved to be conducive for e-mentoring, it became clear that the researchers had overlooked the human-capacity aspect of managing an e-mentoring programme. For example, the programme had 15 mentors and 73 mentees. Some mentors had seven learners each, while others had 10. This proved to be a challenge be-

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cause some mentors lost track of academic progress for some learners as they focused on those who chatted the most on WhatsApp.

While there is not yet an agreement on the number of mentees each mentor must have, researchers assert that mentors must only accept a quantity they can psychologically handle [39]. This is because, as a psychological process, e-mentoring requires mentors to be present at each conversation [40]. However, because of the many mentees compared to the mentors, it became difficult to facilitate this psychological process. Moreover, it was difficult for these mentors who did not receive enough e-mentoring training to manage more than two learners at a time. While there were mutual agreements signed by both parties at the initial stage, because of the dynamics above, most relationships collapsed.

Urban savior syndrome

After the programme implementation, it was apparent that there was what researchers termed 'urban saviour syndrome'. This can be defined as the tendency of people from urban areas to assume that they can easily solve problems in rural areas because they have been exposed to development and innovation more than their counterparts in rural areas. Traditionally, people who move from rural areas to urban areas, when they go back to their homelands after years of work or study, are perceived to have new knowledge as ideas of development [41]. As a result, they tend to feel that development of their communities is in their hands, as they have been exposed more than those who have remained in the rural areas. In the first meeting with both mentors and mentees, all parties seemed to have confidence that the initiative was going to benefit them as the researchers came from an urban area. The urban saviour syndrome was also more apparent during the initial meeting with the teachers who exhibited evidence of inferiority as researchers presented the e-mentoring concept.

The assumption that projects which were implemented in urban areas would work in rural high schools proved to be a challenge as it clouded the researchers' contextualisation of the initiative. For example, during the pairing sessions, researchers struggled to understand why learners had not contacted their mentors in the first four weeks after introduction. The researchers discovered at a later stage that mentees thought it was the responsibility of the mentor to contact them. It was another misconception based on the prior experience in an urban setting where the learners were more proactive in the e-mentoring relationship.

It appears that, as researchers, we imposed an urban culture of communication which the learners in the rural high school could not understand. This can be attributed to the idea that, in rural settings, a mentor takes seniority and is expected to be the one doing most of the communication. This is because, in African rural areas where collectivism prevails, high power distance [42] is a reality, and people in lower levels believe in taking instructions from their seniors. Failure to understand the communication dynamics in this environment resulted in losing a large number of mentees.

Data costs

Although an internet connection is becoming freely available in most South Africa communities, it is only available in urban areas, with little or none in rural areas [43]. Most scholars accept that mobile data in Africa is expensive and, as a result, affects access to overall ICTs[23]. The lack of mobile data is the primary barrier to a successful e-mentoring programme. This conclusion parallels the reality of the current study. The cost of data cost affected both mentors and mentees. For mentors, they experienced data issues during vacations when they could not access their free university WiFi. During the e-mentoring programme, researchers realised the benefit of university WiFi for nurturing the mentoring relationship for rural high schools. On the other

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hand, we also found that data cost issues privileged mentees with better financial resources – thereby perpetuating inequality in the programme.

11.2 Affordances of IM in e-mentoring high school learners

In a school environment, IM has both pedagogical and social affordances [24]. Literature shows that IM enhances the relationship between teachers by increasing communication between them beyond the school environment. This section reflects on affordances we found in the context of e-mentoring.

Boundlessness

The advantage of IM in e-mentoring is its ability to forge relationships across time and geographical locations [44]. The majority of the mentors in the programme spend most of their time at university further away from the mentees. Despite the distance, they can communicate with the learners and help assist them with their formative assessment, and overall career planning. Moreover, for the mentors with mentees in Grade 12, they were able to advise them about the university degrees to study, and institutions to apply to.

Ubiquity

IM technologies such as WhatsApp have become ubiquitous in the school environment. This allows e-mentoring programmes to use technologies which are immediately available for learned [45]. In a learning environment, the researchers observed that the ubiquitous nature of WhatsApp allows the mentoring relationship to be firmly developed. Thus, the more participants chat, the more they eliminate anonymity and begin to trust each other [46].

Scalability

Scalability is defined as the ability of a technology to perform various activities and manage increased levels of demands in a single system [47]. Since its acquisition by Facebook, WhatsApp has file-sharing, video-calling and voice-calling capabilities. The video-calling capability is very instrumental for the researchers to conduct feedback meetings with head mentors. The video feature is able to capture those non-verbal cues which were highlighted by [6] earlier. In addition, researchers use WhatsApp to share all information about bursaries, university application seasons and information about various degrees and their matching career paths.

12 Implications of the study and conclusion

During critical reflection, it became clear that it was still too early for e-mentoring programmes to operate independently without one-on-one meetings in a rural context. Because of challenges associated with access to mobile data, learners may not be able to have frequent chats with their mentors. Moreover, there is still a need to conduct awareness campaigns of what mentoring is, and its significance to learners' self-actualisation and academic success in rural areas. While school authorities identified the need of mentoring, they were not aware of what it entailed – and hence it was difficult for them to communicate effectively about e-mentoring to the learners.

To ensure a successful e-mentoring in rural high schools, implementers must consider cultural aspects that may affect communication between the mentor and mentee. For example, if a mentor is a senior, which is usually the case, they may have to highlight the need for the mentee to be more proactive in communicating their needs and

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expectations in the relationship. Moreover, e-mentoring initiatives in rural areas are not void of socio-economic challenges that affect learners in that context. Researchers need to consider conducting a contextual analysis to identify the challenges that might affect intervention implementation prior to the launch of the programme. Future work in this area can focus more on using ethnographic methodologies to assess the use of IM in rural contexts.

Despite its potential to transform education, e-mentoring cannot operate independently without one-on-one meetings in rural areas. During the critical reflection, the researcher found that there are certain challenges that are unique to rural areas which may affect the success of an e-mentoring initiative. This relates to factors such as data costs and cultural elements which are a reality in rural areas. Moreover, the study makes an interesting contribution with regard to implementing e-mentoring programmes in rural areas. This pertains to ensuring that e-mentors have training, and that they understand the significance of constant communication in an e-mentoring relationship. There should also be training for mentees to understand how to be proactive in a mentoring relationship, to ensure that they achieve their mentoring goals.

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Electronic Data Disposal Practices in Selected Companies in Cape Town, South Africa

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Abstract. Most businesses deal with sensitive data in one form or the other. Efficient data management require that operations of data storage and data disposal are handled in a way that preserves the integrity, security, and privacy of data at all times. So far, there is a dearth of information on the electronic data disposal practices of many companies, hence young businesses and start-ups mostly lack a reference operational guide for electronic data disposal (EDD). This paper presents the outcome of a survey that involved 20 participants, and 13 companies on EDD practices of some companies in Cape Town in the Western Province of South Africa. By using an online survey approach, and analysis of the collected data, the study found that Over 76% of respondents claimed that their companies have an EDD policy in place, over 50% of respondents claimed that their own company is aware of the data protection laws, and have data restriction schemes in place, while majority agreed that their companies do make attempts to brief their employees on EDD policies. However, a majority (80%) of companies are unaware of international EDD standards, and only 44% of company employees are aware of alternative EDD techniques apart formatting of storage devices. Also, the implementation and integration of electronic data management and EDD policies at all levels of an organisation are only applicable in few (38%) of the surveyed companies.

Keywords: Data management, Electronic Data Disposal, Data privacy, Data protection.

1 Introduction

Every business in the world have their share of sensitive data stored on computers and servers, whether it is financial, medical, client or even employee information, and sensitive company information about their products/services that can be leaked to competitors [1]. Therefore, it is necessary to ensure that company data is secure. The issues of electronic data disposal (EDD) in the industry are on the rise due to concerns about the privacy and security of sensitive data [2]. EDD entails the mechanism and practices that are used for securely disposing of all confidential data that are stored on electronic storage devices when they are no longer needed.

Despite the new opportunities provided by cloud migration that enables free access to store data from anywhere in the world and offsite protection, hard drives and solid-state drives are still remain a popular form of storage in many companies [3]. However, like many electronic devices, these devices do not last forever and need to be maintained or new stock of machines need to be installed to keep up with new technology or after the expiration of their useful life (Shah, 2016).

Electronic data disposal (EDD) has been considered a huge concern across the globe especially with the involvement of sensitive information [4]. Various EDD methods follow a set of data disposal standards to ensure that when electronic data is disposed of, they are not recoverable [2]. However, there is no definitive report that

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indicates that South African companies are complying with EDD policies and adhering to international EDD standards. There is a possibility that many companies risk having the security of their data compromised when disk storage media and devices are discarded, which will endanger the well-being of the owners of such data [5, 6]. The dearth of information on EDD practices has led to limited awareness on EDD best practices, which could be beneficial as a reference guide for start-up companies, upcoming businesses, and even individuals.

This paper presents the report of a survey on EDD practices in selected companies in the Cape Town area of the Western Cape Province of South Africa. The study examined two main research questions, which are i) what are the electronic data disposal policies that are in place in companies in Cape Town to ensure secure electronic data disposal? and ii) what are the electronic data disposal techniques and standards being used by companies in Cape Town? The objective of the study is to gain an overview of techniques, measures, practices, standards, and policies that are being employed by selected companies in the Cape Town region of South Africa in order to draw observations that could serve as an intellectual guide for upcoming practitioners and start-up companies. To do this, we mounted an online survey in which 20 respondents from 13 companies participated. The survey responses were analysed in order to derive conclusions from the study. This study makes a significant contribution to the discussion on the topic of electronic data disposal, which until now is a relatively under-explored in the literature, but one that is particularly important given the growing importance of data as the most valuable resource in the world, and the need for more data security.

The rest of this paper is organised as follows. Section 2 presents the background and related work. In Section 3, we describe our study design, while Section 4 presents the results of the study. In Section 5, we discuss the observations, while the paper is concluded in Section 6 with a set of recommendations.

2 Background and Related Work

In this section, we provide a background on issues of electronic data disposal (EDD), EDD methods, EDD standards, and also a review of previous studies on EDD.

2.1 Electronic Data Disposal (EDD)

Electronic data disposal is concerned with data sanitization activities that are used for securely disposing of all confidential data that are stored on electronic storage devices when they are no longer needed. EDD is essential for effective data protection within an organization in order to avoid unwanted security breaches, and ensure the safety of personal and corporate data.

The most common method of EDD that is used by most computer users is to send a file to the recycling bin located on the desktop which is then emptied, giving the user the impression that the file has been permanently deleted [2]. However, many users are unaware of the additional steps required to completely sanitize their storage device of unwanted documents [5]. Although all modern file systems provide the user with the ability to delete files, the operating system simply unlinks the file, clearing hard drive space and giving the impression that the file has been removed. File system designers implemented this technique for efficiency, as [2] states that permanently removing data from an electronic storage device is a more complicated process.

An experiment conducted by Valli [6] portrays the clear gap associated with just deleting to the recycle bin or formatting a hard drive as compared to effective deletion methods. The experiment involved obtaining randomly selected hard drives from auctions in Australia. Eleven (11) Hard drives were purchased and forensically analysed.

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Recovery techniques used ranged from simple to complex requiring specialised recovery tools. Of the 11 hard drives analysed, 10 had data that were recoverable using a recovery technique. All the drives examined contained a Microsoft Operating System that uses a file allocation table 16 or 32 (FAT16/ FAT32) to store the data. Valli in [6] further noted that 9 of the 11 hard drives were simply formatted to erase the content, which made it easy to recover using forensic software. Most of the drives showed traces of usage in the corporate environment entailing that these drives still have remanences of old corporate data. The experiment concluded that only 1 out of the 11 drives have been securely erased and the data could not be recovered. This illustration underscores the need for effective EDD whenever there is a need to discard data storage devices.

2.2 Electronic Data Disposal (EDD) Methods

Electronic data disposal could the done in-house by a company or outsourced. Some of the recommended methods include:

Degaussing. This is the process of simply placing a strong magnet near the storage device to scramble and destroy the magnetic fields used by the device but is unreliable, expensive and time-consuming. This method is complex and must be done by trained professionals [2, 7, 8].

Destruction. This is the physical destruction of an electronic device. Although this method does present environmental effects, it is considered an economical and effective approach to render devices unreadable [7, 8]

Data erasure. This involves erasing the entire partition of the disk by using a software utility, which will securely delete the information on the partition so that no data, metadata, and directories can be found. Users can specify the files and the number of passes and writing patterns. Unfortunately depending on the file size, overwriting may be time-consuming [8].

2.3 Electronic Data Disposal Standards

According to [2], the three main international standards for secure data disposal accepted by the technology industry are the following:

US Department of Defence standard. The document is the compliance standard for many manufacturers of erasure software. The main points of the standard are that i) the erasure ensures that all addressable locations on the hard drive have been overwritten; ii) the media types covered by this standard include magnetic disks, optical disks, memory, and printers; iii) If information is, or was in the past, deemed to be classified, the standard requires that the media be physically destroyed [2].

Gutmann Method. This standard was developed by Peter Gutmann as a 35-pass data overwriting method to work on older disks that use run-length-limited encodings. The basic idea is to flip each magnetic domain on the disk back and forth as much as possible without writing the same pattern twice in a row and to saturate the disk surface to the greatest depth possible [8]. Gutmann further stated in his paper that 35 is not a perfect number of passes but it does make the recovery of data using advanced methods more challenging ([2].

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National Institute of Standards and Technology Standard. This standard was issued in 2006 and released with the intention of helping companies implement an effective sanitization program with proper methods and controls for the disposal of electronic data [2].

2.4 Related Work

In [2], the author recommended a set of practices that a company must follow when dealing with electronic data disposal regardless of whether the company does in-house or outsourcing for electronic data disposal. These practices include: i) developing a program around the continuous disposal of all electronic equipment, because all electronic equipment have different life span; ii) considering the option of remote electronic data disposal technologies that improve the time and cost of deleting sensitive data; and iii) putting a measure must in place to ensure that if data cannot be deleted from selected devices, then the devices must be physically destroyed. Also, [9] explains that earlier research and field surveys, suggests that employees seldom follow information management procedures and data disposal policies. The authors stated that the policies are used as mere guidelines or directions by employees instead of enforced rules that are specified as general standards.
In [10], it was observed that a broad cross-section of organisations in Australia and the United Kingdom do not adequately protect or erase confidential data stored on hard disk before discarding them. An experiment was performed that confirmed their observation in 90% of the cases examined. Also, [11] observed that much useful information is inadvertently given away regularly when electronic devices with in-built data storage such as computers, mobile phone, and others are disposed after their useful life. In a research that spans 4 years, and involves a collaboration between three universities in Australia, the UK, and USA, the study after forensically examining 100 computer disks and 160 hand-held devices found that both organisations and individuals seldom do enough to protect useful data that have been stored on disk before disposal of such equipment. In [12], a review of various methods for data sanitization was presented. It was observed that many of the methods do not offer the highest level of security. The authors reported that secure data erasure and physical destruction of the device are among the most secure method. The survey on electronic data disposal (EDD) presented in this paper represents a pioneering effort that is aimed at providing insight on the EDD practices in organisations, and particularly from the South African context.

3 Study Design

A study design that was based on questionnaire design, data collection through an online survey, and data analysis of survey responses was adopted. An overview of the process is presented in Figure 1.

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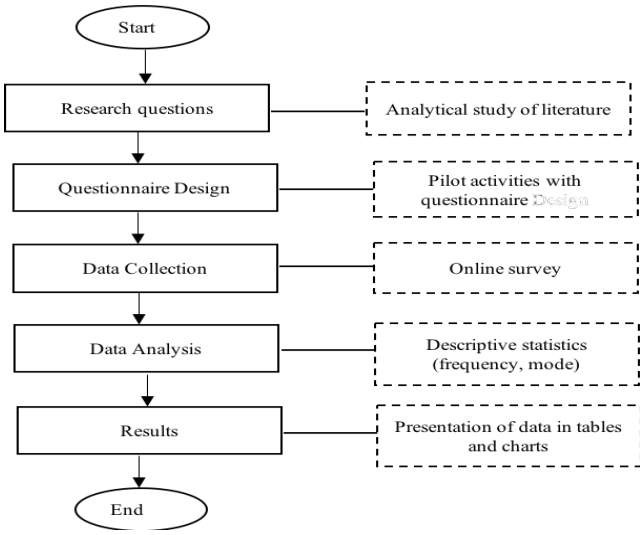

Fig. 1. Overview of the Adopted Research Design

3.1 Structure of the Survey

The survey-questionnaire has two sections. The first section targeted top level/ human resource managers and posed questions on electronic data disposal policies. The second section targeted the IT Department or IT specialists of companies and involved questions related to electronic data disposal techniques, procedures and data management in general.

A pilot test of the questionnaire was conducted by using selected experienced individuals including the project supervisor of the researcher in order to ascertain the appropriateness of the survey questions. The observations made during the pilot test of the questionnaire were used to revise the questionnaire to produce the final version.

3.2 Participants Enrollment and Data Collection

Participants were recruited for the survey via information technology forums and social groups that include LinkedIn, and the Information Technology Professionals of South Africa WhatsApp group. The platforms provide links to employed IT professionals and some managerial staff of different companies. The information obtained from the list of contacts enabled the researchers to contact participants via electronic mail and telephone in order to obtain their consent. Once consent was received, the survey link was sent to the participants. The survey was hosted on Google Forms, and 30 participants from 20 companies that are based in Cape Town were contacted. At the end of the allocated 1-month period. A total of 20 participants from 13 different companies responded to the questionnaires.

3.3 Data Analysis

The main analysis tool that was used for this study was Microsoft Excel 2013. It is a common tool used for quantitative data analysis due to its comprehensiveness, flexibility, and ability to accommodate any type of data file. The software was especially useful for small scale surveys and was used to generate tabulated reports and descriptive statistics. During the data analysis, a mixture of nominal, ordinal and interval measurements was identified and interpreted using descriptive statistics. All participants were kept anonymous and were assigned aliases such as Company 1, Company 2, Company 3, Participant 1, Participant 2 and so on. An overview of the pattern of participation by the companies and different types of respondents is shown in Table 1.

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Table 6. Overview of Participants in the Survey

Participation by Companies	Participation by Different Respondents
Company 1 - 1	Data Analyst - 1
Company 2 – 1	Service Desk - Coordinator - 1
Company 3 - 1	Managing Director - 1
Company 4 - 2	System Administrator - 1
Company 5 - 2	Software Developer – 11
Company 6 - 2	Automation Scripter and Tester - 2
Company 7 - 1	System Analyst – 1
Company 8 - 3	Technician – 1
Company 9 - 1	Researcher – 1
Company 10 -1	
Company 11 - 1	
Company 12 - 1	
Company 13 - 1	

4 Results

The first section of the questionnaire focused on policies and practices on electronic data disposal (EDD) in organisations, and targets respondents who are in a managerial position in a department of a company. The questions focused on issues that relate to electronic data management policies, the types of data the company works with, data access and security measures, and the Protection of Personal Information (POPI) Act. The POPI Act, Act No 4 of 2013, for the Republic of South Africa aims to promote the protection of personal information processed by public and private bodies [13]. It also considered the nature of data being handled within an organisation (participants indicated more than one option), and how regularly employees of a company are briefed on data management policies. The analysis of results is presented in Table 2.

Table 2. Policies and Practices on EDD in the Companies

S/N	Variable	Agree	Disagree	Neutral
1	Existence of electronic data disposal policies	76.9%	7.7%	7.7%
2	Level of implementation and integration of electronic data disposal policies	38.5%	23%	38.5%
3	Unrestricted access to company data	33.3%	58.3%	8.4%
4	Full awareness and implementation of the POPI Act	53.9%	30.8%	15.4%
	Variable	**Sensitive data**	**Protected data**	**Public data**
5	Nature data being handled	84.6%	53.8%	30.8%
	Variable	**Regularly**	**Somewhat**	**At inception**
6	Degree of Briefing on Data Management Policies by Company	30.8%	53.8%	15.4%

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The second part of the questionnaire focused on the standards and techniques being used for electronic data disposal (EDD) in organisations. It targets participants who are in an IT position in a department of a company. It focused on issues such as the mode of outsourcing of electronic data disposal, electronic data disposal standards and frameworks, security checks, and employee awareness of EDD practices. The analysis of results is presented in Table 3. Also, questions were asked in order to gain an overview of the different types of techniques that are being used for EDD in a company, for this, participants could select more than one option. The analysis of the responses is presented in Table 4.

Table 3. Standards, Procedures, and Techniques of EDD in the Companies

S/N	Variable	In-House	Outsourcing	None
1	Handling of electronic data disposal	83.3%	11.1%	5.6%
	Variable	**Agree**	**Disagree**	**Neutral**
2	Compliance with international electronic data disposal standards	5.5%	11.2%	83.3%
3	Existence of an electronic data management framework in the company	55.5%	31.5%	6.6%
4	Employees within their company know of alternative electronic data disposal methods besides simple formatting	44.4%	38.9%	16.7%

Table 4. Techniques of EDD in the Companies

Technique Implemented	Percentage of Usage in Companies
Data Erasure	58.80%
Degaussing	5.90%
Physical Destruction	17.60%
Formatting	82.40%
DBAN	5.90%
None	5.90%

5 Discussion

The observation from the results are now discussed from the perspectives of the two main research questions that the survey was designed to investigate.

5.1 Electronic Data Disposal Policies and Practices in Organisations

RQ1: *What are the electronic data disposal policies that are in place in companies in Cape Town to ensure secure electronic data disposal*?

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The study revealed that most companies deal with sensitive data (84.6%) and protected data (53.8%), which emphasises the need for effective policies and practices on electronic data management and electronic data disposal (EDD). Additionally, issues that address other aspects can be the deduced from the result of the survey.

Existence of electronic data disposal policies. Over 76% of respondents agree to the existence of electronic data management policies in their companies of which EDD is an integral part, but over 15% either disagree or are neutral. This indicates that companies are implementing steps to ensure good electronic data management, and electronic data disposal, which is a positive thing.

Implementation and integration of electronic data disposal policies. The result shows that over 38% of respondents believe that the implementation and integration of electronic data management policies occur throughout all levels in their company in which EDD is an integral part. However, a significant 23% believes that there is nothing concrete in place, while over 38% are not sure. This suggests that companies need to do more to entrench best practices in the aspect of implementation and integration of electronic data management policies at all levels in their organization.

Access to company data. The results of the data indicate that more than 50% of companies restrict employees from accessing company data from elsewhere in the company besides from their own workstation in order to prevent unauthorized access and tampering of data.

Awareness and implementation of the POPI Act. The result show that over 50% of the companies do enough to give their employees full awareness of the implementation of the POPI Act. This indicates that more than half of the number of companies in Cape Town are conforming with the POPI Act and understand its importance with regards to personal data protection. But still, a significant number of companies (over 46%) do not provide sufficient awareness of the POPI Act or make their employees to be aware of it. This is an obvious area where improvement is required.

Briefing on data disposal policies by a company. With over 80% of respondents affirming that their company either somewhat or regularly provide briefings on data disposal policies, this indicates that majority of companies take necessary steps to brief employees on electronic data disposal policies, which is a positive development.

5.2 Electronic Data Disposal Standards and Techniques in Organisations

RQ2: *What are the electronic data disposal techniques and standards being used by companies in Cape Town*?

Over 80% of respondents indicated that the EDD activities in their company are done in-house and only about 20% of EDD outsourced, we can deduce that most organisations have direct control on EDD activities, and are in a position to implement any form of improvement that may be necessary. The other things that can be deduced are discussed as follows.

Compliance with international standards. Over 80% of respondents claimed that they that are unsure whether their companies comply with the international electronic data disposal standards such as the US Department of Defense (DoD) standard, Gutmann method, and the National Institute of Standards and Technology (NIST) standards. This suggests that many companies in Cape Town are not aware of these international EDD standards, which makes it difficult to have it entrenched in their processes and make them well known within their organisation.

Electronic data management framework. Based on the survey response, over 55% of respondents claiming that their companies have a known electronic data management framework in place, while over 30% do not have any in place. This indicates that many companies have well-defined guidelines for electronic data disposal. However, there are still a significant number of companies where no such frameworks for

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electronic data management exist. Therefore, more companies need to improve in this area.

Knowledge of alternative electronic data disposal methods. Over 44% of participants acknowledged that employees within their company have knowledge of alternative EDD methods besides simple formatting, while over 55% were either unsure if employees within their company are aware of alternative EDD methods or believe that they only know about simple formatting. This indicates that the majority of employees within companies are not aware of the risks involved when only simple formatting is used for deleting data. Hence, companies need to take additional steps to provide awareness of alternative EDD methods among employees.

Application of electronic data disposal techniques. A percentage of over 58% suggests that data erasure, which a standard and acceptable electronic data disposal technique is well known and reasonably used among companies. However, simple formatting of data storage devises remains the most widely used technique. This indicates that majority of companies take the necessary steps to properly dispose of electronic data by making use of both formatting and data erasure techniques to ensure effective data disposal.

6 Conclusion

This paper presents an overview of the electronic data disposal (EDD) practices in selected companies in Cape Town with specific interest on organizational EDD policies, techniques, and standards. A survey of EDD practices in companies is essential in order to assess the maturity level of electronic data disposal practices and draw vital lessons that could serve as a guide for upcoming practitioners and young business organisations. This is also important because very few studies on electronic data disposal practices have been reported so far in the literature. From this study, we can attempt to make some generalisations, which are now presented.

From the findings of the study, we can infer that many companies have electronic data disposal policies in place and there is a generally substantial level of awareness of the POPI Act among companies and employees of organisations, but still, more companies need to come on board in providing the necessary awareness on issues of personal data protection among their employees, particularly as it pertains to electronic data disposal. Many companies have implemented some form of restrictions on data access within the organisation in order to ensure the protection of sensitive data from unauthorised persons and the majority of the companies take necessary steps to brief employees on electronic data disposal policies.

There are also many aspects of EDD where improvements are required. It is essential that companies make effort to promote the awareness of international EDD standards, and alternative EDD methods apart for simple formatting among their employees. There are still many companies that are without a clearly defined electronic data management framework that incorporates a guideline for electronic data disposal. Also, many companies do not yet have the implementation and integration of electronic data management policies entrenched at all levels of their organisation. In addition, there is the need for more companies to adopt the use of data erasure as their preferred EDD technique, and to promote more awareness of data erasure as one of the most secure forms of data sanitization.

A major limitation of this study is the small sample size of companies and respondents. However, for the topic of electronic data disposal that has been rarely examined so far in the literature, the outcome of this study offers a significant starting point that will give impetus to more interesting, and more elaborate studies on EDD practices in an organisation in the future. These upcoming studies will be very relevant in the global context and also in the context of developing nations like South Africa. In fu-

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ture work, we shall consider mounting a bigger and broader survey than spans more companies across various sectors and regions of South Africa, in order to provide a basis for more robust generalisations on electronic data disposal practices by companies in South Africa.

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The Use of Mobile Data Services Among Women in Cape Town – South Africa

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Abstract. The mobile has grown to be one of the most far-reaching technologies, offering transformative opportunities to its users. While it provides a means for communication and social connectedness for most people, mobiles also offer opportunities to information services by providing access to the internet. This is advantageous to many in sub-Saharan Africa, where computer penetration is still low. Although there are a number of studies done on the usage of Mobile Data Services (MDSs) in general, a limited number of studies focus on usage among women, despite the documented gendered digital divide. This study adopted the Decomposed Theory of Planned Behaviour (DTPB) to understand MDSs' usage among women in Cape Town, South Africa. A total of fifteen women were purposively sampled to provide insights on their mobile data service usage. We used in-depth interviews to collect the data, followed by a thematic analysis. The results indicate that while female consumers used MDSs that mostly met their needs as women, cost continues to be a huge barrier to the use of these services. The findings will provide more insight in the area of MDS development and marketing for telecommunication providers.

Keywords: Mobile Data Services (MDSs), Women, Technology Usage.

1 Introduction

Mobile technology including mobile phones have been lauded for enhancing the lives of individuals, as well as contributing to increased revenue for businesses in their respective economies. These devices have evolved over time and their functionalities have immensely improved. With the change in appearance and features, as well as the increased pervasiveness from capabilities resembling those of desktop computers and added mobility [1], mobile phones have become an extension of the owners' personality [2], hence they have permeated almost every sphere of life. In their basic iteration, these devices are known to provide ease and convenience for communication through the use of text messaging and voice calls. However, rapid advances in mobile and internet technologies have birthed the concept of mobile computing. At the centre of this phenomenon are Mobile Data Services (MDSs) which are as a result of the convergence of mobile communication technologies with data services [3, 4], made possible by the internet. As a result, other services made possible by the more advanced iteration of mobile phones include internet access, gaming for entertainment and online transactions, among others. These services have become an attractive sphere for

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telecommunication companies in serving to increase their revenues [1] as they provide value-added services to their consumers.

While mobile connectivity and usage including MDSs is spreading rapidly [5, 6], it is not spreading equally [5]. There still exists a gender divide in the access and use of Information and Communication Technologies (ICTs), with women lagging behind [5, 7]. Even when women own mobile phones, there is a significant gap in usage, especially of 'transformational services, such as mobile internet'[5]. In addition to this documented disparity, gender and technology studies have shown that there are differences in how men and women adopt and use technology [8, 9]. Motivators for use among these two groups are also varied. The findings in Pedersen et al., [10] indicate that while enjoyment was an important determinant to using mobile chat services among women, usefulness, for men, was the driver to use.

Despite these conclusions in Information Systems (IS) studies that gender plays a mediating role in the adoption and use of technology, there is a dearth of MDS studies that focus on women's use. For this reason, this study seeks to explicate the use of MDSs by women in South Africa by answering the question: **How do women in South Africa use mobile data services?** South Africa was chosen because its developed telecommunication sector can easily support new mobile technologies and services.

We used constructs from the Decomposed Theory of Planned Behaviour (DTPB) to understand usage among the study participants. These were purposively sampled and interviewed, using in-depth interview guides whose questions were developed using the selected constructs of DTPB. We believe that the insights gained will be beneficial in the area of MDS marketing in telecommunications companies, especially with regard to gender-based market segmentation. The study also gives room to explore what additional services would be required by women users to play a role in enhancing their lives.

The rest of this paper is organised as follows: Section 2 situates the study in literature, Section 3 presents the research framework, followed by the research design in Section 4 and, finally, the findings and discussion, and conclusion in Sections 5 and 6 respectively.

13 Literature Review

13.1 Mobile Data Services

The area of MDS is expanding extremely fast with the advancement of technology and mobile devices [11]. These information and data services can be classified into four categories [3, 4], namely, communication services (e.g., Short Messaging Service (SMS), Multimedia Messaging Service (MMS), chat room), information services (e.g., location services, weather information, news), entertainment services (e.g., music, mobile games, ringing tones) and transactional services (e.g., banking, online shopping). The level of usage of these services varies from user to user, as made evident in Ramburn and Van Belle [12] . Though the services are also varied, research indicates that the most often used MDSs are those related to messaging services [6, 12].

MDSs are considered unique because of affordances such as mobility, scope of usage, personalisation and usage costs [3]. Mobility refers to the fact that consumers can access MDSs anytime, anywhere. Secondly, MDSs allow users to engage with a variety of activities ranging from leisure (e.g., downloading music) to business (e.g., m-Banking). Because most consumers have exclusive access to their mobile phones [3], they have the privilege of customising their phones to fit their own preferences and needs. This may range from selecting ring tones to setting security features such as phone-unlock patterns. Finally, unlike services delivered through fixed lines that are

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free, most MDSs attract a cost to usage that is normally deducted from prepaid or pay-as-you go contracts. Therefore, in such a study, it is useful to consider the impact of cost on consumers' behaviour [3].

13.2 Women, Technology and Adoption

Women contribute to a large percentage of a country's total population. Their contribution to development by use of technology can therefore not be overlooked. However, over the years, there has existed a digital divide with women reporting only marginal use of ICTs [13]. Though statistics report progress in bridging the gap, women are generally still lagging behind [14].

In the area of adoption and usage of technology, literature indicates that women's decisions to use technology are based more on perceptions of the technology's ease of enjoyment, contrary to men who are strongly influenced by their perception of usefulness [9]. As mentioned earlier, motivations for use are also varied. For example, women are likely to use their phones for social reasons, mainly to maintain connectedness with family and friends, while men are more likely to use their phones for professional and work-related reasons [14].

13.3 Mobile Statistics and Internet Penetration in South Africa

South Africa has one of the most advanced telecommunication infrastructure of all emerging markets [12]. The telecommunication sector contributes approximately 6% to South Africa's GDP. Like most emerging markets, mobile adoption rates in South Africa have been remarkably high [12], with more than 70% of the mobile subscribers accessing the web from their mobile phones [15]. In fact, 75% of all web traffic in South Africa is from a mobile phone [16]. Unlike many other African countries, there is no significant variance in mobile-phone ownership between men and women in South Africa [14]. This notwithstanding, there still exists a digital divide in usage of ICT. For example only 11% of women use internet services compared to 20% for men [14].

14 Conceptual Framework

This study was informed by the Decomposed Theory of Planned Behaviour (DTPB), which is an expansion of the Theory of Planned Behaviour (TPB). The DTPB identifies specific salient beliefs that may influence ICT usage among individuals and is therefore believed to have better explanatory power than the pure TPB model [17].

DTPB has a number of constructs grouped into three categories (Fig. 1), that are understood to be influential to the level of adoption and usage behaviour of an individual of a specific technological device or application. To make the constructs more relevant to the MDS study, the naming adopted by Hong et al. [3] was used as indicated in Fig. 1. Attitudinal beliefs represent constructs that arise directly from an innovation's characteristics, while normative beliefs relate to influences from social circles (people perceived as important by the consumer) and media from MDSs marketing campaigns. Lastly, perceived behavioral control characterises external situations in the MDS environment that a person may not have complete control over [3].

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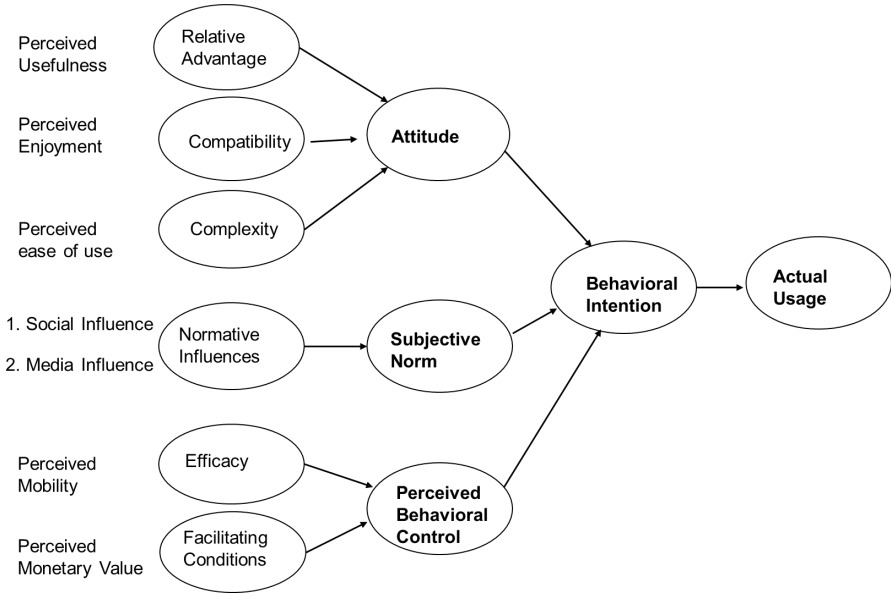

Fig. 7. Decomposed Theory of Planned Behaviour (Adapted from Shih & Fang [18]) with naming from Hong et al. [3]

For the purpose of this study, the framework will not be used to its full extent. Specific constructs were selected from each category. Because the study focused on individual use, constructs that were deemed most relevant to this were selected. These include perceived usefulness and perceived ease of use from attitudinal beliefs, social influences from subjective norms and perceived monetary value from perceived behavioural control. Perceived usefulness and perceived ease of use have been consistently dominant in explaining usage behaviour [3]. In addition to this, these two constructs affect a consumer's personal usage more because they are instrumental in enhancing one's effectiveness or convenience in daily activities [3]. On the other hand, MDS usage attracts monetary costs for consumers. Perceived monetary value is therefore considered useful for consideration because of the concomitant high data costs in South Africa [19].

15 Research Methodology

15.1 Design and Sampling

A qualitative cross-sectional approach was adopted to understand how women in Cape Town use MDSs. A total number of 15 women between the age of 18 and 52 were purposively sampled. All the participants had to own an internet-enabled mobile phone and have experience in using mobile data. To ensure diversity, the sample comprised of female students, women in formal employment and those in 'other employment'. The demographics of the participant are presented in Table 1.

Table 7. Participant Demographics

#	Age	Sector
Participant 1	18	Student
Participant 2	52	Financial
Participant 3	28	Construction

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Participant 4	43	Financial
Participant 5	42	"Other" Employment
Participant 6	21	Student
Participant 7	31	Financial
Participant 8	34	Academic
Participant 9	29	Financial
Participant 10	21	Student
Participant 11	27	"Other" Employment
Participant 12	24	"Other" Employment
Participant 13	30	"Other" Employment
Participant 14	35	Government
Participant 15	36	Education

15.2 Data Collection and Analysis

The data was collected in 2016 with the aid of in-depth interviews, which lasted between 30 and 45 minutes per interview. The questions were structured around use as informed by the theoretical constructs selected for the study. The interviews were audio-recorded and later transcribed. We then analysed the data to identify patterns. These patterns were coded and grouped into higher order themes.

15.3 Ethical Considerations

An ethical clearance letter was obtained from the University of Cape Town. All participants were formally approached to take part in the study and, upon their acceptance, they were invited to sign the informed consent form. Data was used only for the purposes of this study. Permission to audio-record was sought from each participant. Recordings were stored on a password-encrypted memory stick that only the researcher had access to. Finally, the findings were presented in a way that protected the participants' identities. For example, instead of referring to a participant by name, a code was assigned (e.g., Participant 1).

16 Findings

All the participants who were interviewed had smartphones and subscribed to some form of data service on a daily basis. The various contract options gave participants some flexibility in the use of MDSs. For example, the pay-as-you-go contracts allowed them the option of buying airtime and data as they needed. Most participants indicated using between R200 and R600 per month on mobile data. In line with the constructs that were used, the findings are summarised in Table 2.

Table 8. MDS use in South Africa by Female Consumers

Constructs	Findings	Responses	Participants
Perceived Usefulness	Acquiring information and job hunting	*'Currently, I am using it to apply for jobs since I'm unemployed. Sometimes, when I go to the internet café, it's full so I use it for my applications and my social media.'*	4, 5, 11, 14
	Research purposes for schoolwork	*'The internet I use a lot, you know when you have to google something, to find out something. It's probably my go-to-google.'*	1, 6, 10

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	Social media to stay connected with family and friends	*'Mobile data allows me to keep connected with my friends and family through WhatsApp.'*	1-4, 7, 8, 9, 11, 13-15
Perceived ease of use	Services were easy enough to use	*'Using most of these services is very easy. I have not experienced any issues thus far.'*	1, 3, 4, 6, 8, 13
	Mature group requires assistance of their children	*'The only service I use is WhatsApp. For most of them, I have to ask my daughters for assistance.'*	2, 5
Social Influence	Some Data services were used because everyone else around them was using them.	*'I use Whatsapp a lot. I think everyone is on Whatsapp these days'*	1,5,7,13-15
Perceived monetary value	Data is very expensive	*'I would love for it to be reduced to at least R100 for 1G because it is too expensive.'* *'Uhmmmm, it's just never enough and very expensive, jah.'*	1-5, 8-10, 12, 14, 15
	Data for these services expires	*". . . These bundles expire – most cases 30 days or over 2 months at a reduced price.* *For the life of me, I do not understand why data expires. You buy it; it is yours and doesn't rot."*	5, 11

17 Discussion

Out of the four MDS categories documented in Hong et al.[3], and ITU Internet Report [4], this study noted that most of our participants made use of only three of the four. These are communication services, informational services and transactional services. The researchers attribute this to role definition of women compared to men. Most women bear a greater burden of domestic responsibilities [20, 21] in addition to their work and hence have to wear different hats for their various roles. Thus it was noted that the categories of use among women related more to the fulfillment and execution of these varied roles. For this reason, most of the participants indicated enjoying text messaging which could be for the purpose of communicating with their friends and family, hence maintaining their social ties. Similar to the findings in Ramburn and Van Belle [12], it was evident that the various forms of messaging are a popular service among women too. For example, in this study, most female participants indicated using WhatsApp. This choice, again, may be attributed to perceived monetary value, because of the cost of SMS that is charged by providers and also the fact that most of their contacts and people they valued were also using the platform. Hence this ease of accessibility and availability of their significant others resulted in a social influence their increased used of a particular data service.

For more mature consumers, the major barrier to MDS use was related to perceived ease of use. These participants indicated that some of the MDSs were not as easy to use and therefore they resorted seeking help from the younger members of their families. However, it is important to note that help was mostly sought on MDSs whose perceived usefulness was high such as SMS. Other services that were not perceived as being too useful were simply ignored all together.

Similar to the findings in Rowntree [[5]; Ramburn and Van Belle [12]; Gillwald et al. [14] on various technology adoption and use barriers, this study noted that high costs were a major hindrance to the use of MDSs. According to Kim et al. [6], this af-

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fects women more disproportionately compared to men. This position was not confirmed as the study did not compare use between men and women.

18 Conclusion

This study sought to understand the use of MDSs among women in South Africa. Fifteen female participants were interviewed and DTPB was used to understand usage behaviour. It was noted that for the most dominantly-used MDSs, perception of quality in terms of relevance, usefulness and ease of use was greater than their perceptions of monetary sacrifice. Since perceived ease of use and perceived monetary value contribute to the dominant use of messaging services, telecommunication providers may need to factor these into the design of other MDSs. MDS providers would do well to consider the cost of usage if a greater variety of MDSs is to be adopted by users. In summary, we suggest that to continue bridging the digital divide, telecommunication providers should consider gendered market segmentation where MDSs are designed to meet and support the unique needs of women. Based on the findings of this study, this move is bound to increase adoption and use.

A major limitation of this study is that the sample was drawn from only one metropolitan area. A bigger and more diverse sample may be necessary to validate the findings of the study. For future research, it will be interesting to explore how usage drivers of mobile data services compare between men and women in South Africa, to determine if there is a significant difference.

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Characterizing Sensors Using Portable ARM Devices

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Abstract. In this paper, we describe the benchmarking tests that were carried out in an effort to compare our new smart experimental setup with our previous setup using massive precision appliances. The work involved using some specific conditions that have always been considered in the previous setup. Using our hybrid Planar Hall Effect (PHE) sensor with other Industrial Anisotropic Magneto-Resistive (AMR) sensors, the characteristics of the sensors were determined and compared to each other.

Keywords: AMR, PHE, Sensors, Measurement and Detection

1 Introduction

Planar Hall Effect sensors measure the change in anisotropic magneto-resistance caused by an external magnetic field in the Hall geometry. The sensor responds to magnetic field components in the sensor plane as opposed to the ordinary Hall sensor, which measures field components perpendicular to the sensor plane.
On the other hand, the AMR sensors involve studying the property of a material in which a dependence of electrical resistance on the angle between the direction of electric current and direction of magnetization is observed. The effect arises from the simultaneous action of magnetization and spin-orbit interaction and its detailed mechanism depends on the material.

1.1 The Setup

Fig. 1 shows the various benchmarking tests that were carried out at the Institute. The Keithley Voltage Source and the Keithley Nanovoltmeter represent the first test and they were together used to perform the experiment labelled ‘Test A’. The Lockin Amplifier with the Waveform generator were used to perform the experiment labelled ‘test B,’ and the AD Circuit with a combination of Renesas and Analog Devices embedded devices were used to carry out the experiment labelled ‘Test C’. Our in-house PHE sensors were used.

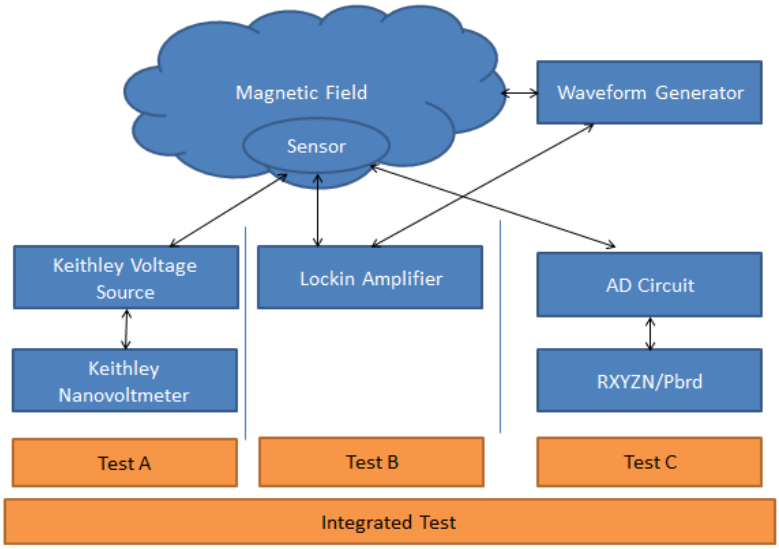

Figure 1: The Various Benchmarking Tests

Embedded Components/Devices for Instrumentation and Measurement.
The experiment carried out for Tests A, B and C are the same but on different instruments and at different times. Our PHE sensors were excited at varying conditions and the measurements were gathered, processed and reported in this article.

2 The Benchmarking Test

2.1 Benchmarking the DC Excitation in the AD Circuit with the Precision Appliance (No Magnetic Field)

The below (fig. 2) was achieved using a sensor with a resistance of approx. 20KOhms. Compliance voltage was set at 105V and 40mA. Both stable and unstable conditions were tested. A stable condition is when the blue indicator in the AC/DC voltage source is permanently on. At this point, the voltage source can be said to excite (a sensor) at the set voltage and current. An unstable condition is when the blue indicator in the voltage source is blinking. At this point, the source is exciting a sensor at a slightly varying current (though at the set voltage) owing to a mismatch. It is worth mentioning that a member or the team had taken the blinking indicator as no voltage output and should not be used. It took some efforts to explain, demonstrate and convince that the device still works at that state and would produce the exact result/output in an experiment.

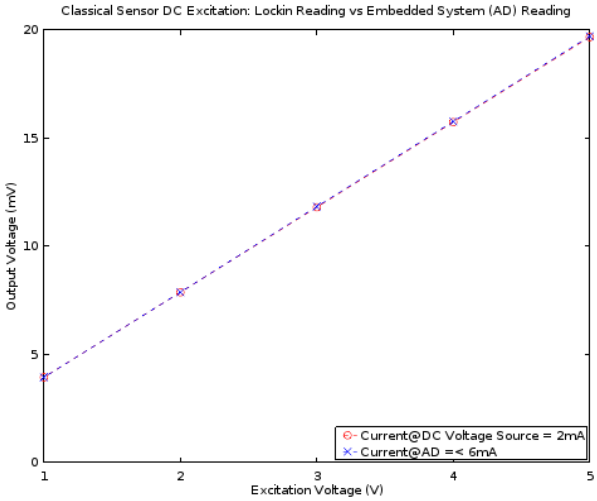

Figure 2: Comparing the Classical Sensor DC Excitation between Lockin and AD (No Magnetic Field)

2.2 Benchmarking the DC Excitation with AC Magnetic Field in the AD Circuit with the Precision Appliance

It is worth mentioning that the below measurement (fig. 2) was taking using the Keithley DC voltage which injects noise into DC experiments. In most cases, when the classical sensor is tested with a DC excitation, a set of battery (9VDC) is used.

Fig. 2 shows the relationship between the output voltage and the magnetic field. The slope of fig. 3 is the sensitivity of the sensor. Using the first two co-ordinates, the sensitivity (i.e. change in output volt/change in magnetic field) is approximately 0.3mV/T for both experiments (lockin/Keithley vs AD Circuit).

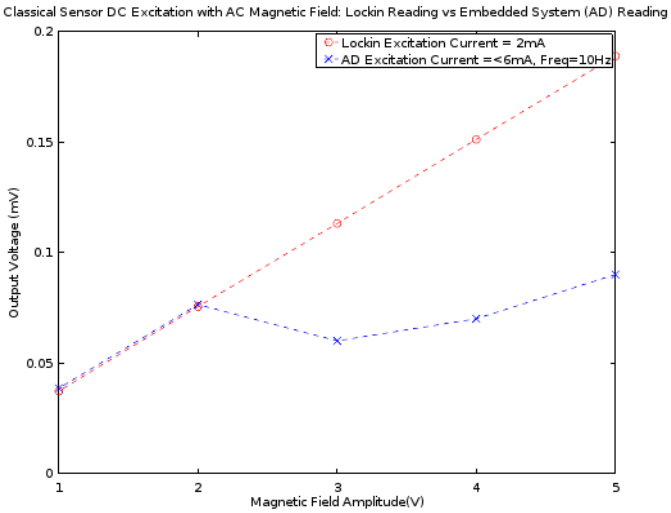

Figure 3: Comparing Classical Sensor DC Excitation with Magnetic Field between Lockin and AD

2.3 Benchmarking the AC Excitation in the AD Circuit with the Precision Appliance

The below (fig. 4) was achieved using a sensor with a resistance of approx.. 20KOhms. The result shows that the AD circuit is capable of achieving the same result as the

precision appliance. While the gain in the precision appliance is 0.00375, the gain in the AD circuit is 0.00359.

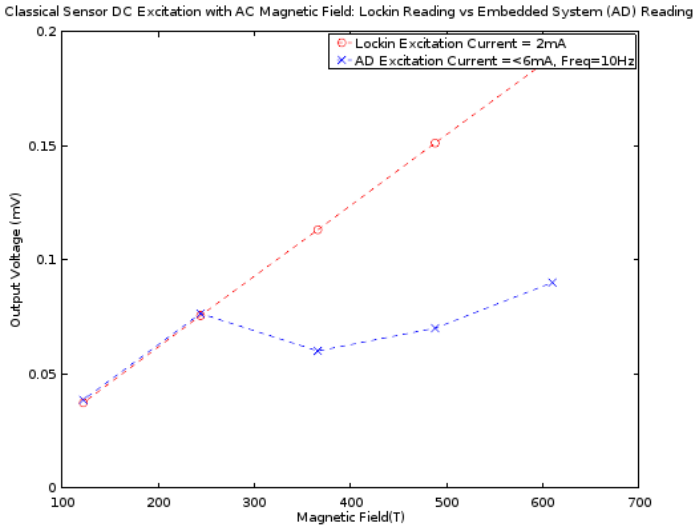

Figure 4: Comparing Sensitivity in Classical Sensor DC Excitation between Lockin and AD

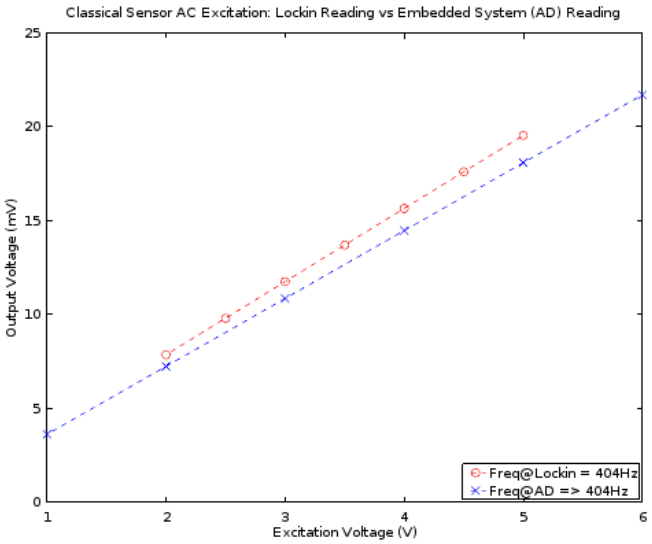

Figure 5: Comparing Classical Sensor AC Excitation between Lockin and AD

2.4 Benchmarking AD Response to Changing AC Magnetic Field

The below (fig. 6) showed how the AD circuit responds to changing magnetic field. The magnetic field in the below diagram changed from -14 to 0, and from 0 to 14. Using both the National Instrument Software and the AD software, the results obtained in the two were highly identical. Although the National Instrument Software user interface is not presented here (owing to the limited space), the experiment was carried with the help of a group member, who validated the results. The validity of the result was the gradual rise and drop in the voltage as the field changed. It simultaneously changed with the National Instrument's.

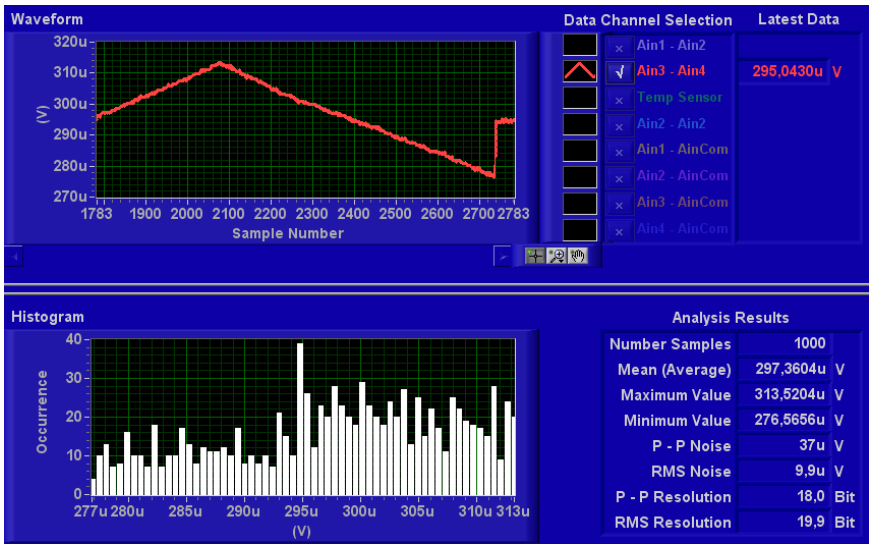

Figure 6: Response in AD measurement with Changing Magnetic Field

The peak-to-peak noise value of a signal is 1.41 times the RMS value of the noise signal and its instantaneous value is usually less than 8x the RMS value. The RMS and peak-to-peak noise values are a combination of both the internal and external noises. Random white (Gaussian) noise always has some rare spikes which reach towards infinity and are usually ignored. The internal noise is the noise generated within op-amps, while the external noise is picked up due to magnetic and electric coupling.

Noise sources within an op-amp include resistor noise, KTC (Johnson-Nyquist) noise and current noise and can all be referred to as a voltage noise. A voltage noise is at the two inputs and two current noise sources, one in each input, of an op-amp, in this case the op-amps in the AD circuit. The noise values in the above figure are the rms and (instantaneous) peak-to-peak noise.

2.5 Benchmarking the DC Excitation with AC Magnetic Field in the AD Circuit

The below (fig. 7) is an integrated test, which involves using the Keithley voltage source as a DC source, injecting an AC magnetic field via the agilent waveform generator and taking measurements via the AD circuit. Fig. 9b is used to determine the sensitivity during the integrated test. The graph shows that the sensitivity varies with the induced current or output voltage. In addition, it can also be dependent on the frequency of the applied field. The sensitivity in fig. 6b is 0.06uV/T.

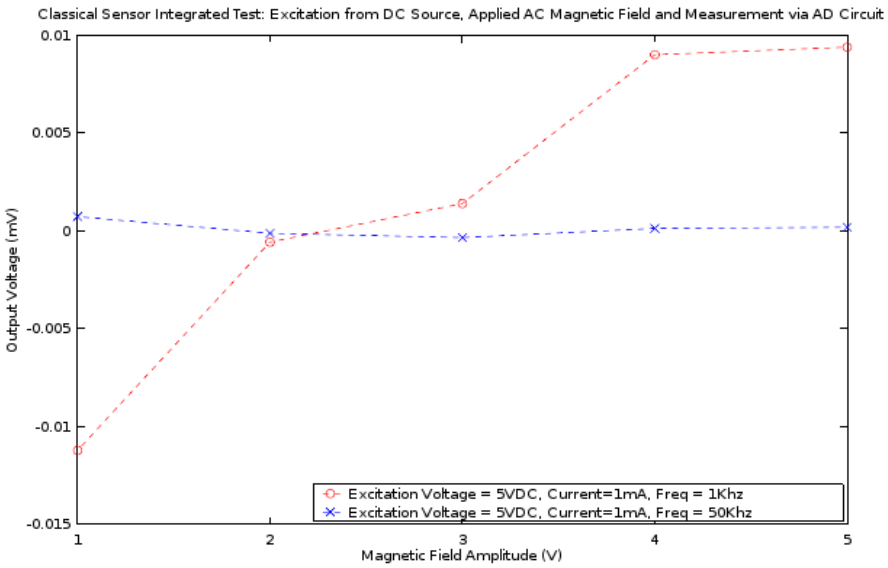

Figure 7: The Classical Sensor Integrated Test

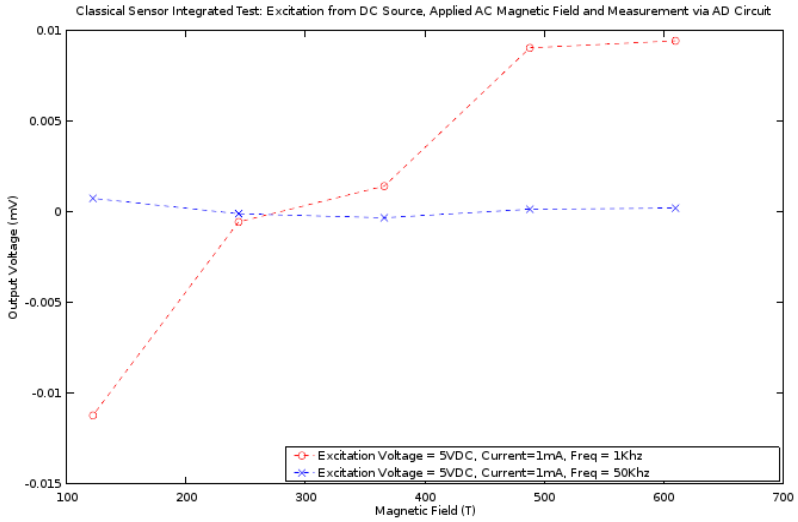

Figure 8: Sensitivity Measurement for The Classical Sensor Integrated Test

The measurement at 50KHz for both fig. 5a and 5b yielded very small changes in the output voltage making sensitivity negligible. The reason is that the frequency of the AD circuit is at maximum 5KHz. Most measurement in the lab at taken at 113Hz and 1.13KHz, hence, the board is capable of measuring data at the frequency range and beyond.

2.6 Comparing AC Excitation (No Magnetic Field) between the Classical Sensor and the Commercial Sensor

The digital interface refers to I2C (Inter-Integrated Circuit) communication mode with terminals like the sdata, sclock, Din e.t.c. The analogue interface refers to the generic interface with two input and two output terminals. The commercial sensor has five terminals, which were connected to the jumpers on the digital interface of AD circuit. The below result (fig. 9 and 10) shows the comparison of the classical sensor to a commercial sensor using AC excitation with no magnetic field. The sensors induced voltage directly changes with the excitation voltage. Based on AC excitation, the gain for the classical sensor is 0.00375 (i.e. output voltage/excitation voltage) and the gain for the commercial sensor is 0.00535. Based on DC excitation, the gain for the classical sensor is 0.00375 and the gain for the commercial sensor is 0.0075.

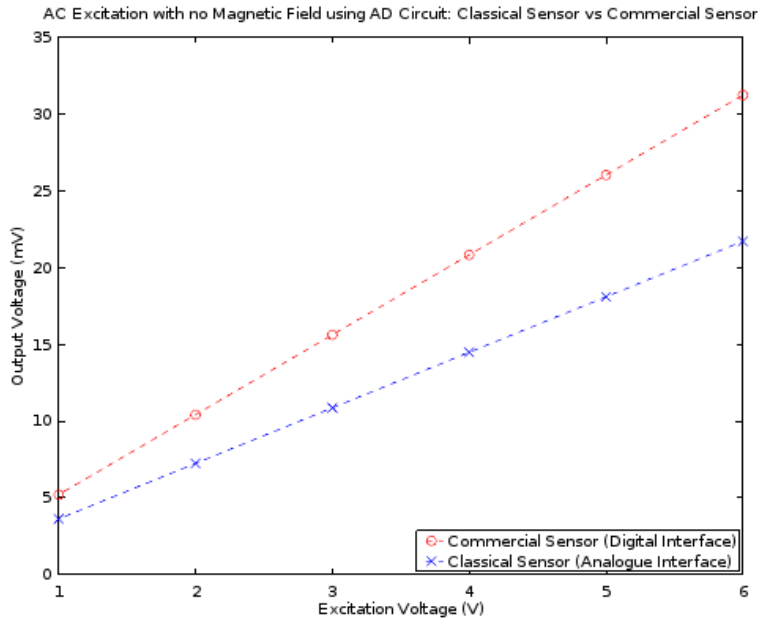

Figure 9: Comparing AC Excitation with no Magnetic Field between the Classical Sensor and the Commercial Sensor

Fig. 11 confirms the effect of noise in DC excitation, especially in the AD circuit. Using the commercial sensor, it is found that a DC excitation has more noise effect than in an AC excitation. The noise could however be reduced using filters; some of them are available in the circuit/software. Another observation was when the DC excitation was done with the Keithley DC source. There were irregular readings that confirmed that the sensor is not a classical sensor. A different type of the sensor (i.e. with the same parameters) was purchased and used by our other team member when wanting to characterize the sensor since the DC source cannot cater for the set/reset current required in the same sensor used with the AD circuit.

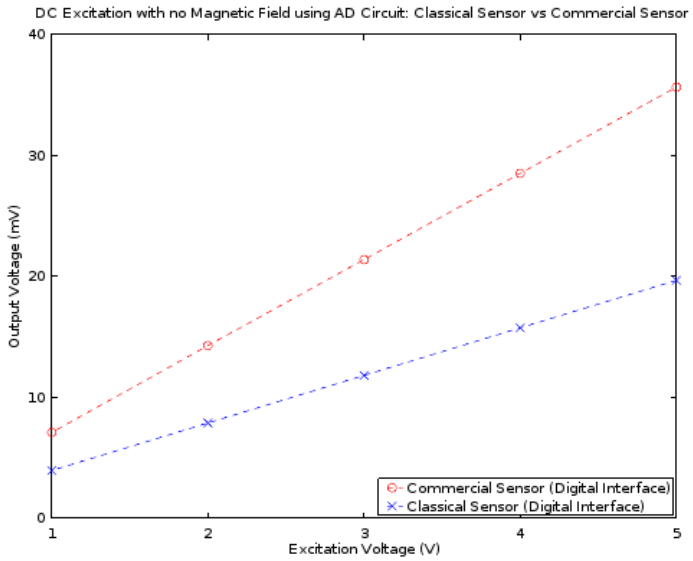

Figure 10: Comparing DC Excitation with no Magnetic Field between the Classical Sensor and the Commercial Sensor

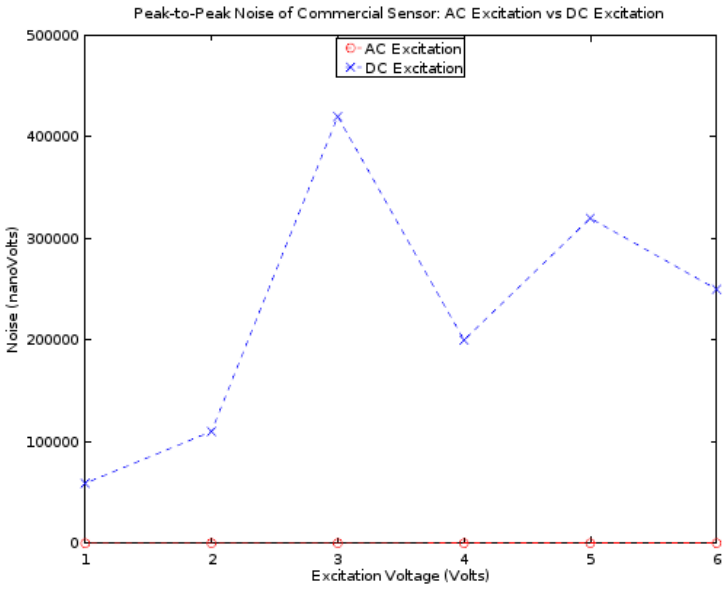

Figure 11: Comparing AC Excitation with no Magnetic Field between the Classical Sensor and the Commercial Sensor

3 Conclusion

Another achievement was successfully building Real Time Operating System (RTOS) and Component-based/Embedded Linux on the boards. The building and deploying of an embedded linux was demonstrated to a member of the team. Arch linux was deployed on the Pbrd embedded system via its storage – SDCard – and shown running via a serial-to-USB interface.

4 Acknowledgements

Our thanks to the Erasmus Mundus and the Institut Charles Gerhardt Montpellier for providing the grant and environment to carry out this research work. And special thanks goes to Souleymane Kamara, Quang-Hung Tran and other members of the ICG group for their support.

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Development of a Bilingual Medical First Aid Mobile Application

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Abstract:
In the African contest, emergencies resulting from accidents and illness occur all around us in everyday life and knowledge of what needs to be done to manage an emergency situation can make the difference between life and death. This is where first aid applications come in handy to provide the information needed to help emergency victims, especially by those people who do not know any basic first aid information. However, if one does not understand the language implemented in a first aid app, the application is useless to that person. Therefore this paper, "Development of a bilingual first aid mobile application", is all about a mobile first aid application which was implemented in English and SiSwati to help all Swazi citizens to understand the content inside the app hence using it effectively with understanding to administer first aid.

Keywords: Medical, First Aid, Mobile Application

1. INTRODUCTION

The body of a human is very vulnerable to injuries and trauma, and we never knew when any injury may happen to us or the people we love around us, so it is very imperative to have some basic information on how to take care of critical situations so that they can be kept from going from bad to worse until medical help arrives (Smart, 2014). According to the Collins English dictionary first aid may be defined as simple medical treatment given as soon as possible to a person who is injured or suddenly becomes ill. There are many reasons why first aid is important, just to mention a few, first aid controls an emergency from going from bad to worse until medical help arrives so the situation can still be manageable. Secondly first aid can reduce physical pain in the patient in case of an emergency as it guides on ways of relieving physical pain. To crown it all first aid can go a mile further to saving lives. In as much as first aid is very imperative, it is undoubtedly true that not all of us will be trained to administer first aid. But then how do we secure ourselves and those we love around us in case of emergencies. The basis of this study is to find a way in which every individual can use their smart phones to help a patient in case of emergency before the arrival of

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professional medical experts by developing a bilingual mobile app that will guide through all the steps to be taken when administering first aid. From previous studies different first aid mobile applications have been developed using different algorithms. These include the most commonly used one, the Red Cross first aid mobile app, which is interactive and include videos to guide you through first aid administering. Its content is available in English and in Spanish (Red Cross Society, 2017). Many people die because of situations that could have been avoided by first aid. According to St Johns ambulance 150,000 people die annually in the United Kingdom (UK) unnecessarily because first aid is not widely enough known and they state that 24% of the population would do nothing if they saw somebody struggling (St John Ambulance Press Association, 2010). Well the question is, if a first world country like the UK suffers such harsh conditions due to lack of knowledge in first aid, how much more when it comes to Swaziland. It has been observed that many people die unnecessarily especially because of diseases like heart attacks that can be easily managed by first aid. Also many people lack the skills and knowledge in administering first aid. Even though other medical first aid applications already exist, it has also been noted that it could be really frustrating for illiterate Swazis to use them hence a bilingual application will be developed to tackle these challenges. The aim of the paper is to tackle and minimize the number of unnecessary deaths caused by lack of skills and knowledge of first aid especially in Swaziland with the aid of mobile application on bilingual platform.

2.0 LITERATURE REVIEW

2.1 Review of related literature on first aid

According to Adams Safety (2015), around 70% of people who suffer a heart attack die before getting any medical aid. Many of these deaths are preventable. However due to the absence of any knowledge and training most people fail to provide immediate medical help to the patient. This means that there is still a lot to be done, people still need to be trained about first aid in order to save lives and prevent unnecessary deaths. A large percentage of people don't feel they could save life in an emergency, and those who would administer first aid, their efforts would be in vain as in many cases they would administer the wrong procedure (St John Ambulance Press Association, 2010). According to www.firstaidwindsor.ca, 2 out of 3 people do not feel confident trying to help in case of an emergency situation. 1 out of 4 people would do nothing and simply wait for an emergency response to arrive or hope that someone who knows first aid would come. Although governments and organizations such as the Red Cross are putting unlimited efforts to training people on first aid but the current numbers are alarming. This actually shows the reality that relying on other people who know first aid is not the point www.firstaidwindsor.ca .

2.2 First Aid mobile application

First aid mobile applications are applications for mobile phones that uses different intelligent algorithms to judge the ongoing situations and give the user detailed instructions on how to handle the emergency at hand (Zanner, 2007). Some may even provide pictures just to demonstrate the actions to be taken. Most of them are usually standalone, meaning they don't need any internet connection to work because they are needed for emergency. These mobile applications work in various environments including the Android Operating System (androidOS) and the iPhone Operating System (IOS). More advanced applications also navigate to the nearest hospital. Some of the applications have specific information like the resuscitation application which only specializes on how to administer resuscitation only however some has general information on first aid which means that they can be used for first aid in general. There are various languages used in the apps with a better part of them being English. The general usage of first aid mobile applications is in a case of emergency it can be used

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to help injured victims at least by someone who doesn't have any skills on administering first aid.

Most first aid mobile applications have land monitoring portals which uses Google maps APIs and open source Geographic Information System (GIS) implemented in them. A Google map is a web mapping service developed by Google. In Surachat (2013) piloted a study in Thailand about a first aid mobile application that uses this architecture. On top of giving instruction for preliminary taking care of patients it also navigates patients to the nearest hospital. The application has its Graphical User Interface (GUI) implemented in Thai language as the application target group was the citizens of Thailand. The GUI language limits the usage of the application though as only those who know Thai language can use the application. To develop the application, the native development technology was used. Native applications are built using vendor specific programming languages and development toolkits, they are binary executable files that are installed through an app store and they have full access to the hardware and functionalities of the device (Mahmudul & Ariful, 2016). Surachat (2013) proposed that the application should only run on android OS as it is the most popular mobile OS nowadays, so in as much as most of the population will gain from the app, IOS, windows Operating System and other mobile Operating System (OS) users will not have access to the app hence the need for future work to cater for other OS users. The good thing about the app being native though is that it is much faster and efficient than apps developed using co-technologies (Mahmudul & Ariful, 2016).

3. METHODOLOGY

The waterfall model has been selected because of its strengths which include amongst them all, its simplicity to understand and use. The model is easy to use because its phases are in a linear sequential manner. Secondly this model is easy to manage as it is fixed and uncompressible, each phase has its own end product and once you are done with a phase you continue to the next phase, there is no going back and forth (Bassil, 2012). To crown it all, since our project is rather small, this model will work out fine because it is very excellent for small projects.

3.1 Use case diagram

The use case diagram represents the interactions that take place between the user and the application itself. Figure 1 shows all the functionalities that the user can initiate in the application. So the user first initiates the application, then on the open screen the user is prompted to choose a language. After language selection, the application displays the menu of first aid instructions in the chosen language. When the user clicks first aid choice, the app displays the information for that first aid.

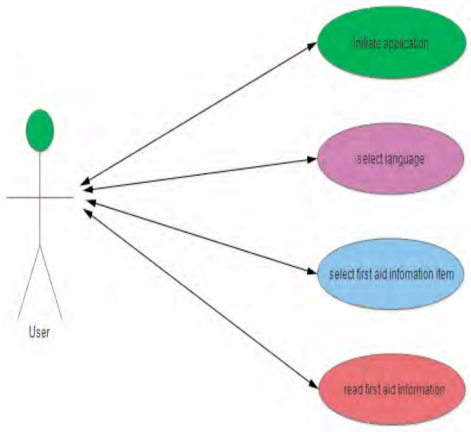

Figure 1: Use Case Diagram for the first aid application.

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3.2 Application Flow chart

Figure 2 shows how the steps of the processes of the application fit together. It shows what happens at each stage and how it affects other action .

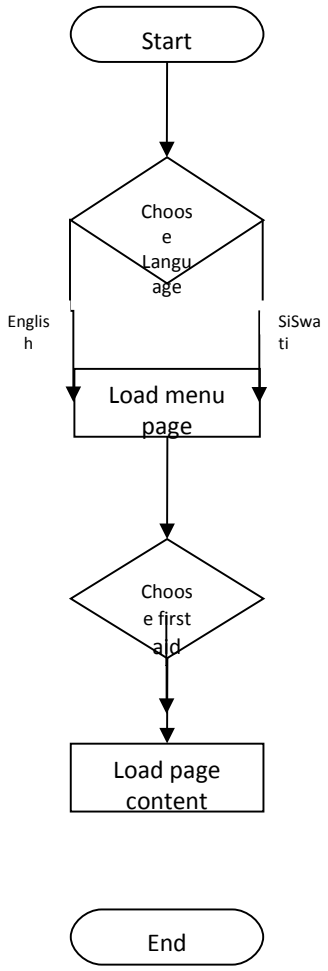

Figure 2 shows the system flowchart

3.3 System Sequence Diagram

Figure 4 shows the interactions between the user and the application in the order in which the interactions occur. It also shows the message passed in each stage.

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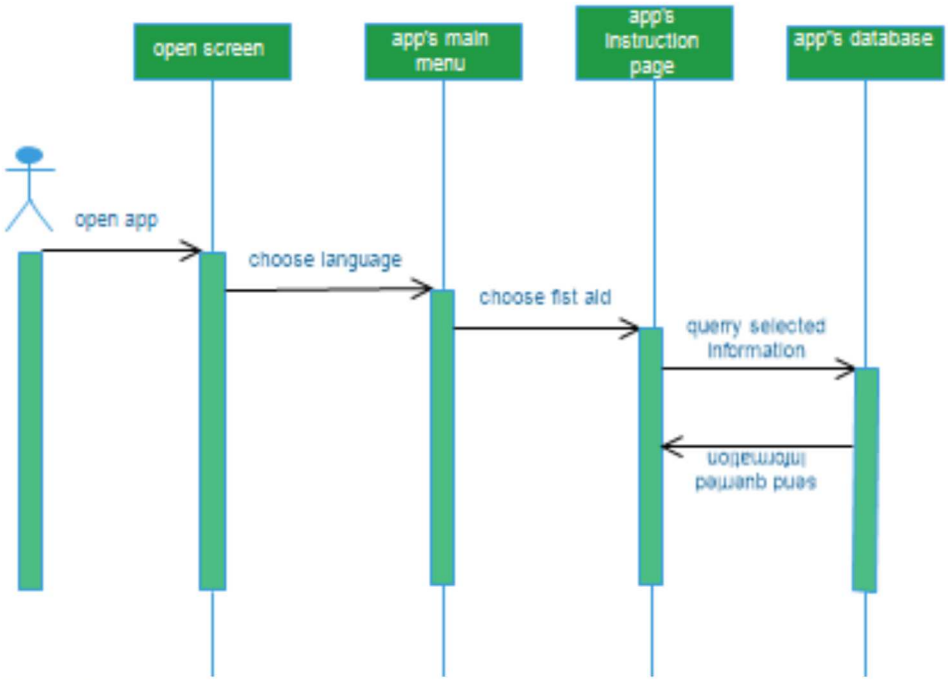

Figure 3: System Sequence

4. SYSTEM IMPLEMENTATION

Android Studio IDE (Integrated Development Environment)

Android studio is an IDE developed by Google and designed specifically for Android operating system development. It is freely available for download on windows; macOS and Linux based operating systems. It is a primary IDE for native Android applications. The language it uses for development is strictly java programming language. It also supports XML for (Graphical User Interface) GUI design. Figure 4 shows the Android studio interface which is used for coding and debugging a mobile application.

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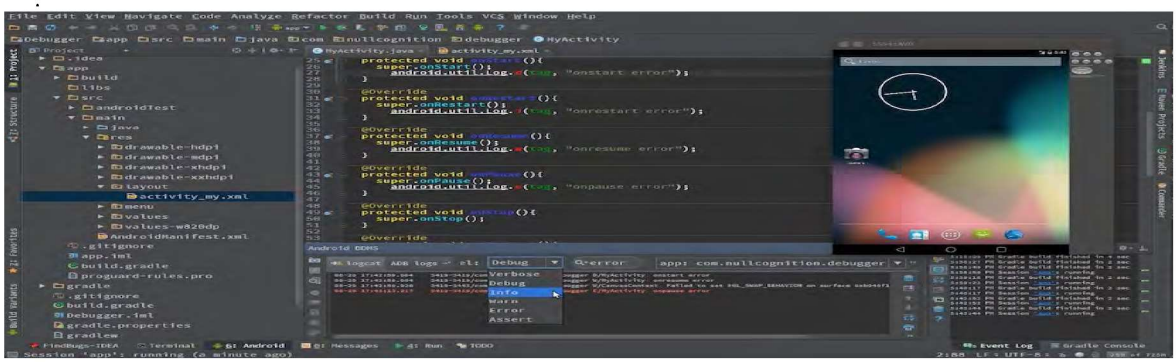

Figure 4: Android Studio interface

DB Browser

DB Browser for SQLite is a high quality, visual, open source tool to create, design, and edit database files compatible with SQLite. It allows users to browse database objects and structures. Figure 5 display information about object,;tables, views, triggers and indexes on the DB browser interface. It also has tools that enable users to interact with these objects such as tools for viewing the contents of objects such as tables and

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views, tools for importing and exporting data, tools for altering tables and views, an SQL query builder and many more.

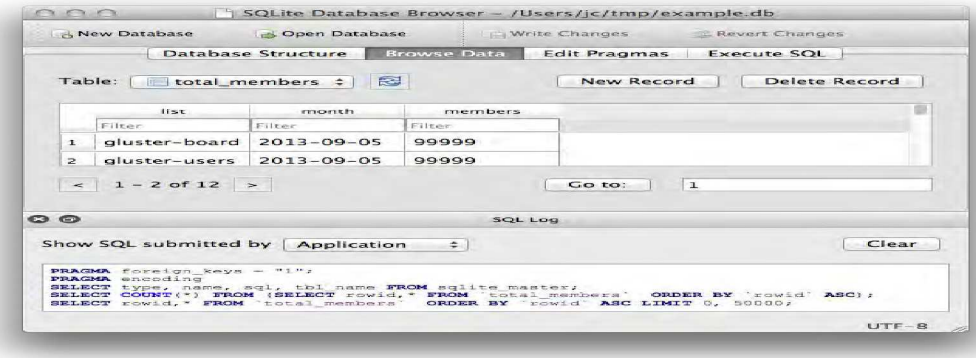

Figure 5: DB browser interface

4.1 System Test Results

This section discusses the system test results and the user interfaces of the application. On the open screen the user has to choose the language of preference before moving to the next activity. So if the user chooses English, he will be taken to an English activity and if they choose SiSwati they will be taken to a SiSwati implemented activity. Figure 6: shows the open screen of the application.

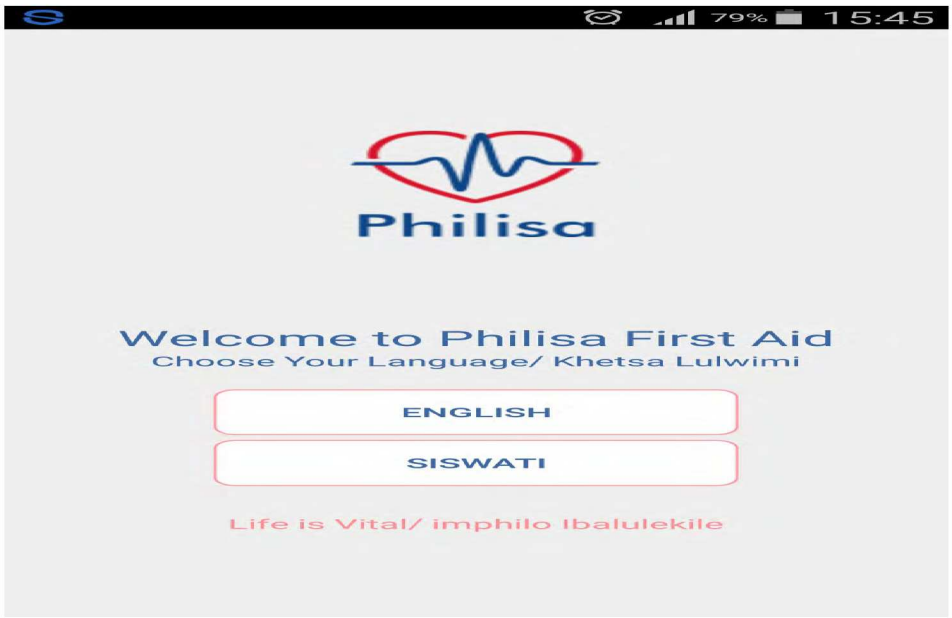

Figure 6: the open screen of the application

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Figure 7:The English implemented interface.

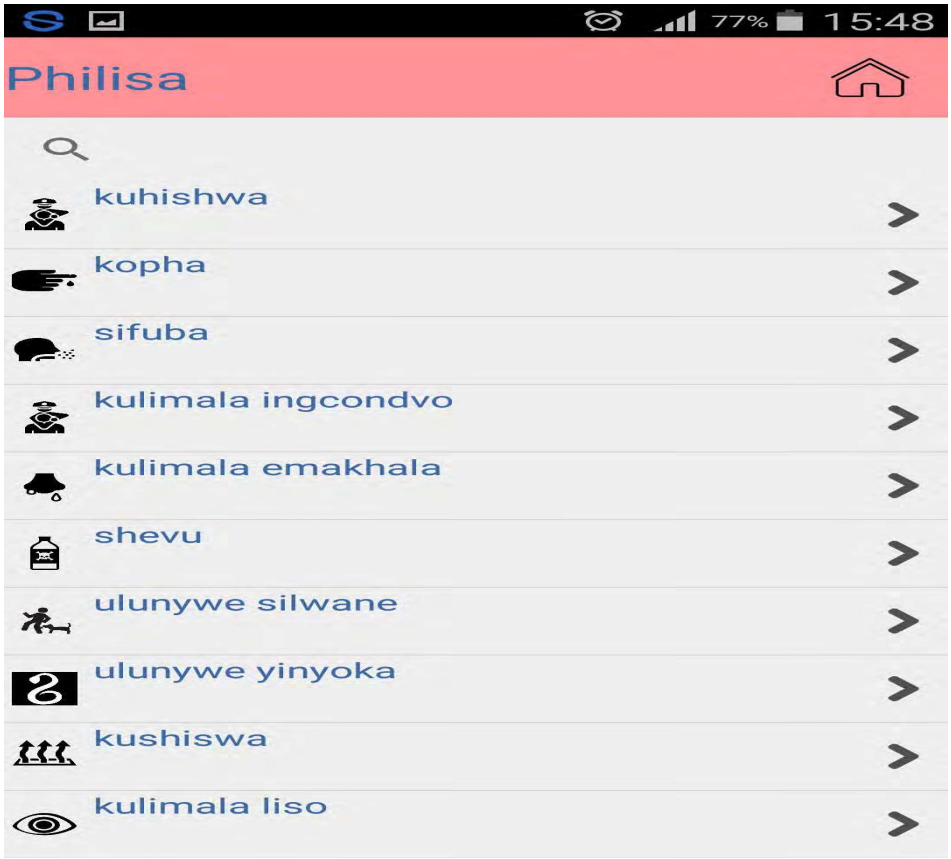

Figure 8: the SiSwati implemented interface.

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Once the user is on the activity where there is a list shows on figures 8 and 9 of emergencies they can either choose the emergency they want to go through or search to filter the list view for what they want as shown on figure 9.

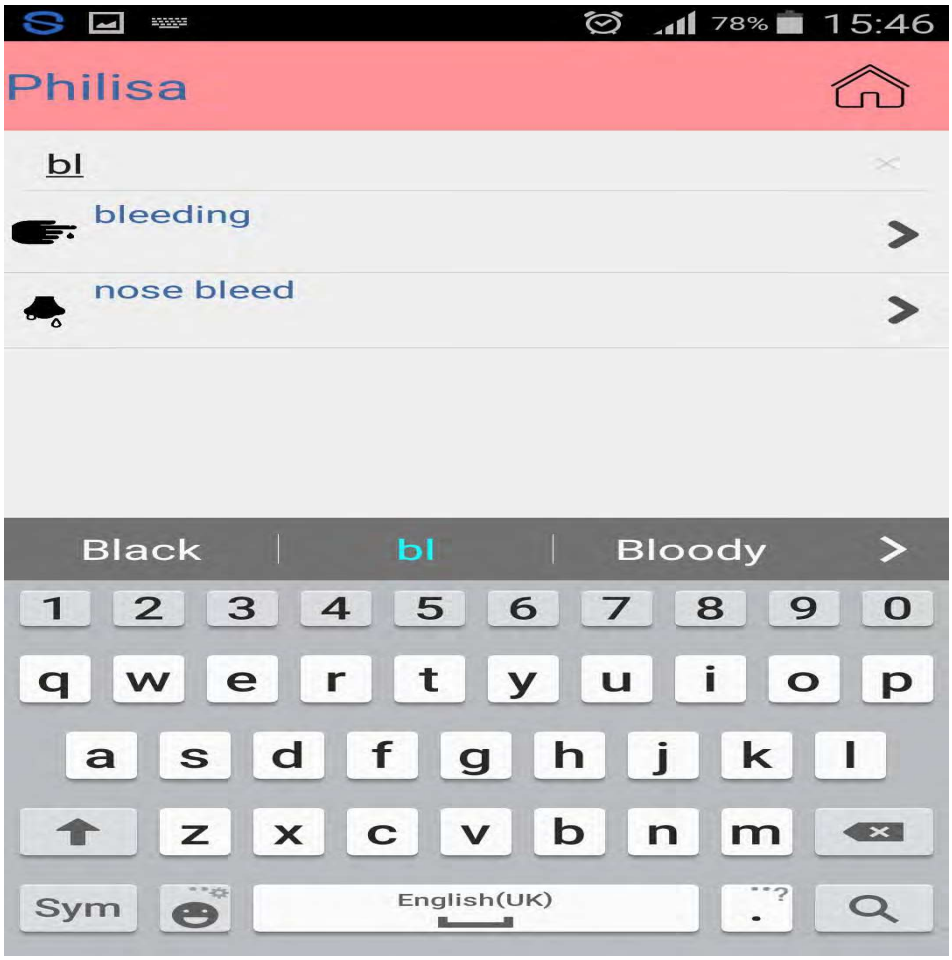

Figure 9: the searching feature of the app.

Once the choice has been made, the user can then be taken to the activity where there are the guidelines on how to administer the first aid. Figure 10: shows the English implemented activity.

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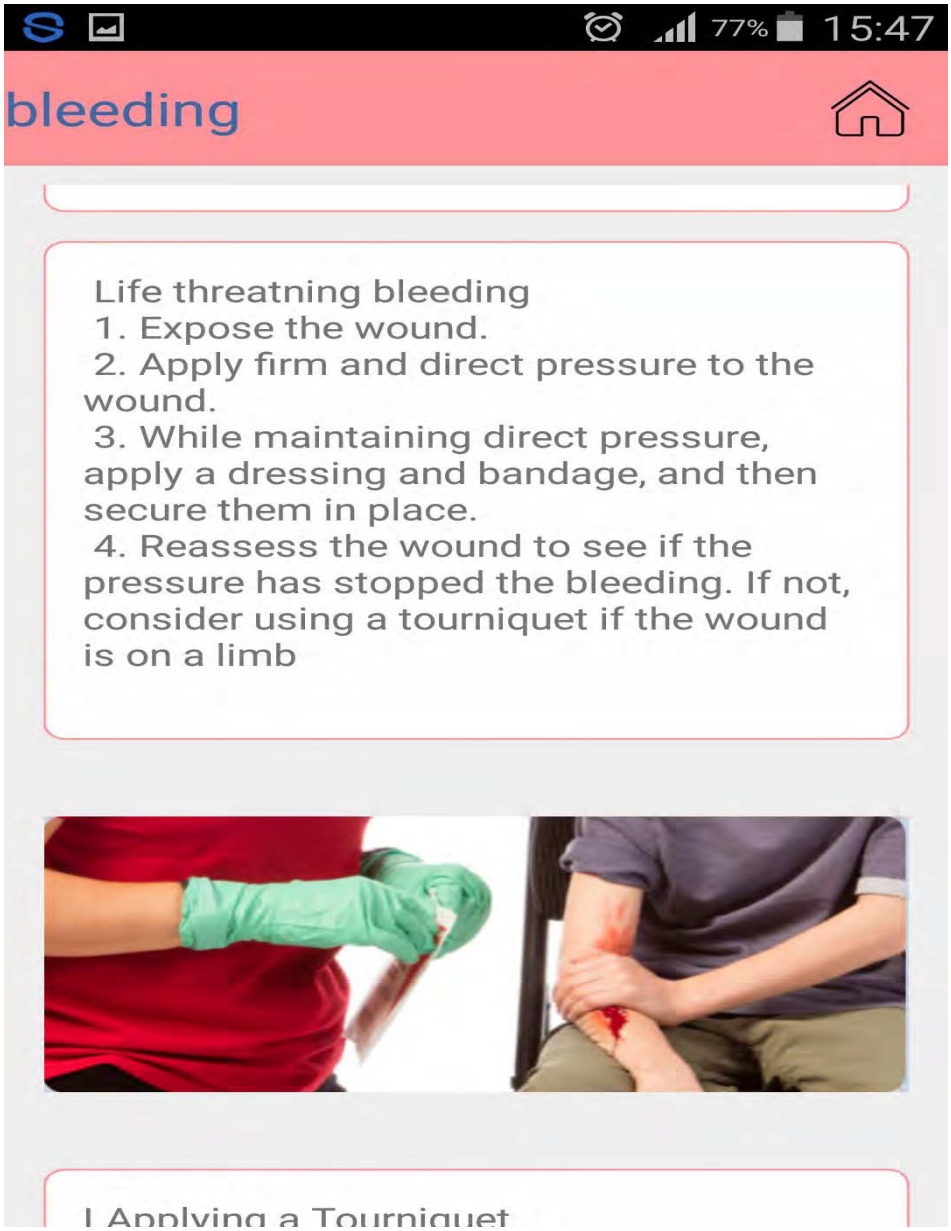

Figure 10: the guidelines on how to administer first aid in English

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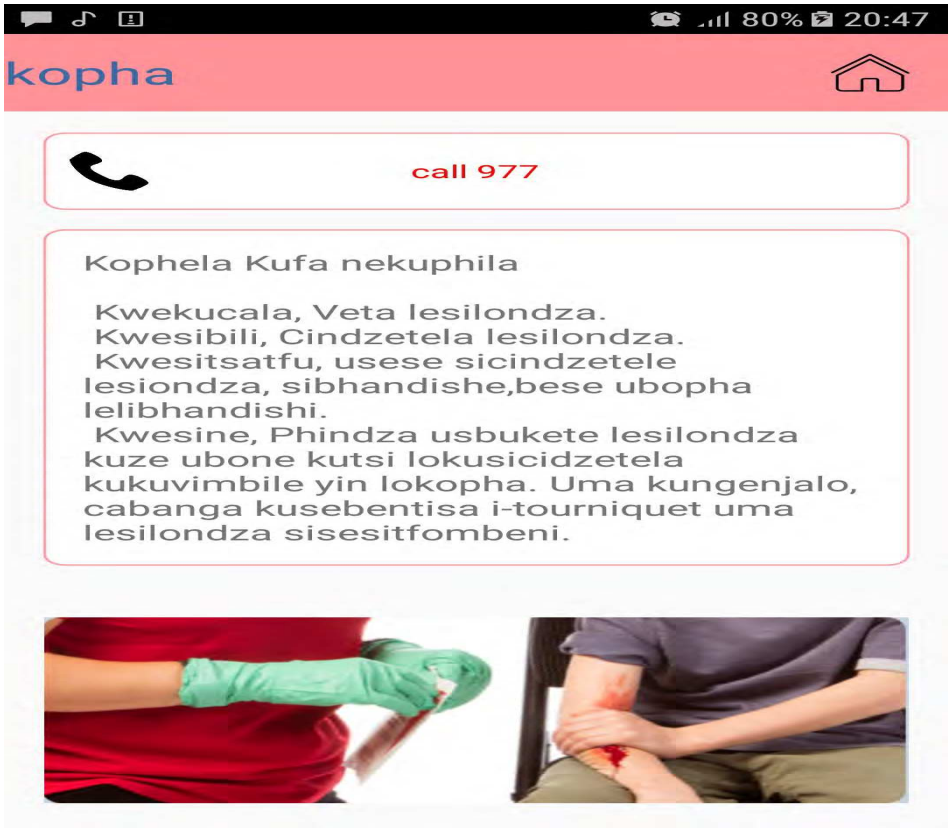

Figure 11:shows the guidelines on how to administer first aid in SiSwati

The user can also call for emergency help from the application if the situation needs professional help, using the call button shown in figure 11. When that button is clicked they are taken to a page like the one on figure 12.

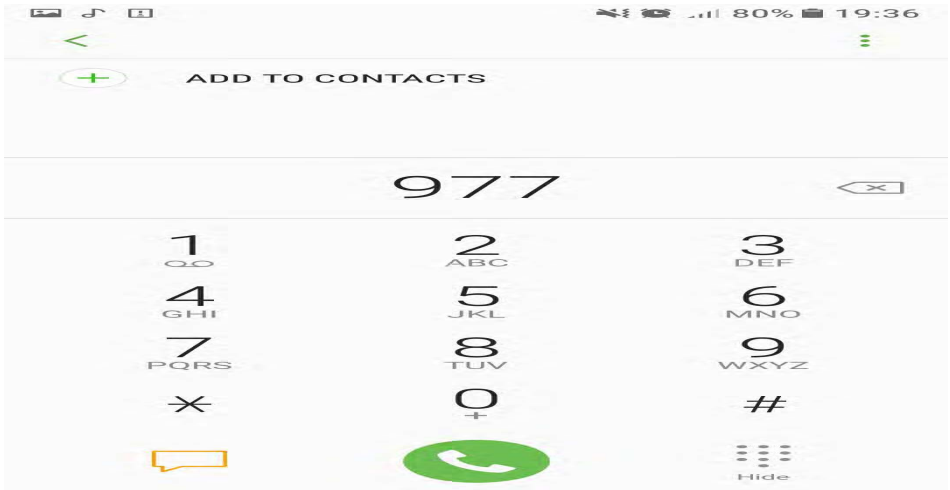

Figure 12: shows the screen for calling.

5. CONCLUSION AND FUTURE RECOMMENDATIONS

Medical first aid applications are very imperative in taking care of emergency situations, especially for people who do not have any information on administering first

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aid. However the applications are useless if the information they provide is not understood. So it is also important that the applications be implemented in languages that people understand and are comfortable with. From the literature review we have seen that there are quite a few bilingual applications and a lot more implemented in English Language only. This application provides a way for Swazi citizens to use it comprehensively and effectively towards saving lives, by proving the two official languages of ESwatini that almost every Swazi can understand.

Hopefully this new system will go a long way to help Swazi citizens save more lives and learning and mastering some of the first aid tricks as they continue to use the application.

For further development, Google maps API can be added to the application so that users can navigate to the nearest hospitals in case they need to visit one. Again the app can also add in some learning test and quizzes section so that the user can learn how to administer first aid and see how much knowledge they have acquired. Furthermore the application could be made more interesting by rating users and awarding medals or gold stars after they answer the test questions.

COMPETING INTERESTS

The authors declare that there are no competing interests regarding the publication of this paper**.**

SUBMISSION DECLARATION

The authors declare that the research reported in this paper is original and has not been published previously and it is not under consideration for publication elsewhere. The publication is approved by the authors and if accepted for publication, it will not be published elsewhere.

AUTHORS' CONTRIBUTIONS

Dr Stephen G. Fashoto is the paper coordinator and shared the overall responsibility for the work with Dr. Gabriel O. Ogunleye, which was done in two parts. The first part on introduction and review of the related literature was carried out by authors Fashoto and Ogunleye while the second part on methodology and implementation was carried out by authors Dr. Odim and Mr. Gwebu. Finally, Dr. Fashoto and Dr. Ogunleye concluded the work and drafted the abstract. Dr. Fashoto, Dr. Ogunleye and Dr. Odim proofread the manuscript.

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Evaluating the Level of ICT Adoption in Government Hospitals in Nigeria

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Abstract: Information and communications technology development are not of particular breakthrough technologies, but rather those of rapid and continuous improvement in price-performance of both computing and communications, the explosion of bandwidth capacity in fixed and mobile networks, and the emergence and development of the internet and internet-based applications. The purpose of the study was to establish the factors influencing adoption of ICT in public hospitals in FCT, Abuja; and to determine the influence of training, infrastructure, availability of funds, and the influence of ICT staff attitude on the adoption of ICT in those hospitals. The study was guided by the innovation-diffusion theory, technology acceptance theory and contingency theory. The study employed a descriptive research design where it targeted 7 public hospitals. The study population consisted of ICT managers, record keepers, clerks, cashiers and laboratory technologists. The study sample size comprised of 100 staffs who were engaged in the study. The data collected was analysed using descriptive statistics (measures of central tendency and measures of variations), correlation coefficient and linear regression to achieve the objectives of the study. The quantitative data generated was analysed using descriptive statistics with Statistical Package for Social Sciences (SPSS) version 20. From the research findings, the study revealed that majority of the respondents as shown by 64.71% had served the institution for more than 9 years whereas 29.41% of the respondents had served the institution for a period of 6 to 8 years, 3.53% had served the institution for 3 to 5 years and only 2.35% of the respondents had served the institution for a period of less than 2 years. The finding of the study are as follows: i) the cost of ICT training materials is considered to be among the problems that negatively affects the implementation of ICT in most health facilities, ii) the medical equipment management involves other essential activities which ensure that equipment is effectively planned and budgeted for, procured, and operated. iii) the installation of ICT infrastructure is a major drawback to the adoption of ICT, iv) Developments in ICT technological infrastructure in hospitals have drastically influenced the competitive business environment in health sector as proved by the emergence and strengthening of the global economy, and the transformation of industrial economies to knowledge-and-information-based service economies, v) On the influence of ICT staff attitude on ICT adoption, the ICT adoption has been perceived to challenge the traditional management hierarchy and change both the location and the nature of decision making in most public hospitals. The study recommends that the ministry of health should improve the current ICT status for health sector. The Sector should attain tangible and observable ICT diffusion levels. The government should increase the ICT budget to address adoption challenges in public hospitals in FCT, Abuja, as the survey found that high cost of funding ICT programmes is immensely influencing ICT adoption.

Keywords: ICT Adoption, *innovation-diffusion theory, technology acceptance theory and contingency theory*

1. INTRODUCTION

Developed countries have embraced the use of information and communications technologies (ICT) within the hospitals and health clinics. A few examples of the use of ICT include computerization of medical records, electronic scheduling for appointments, and use of the Internet for the purposes of communication and the use of magnetic cards. According to Baldwin (2006), ICT plays an important role in delivering healthcare today. Healthcare professional including doctors and nurses are occupied in what is seen as a radical action plan for improving the national healthcare services in most countries. Wilson & Anderson (2000); Ogunleye et al. (2018), mentioned while health information technology provides the greatest impact on administration functions,

such as decreasing paperwork and workload of healthcare professionals, increasing administrative efficiencies and expanding access to affordable care, it also has shown effectiveness in preventing medical errors by enforcing clinical guidelines and protocols and reducing health care cost.

To overcome the challenges that Government owned hospitals are facing, there is a need to improve information and communication exchange in the healthcare industry in order to accelerate knowledge diffusion and increase access to information, effect of availability of funds, the influence of training and education, influence the availability of infrastructure, determine the influence of ICT staff, determine the availability of e-Health facilities, availability of skilled personnel, determining the extent to which Government policies will affect the adoption of ICT in Government owned hospitals in Abuja and to determine the level of Industry Support on the adoption of ICT in Government owned hospitals in Abuja, Nigeria.

The adoption of information system has shown to improve businesses performance since ICT is known as a tool that improves business competitiveness (Niang, 2009). Hence this study has focused on investigating the factors that influence the adoption of information system in the healthcare industry.

The aim of this study is to evaluate the level of ICT adoption in government hospitals in Nigeria, a case study of FCT, Abuja. The objectives include determining the effect of the following factors on the adoption of ICT in Government owned hospitals in Abuja, Nigeria: availability of funds, training and education, availability of ICT infrastructure, and the attitude of ICT staff.

2. LITERATURE REVIEW

Muhammad, (2009), studied factors affecting the introduction of ICTs for healthcare decision-making in hospitals in developing countries. The study found that information and communication technologies for decision-making are tabling new tools and techniques in the marketplace. There is, however, a lack of studies that assessed the impacts of ICTs on decision making particularly in health sector of such countries. Muga (2004), studied an overview of the health system in Abuja. The study found that the overall thrust for future planning in the health sector should be to firmly address the downward spiral of deteriorating health status. The goal should be to reduce health inequalities and to reverse the downward trend in the impact and outcome indicators. These health inequalities exist between urban and rural overview of the health system in Nigeria's populations and between counties and regions (66 percent of the population of Western Region is below the poverty line, compared with 46 percent in Central Region). Mugeni et al., 2012, in their research on evaluating factors affecting broadband adoption in Kenya argued that relative advantage of broadband internet over its predecessor narrowband internet was very influential in explaining variations in broadband intention. Considering the items used to measure this construct, notably faster download speeds, higher reliability, better quality of service and better quality of experience, policy makers and regulators are called upon to foster an appropriate enabling environment. For example, service and platform competition would spur improvement in download speeds, reliability, quality of service and quality of experience. Availability of a national broadband strategy would also serve as blueprint for broadband development and clearly set targets of download and upload speeds, among others.

Obino (2012), looked at the adoption of information and communication technology by small enterprises in Abuja, the study concluded that ICT has not been well embraced by small enterprises in Abuja. All the variables under study have a statistically significant effect on ICT adoption. The Government of Abuja should develop an appropriate programme to encourage ICT adoption by small enterprises, eliminate all taxes on ICT, establish a special fund to support ICT adoption; support training programmes to develop the capacity of small enterprises to embrace ICT; invest in appropriate communication infrastructure for SEs, and the SE Federation should institute deliberate efforts to encourage SEs to invest in basic ICT tools to help improve their business and make them more competitive. Such efforts could include establishment of a special fund to finance ICT adoption by SEs.

Nzisa (2012), Did a study on investigation of factors affecting the adoption of information and communication technologies for communication of research output in research institutions in Abuja. The findings revealed researchers' priority research communication need was reinforcement of capacity for strategic research through recognizing and prioritizing research communication in budgetary planning. Thus, the findings call for investment in scientific and technological research and its communication, which includes improving tools and infrastructure, especially ICT-enabled ones like Internet connectivity and other e-resources. From the above local studies little has been done on Evaluation the level of ICT adoption in Government owned hospitals especially in Abuja, Nigeria.

2.2 Factors influencing the Adoption of ICT in Government Owned Hospitals in FCT-Abuja

According to Oliver (2005), ICT helps companies and other institutions to increase productivity and create attractive products to be sold on the world market. It improves the quality and decreases lead-times and costs. ICT technology has also fuelled sustainable development by reducing the environmental impact of business activities. There are several factors influencing adoption of ICT in public hospitals.

Availability of Funds

According to Oliver (2005), cost refers to an amount paid or to be paid for a purchase to acquire, produce, or maintain goods or services. Adoption according to this study refers to the application of ICT in hospitals. The cost of ICT equipment and training materials is considered to be among the problems that could negatively affect the implementation of ICT in most health facilities. The higher the cost of computers and their accessories, the fewer computers one can buy with the limited resources. According to Tusubira & Mulira (2009), the cost of computerized equipment is often prohibitive for most hospitals in developing countries and for those who can afford them, routine maintenance and servicing, is yet another problem that is not easily manageable by the first generation computer users. Compared to traditional forms of hospital treatments, technology facilitated has proven to be quite expensive in all areas of consideration (Oliver, 2005).

In attempts to lower the costs, improve the quality and expand the access to health services many developing countries put much hope in electronic health records (Nyella & Mndeme, 2010) and ICT based Health Information Systems (HIS). The migration to electronic medical records is necessitated by limitations of paper based records that include temporal, spatial, and monetary constraints associated with continued paper-based record accumulation and compression over time. Additionally, paper-based systems have limited functionality; many people cannot easily view the same record at the same time. Having electronic medical records can support medical professionals in their decision-making and also improve operating efficiency, thus improving medical care quality (Ayers, 2009).

Influence of Training

Technological innovation has implications for employees of various institutions. Typically, health institutions are lacking in specialized IT knowledge and technical skills. Thong(1999), suggested that the higher IT capabilities the staff have, the higher their potential in the use of information systems, and thus the higher percentage of adopting IT. A small business that has IT knowledgeable employees will lower the knowledge barrier in understanding and using the IT. In order to facilitate the successful implementation of information systems in organizations, and to avoid adoption failure, the health institutions should provide employees with computer education and training courses. IT acceptance among users of IT who form part of a firm employee's base will have a positive impact on IT adoption (Apulu & Latham, 2009).

The lack of knowledge on how to use technology and low computer literacy are factors that affect the adoption of ICT. There is a need for computer education. Owner-managers need to attend training programs that will enlighten them on the benefits associated with the use of ICT. In addition, there is the general issue of skills and

training. The skill deficiencies appearing in institutions like hospitals include not only technical abilities but also management skills (Arendt, 2008). Generally, institutions do not develop training plans. In most institutions, there is reluctance among owner-managers to invest on training their employees because these owner-managers are afraid that following the completion of such training and having improved their qualifications, these employees will leave and find employment in large companies that offer better salaries (Arendt, 2008). Notwithstanding, owner-managers need to conduct training sessions for staff that will assist in creating awareness on the benefits of adopting technology in organizations (Thong, 1999).

Influence of Infrastructure

Despite the immense benefits of ICTs as a means of delivering quality health care services, the potential of ICTs has not been fully harnessed by health professionals especially in developing countries. This is due to problems of infrastructure access (slow or unreliable Internet connectivity). A good ICT infrastructure, therefore, is a condition for enhancing the well-being of a country. Gates (1999), reported that intra- and Inter-organizational networks in some advanced countries function like a digital neural system for the organization. Thus, he said, communication for health purposes has shifted from the largely manual or physical documentary methods to digital communication. Such access to ICTs has helped disseminate information to the rest of the world. In the medical field, Gates (1999) reported, American doctors are able to collaborate as often and as quickly as they want with other medical doctors in other parts of the world through the use of ICTs. For example, while examining a patient, a medical doctor might be able to send an electronic x-ray of a patient to a leading expert in another country who could readily interpret and provide more details of the disease or condition, as well as send feedback to the medical doctor all within a few minutes. Rural health workforce strategy, in their research and application processes, can use the Internet to identify research issues, search literature databases, seek out information on surveys and clinical trials, and publish research results (Eysenbach & Wyatt, 2002).

ICT Staff Attitude

Attitude is a pattern of shared basic assumptions that the group learns as it solves its problems of external adaptation and internal integration that has worked well enough to be considered valid and, therefore, to be taught to new members as the correct way you perceive, think, and feel in relation to those problems. Thus the impact of organizational culture is extensive and intense in organizations where it is manifested in concepts such as “the way we do things around here” or certain rites and rituals of the company, the company climate the common practices and norms and core values. McCullough (2008), suggests three levels of culture: artefacts, espoused values, and basic underlying assumptions. These organizational levels definitely overlap with the national background of an individual, which might create conflicts.

According to Thong (1999), the attitude of the developer of the ICT and the users who either adopt or reject the technology that is used in an organization affects the performance of organizations. IT attitude can be defined as the set of values and practices shared by the members of an organization involved in information activities; this includes people like IT professionals, managers, and end-users. IT attitude being thus a subset of an organizational culture, with unique values that are attached to the IT department. In other words, the way people perceive the usefulness and ease of use of a given ICT will be impacted by the existing national attitude – in this case, that of the medical teams as well as the support staff – together with the common practices, artefacts, espoused values and underlying assumptions of the developer(s) in an organization.

2.3 Theoretical Framework

This section examines the various theories used to inform the study on the factors influencing adoption of ICT. The study is guided by the following theories; diffusion of innovation theory, technology acceptance theory and contingency theory

Innovation- Diffusion Theory

Diffusion of innovation theory was developed by Rogers in 1995. This theory suggests that there are three main sources influencing the adoption and diffusion of an innovation, namely perceptions of innovation characteristics, characteristics of the adopter, and contextual factors. The theory sees innovations as being communicated through certain channels over time and within a particular social system. Individuals are seen as possessing different degrees of willingness to adopt innovations, and thus it is generally observed that the portion of the population adopting an innovation is approximately normally distributed over time. Breaking this normal distribution into segments leads to the segregation of individuals into the following five categories of individual innovativeness (from earliest to latest adopters): innovators, early adopters, early majority, late majority, laggards (Wejnert, 2001). The innovation process in organizations is much more complex. It generally involves a number of individuals, perhaps including both supporters and opponents of the new idea, each of whom plays a role in the innovation-decision.

The study by Rogers (1995) identifies five attributes upon which an innovation is judged. These are relative advantage, compatibility, complexity, triability and observability. Relative advantage refers to the degree to which an innovation is perceived as better than the practice it replaces. Relative advantage is often expressed in terms of economic, social or other benefits. Compatibility refers to the degree to which an innovation is perceived by potential adopters to be consistent with their existing values and practices. Compatibility with what is already in place makes the new practice seem less uncertain, more familiar and easier to adopt. Complexity refers to the degree to which an innovation is considered as a difficulty to understand and use. If potential adopters perceive an innovation as complex, its adoption rate is low. Triability refers to the extent to an innovation may be subjected to limited experimentation. Finally, observability refers to the degree to which the results of an innovation are visible to others. This theory has been applied to study the adoption of various information communication technologies in healthcare.

Technology Acceptance Theory

Technology acceptance theory, introduced by Davis (1989), is an adaptation of the theory of reasoned action specifically tailored for modelling user acceptance of information systems. The goal of the theory is to provide an explanation of the determinants of computer acceptance that is general, capable of explaining user behaviour across a broad range of end-user computing technologies and user populations, while at the same time being both parsimonious and theoretically justified. Ideally one would like a model that is helpful not only for prediction but also for explanation, so that researchers and practitioners can identify why a particular system may be unacceptable, and pursue appropriate corrective steps. A key purpose of the theory, therefore, is to provide a basis for tracing the impact of external factors on internal beliefs, attitudes, and intentions. Technology acceptance theory was formulated in an attempt to achieve these goals by identifying a small number of fundamental variables suggested by previous research dealing with the cognitive and affective determinants of computer acceptance. The technology acceptance theory has also been used by researchers to explain why a particular system may or may not be acceptable to users. It hypothesizes that there are two beliefs, perceiving usefulness and perceiving ease of use, which are variables that primarily affect the user acceptance.

Contingency Theory

Tornatzky & Fleischer (1990), developed a framework for organizational adoption based on contingency theory of organizations. This theory postulates that an effective organization should have a structure which is consistent with its environmental needs. The effectiveness of an organization is based upon its fitness towards both internal and external factors such as environment, organization size, and organization strategy and technological factors to make a decision. In this framework, three key determinants were identified (Donaldson, 2001). Therefore, decision makers should take in to account technology, organization, and environment factors that affect technology adoption. The theory is applicable to the study since organizations operate in different markets, have different management styles and an individual composition of staff etc.

Hence, to follow the idea behind contingency theory, each organization must monitor its own environment and realize that organizations have to deal with different situations in different ways. The technology, organization, and environment framework has been adapted in IT adoption studies in the past and it provides a useful analytical framework that can be used for studying the adoption and assimilation of different types of IT innovation (Oliveira & Martins, 2011).

2.4 Conceptual Framework

The conceptual framework is a diagrammatical presentation of variables in the study as shown in figure 1. The framework illustrates the interrelationship between dependent and independent variables. The independent variables for the study are factors influencing adoption of ICT. The independent variables include: cost of equipment, operational efficiency, human capital and competitive advantage, while the dependent variable is the adoption of ICT.

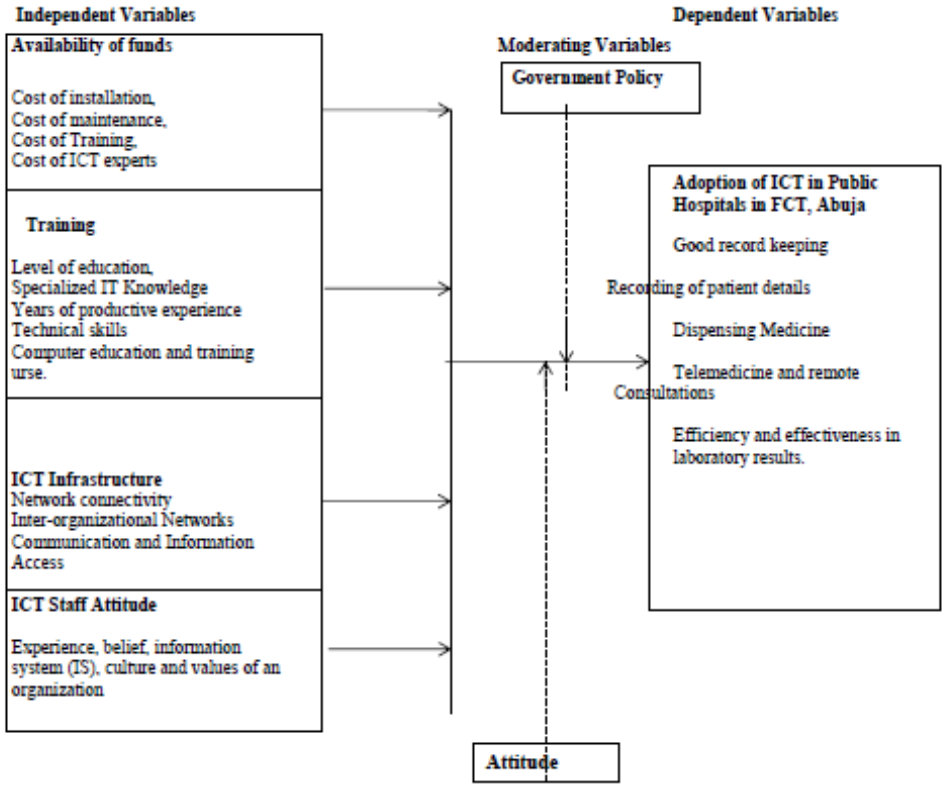

Figure 1: Conceptual Framework

3. RESEARCH METHODOLOGY

3.1 Research Design

This study focused on factors influencing adoption of ICT in public hospitals in Abuja a case of public hospitals in FCT, Abuja. The study employed a descriptive research design. According to Ngechu (2004) surveys is the collection of information from a group through interviews or the application of questionnaires to a representative sample of that group. According to Mugenda & Mugenda (2008), descriptive survey enables the researcher to describe the characteristics of the variables of interest due to its suitability in data collection to answer the research questions. It is therefore justified

that descriptive design is most suited and justifiably adopted in this study. Surveys are useful in describing the characteristics of a large population. Additionally, high reliability is easy to obtain by presenting all subjects with a standardized stimulus which ensures that observer subjectivity is greatly eliminated.

3.2 Target Population

Population refers to the entire group of people, events or things of interest that the researcher wishes to investigate (Creswell, 2003). A study population can be defined as the entire collection of cases or units about which the researcher wishes to draw conclusions. Target population in statistics is the specific population about which information is desired. According to Ngechu (2004), a population is a well-defined or set of people, services, elements, and events, group of things or households that are being investigated. This study focused on a population 15000 respondents which includes; ICT managers, ICT support staff record keepers, finance officers, cashiers' pharmacists, procurement officers, radiologists and laboratory technologists of different levels in the public hospitals in FCT.

3.3 Sampling Procedure

This study used simple random sampling method which is a probability method. This helped in the process of identifying the respondents for data collection. ICT managers, ICT support staff, finance officers, procurement officers, pharmacists, radiology and laboratory technologists are deemed viable when carrying out the research. The sample size of about 100 respondents was equitably distributed and all respondents had equal chances of participating in the study. Purposive sampling technique was used for selection of various staff in the different hospitals that influence ICT adoption as they are considered competent in providing the required information. According to Denscombe (2008), purposive sampling starts with a purpose in mind and the sample is thus selected to include people of interest and exclude those who do not suit the purpose. The method was therefore suitable in selecting the managers who have been engaging in ICT adoption for a reasonable period of time.

3.4 Research Instruments

This study used questionnaires as primary tool for data collection. The questionnaires contained both structured and unstructured questions. The questionnaires were preferred in this study because respondents are assumed to be literate and quite able to answer questions asked adequately. Kothari (2004), terms the questionnaire as the most appropriate instrument due to its ability to collect a large amount of information in a reasonably quick span of time. It guarantees confidentiality of the source of information through anonymity while ensuring standardization (Creswell, 2003).

3.4.1 Reliability of Research Instruments

Reliability is a measure of the degree to which a research instrument yields consistent results or data after repeated trial (Mugenda & Mugenda, 2008). In order to improve the reliability of the instrument, an assessment of the consistency of the responses on the pilot questionnaires will be made to make a judgement on their reliability. According to Kothari (2004), an instrument is reliable when it measures a variable accurately and consistently and produces the same results under the same conditions over time. The idea behind reliability is that any significant result must be more than a one-off finding and be inherently repeatable. For reliability, the researcher will use internal consistency measure known as Cronbach's Alpha (α) which indicates the extent to which a set of measurement items could be treated as measuring a single latent variable Reliability provides a measure of the internal consistency and homogeneity of the items comprising the scale.

3.5 Data Collection Procedures

Permission to collect data from ICT manager who engage in ICT adoption in public hospitals FCT, Abuja was sought from the seven hospitals. The researcher attached a transmittal letter in each questionnaire. The researcher visited each hospital at different times and sought for permission to collect data in the different ways discussed above.

3.6 Data analysis Techniques

The data collected was analysed using descriptive statistics (measures of central tendency and measures of variations) to achieve the objectives of the study. The process of data analysis involved several stages: the completed questionnaires were edited for completeness and consistency, checked for errors and omissions. The research yielded both qualitative and quantitative data.

The qualitative data collected was analysed through content analysis where a thematic framework was developed. The quantitative data generated was analysed using descriptive statistics with the help of Statistical Package for Social Sciences (SPSS) version 20. The findings were presented using tables, frequencies and percentages. Correlation analysis was employed for association analysis. It is a measure of the degree of association between two or more variables that have been obtained from the same group of subjects (Mugenda & Mugenda, 2008), and is used when a researcher wants to predict and describe the association between two or more variables in terms of magnitude and direction.

4. DATA ANALYSIS AND DISCUSSION

4.1 Questionnaire

The study targeted a sample size of 100 respondents from which 85 filled in and returned the questionnaires making a response rate of 85% as shown in Table 1. This response rate was satisfactory to make conclusions for the study as it acted as a representative. According to Mugenda & Mugenda, (2008) a response rate of 50% is adequate for analysis and reporting; a rate of 60% is good and a response rate of 70% and over is excellent.

Table 1: Response Rate

	Questionnaires Administered	**Questionnaires filled & Returned**	**%**
Respondents	100	85	85

4.2 Demographic Information

The study sought to establish the demographic information of the respondents in terms of gender distribution, level of education and period of service as in Table 2.

Gender distribution

Table 2: Gender Distribution

Gender	**Frequency**	**Percentage**
Male **Female**	65 20	76.47 23.53
Total	**85**	**100**

The study sought to establish the gender distribution of the respondents, from the research findings the study revealed that majority of the respondents as shown in Table 2, 76.47% were males whereas 23.53% of the respondents were females. This implies that respondents were fairly distributed in terms of their gender.

Level of Education

The study sought to establish to what level the respondents were educated. It was establish as shown in Table 3

Table 3: Level of Education

Level of Education	Frequency	Percentage
College Diploma	10	11.76
Undergraduate	35	41.18
Master	40	47.06
Total	**85**	**100**

On respondents "level of education attained", the study revealed that most of the respondents as shown in Table 3, 47.06 % had attained master's degree, whereas 41.18 % of the respondents had attained undergraduate degrees and 11.76% of the respondents had attained college diplomas. This implies that respondents were well educated and therefore they were in position to respond to the research questions with ease.

Period of Service

The study sought to establish the period which the respondents had served for in the institutions as indicated in Table 4.

Table 4: Period of Service

Period of Service	Frequency	Percentage
Below 2 years	2	2.35
3 to 5 years	3	3.53
6 to 8 years	25	29.41
9 years and above	55	64.71
Total	**85**	**100**

From the research findings, the study revealed that majority of the respondents as shown in Table 4, 64.71% had served the institution for more than 9 years whereas 29.41% of the respondents had served the institution for a period of 6 to 8 years, 3.53% had served the institution for 3 to 5 years and only 2.35% of the respondents had served the institution for a period of less than 2 years. This implies that majority of the respondents had served the institution for a considerable period of time and thus they were in a position to give credible information rating to this research

4.3 Analysis and Results

Availability of Funds

Table 5: Descriptive Statistics

Variable	Mean	Std. Deviation	N
Adoption of ICT in GVT Hospitals	4.2218	0.76947	85
Availability of Funds	4.3373	0.60530	85

GVT means government, IV means independent variable and DV means dependent variable.

Adoption of ICT in GVT Hospitals is the dependent variable while the Availability of Funds is the independent variable. The results in Table 5 indicate the descriptive statistics for the indicated variables on IV and DV. The means for Adopting ICT in

GVT Hospitals and Availability of Funds based on the 5-likert scale respectively are 4.2218 and 4.3373 with the corresponding standard deviation of 0.76947 and 0.60530.

Inferential Statistical Analysis

Pearson's correlation analysis was done to get the strength of the relationship between the independent variable (Availability of Funds) and dependent variable (Adoption of ICT in GVT Hospitals) based on the hypothesis stated.

Hypothesis

Null hypothesis: There is no significant relationship between Availability of Funds and Adoption of ICT in GVT Hospitals

Table 6: Correlations

		Adoption of ICT in GVT Hospitals	Availability of Funds
Adoption of ICT in GVT Hospitals	Pearson Correlation	1	.921**
	Sig. (2-tailed)		.000
	Sum of Squares and Cross-products	49.735	36.045
	Covariance	.592	.429
	N	85	85
Availability of Funds	Pearson Correlation	.921**	1
	Sig. (2-tailed)	.000	
	Sum of Squares and Cross-products	36.045	30.776
	Covariance	.429	.366
	N	85	85

** Correlation is significant at the 0.01 level (2-tailed).

Results in Table 6 reveal that the Pearson correlation coefficient is 0.921 and a p-value of 0.000. This shows a strong, positive and statistically significant relationship since the asymptotic level of significance (0.000) is less than the predetermined level of confidence (0.05). Hence, the null hypothesis was rejected. Therefore, it was concluded that a significant relationship exists between Availability of Funds and Adoption of ICT in GVT Hospitals.

Table 7: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics			Df2	Sig.
					R Square	F	df1		
1	.921[a]	.849	.847	.30099	.849	465.989	1	83	0.000

Results in Table 7 indicate that the contribution from the Availability of Funds to the Adoption of ICT in GVT Hospitals is 84.9%. This means that Availability of Funds is responsible for Adoption of ICT in GVT Hospitals by 84.9% while other factors fall under (or account) the remaining 15.1%.

Now, since there exists a significant relationship, we can use a regression analysis to find a model that relates the independent variable (Availability of Funds) and dependent variable (Adoption of ICT in GVT Hospitals) based on the hypothesis stated.

Table 8: Coefficients

Model		Unstandardized Coefficients		Standardized	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	-0.858	0.238		-3.611	0.001
	Availability of Funds	1.171	0.054	0.921	21.587	0.000

a. Dependent Variable: Adoption of ICT in GVT Hospitals

Results in Table 8 indicate the coefficients for the independent variable (Availability of Funds) and the constant of the model. The model equation is given as:

Adoption of ICT in GVT Hospitals = 1.171***Availability of Funds** – 0.858 (1)

The results are significant since p-values < 0.05.

Results in Table 9 shows that the overall model equation in equation (1) is statistically significant (p-values < 0.05)

Table 9: ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	42.216	1	42.216	465.989	.000
	Residual	7.519	83	.091		
	Total	49.735	84			

a. Dependent Variable: Adoption of ICT in GVT Hospitals

b. Predictors: (Constant), Availability of Funds

Results in Table 9 shows that the overall model equation in equation (1) is statistically significant (p-values < 0.05)

Training and Education

Table 10: Descriptive Statistics

	Mean	Std. Deviation	N
Adoption of ICT in GVT Hospitals	4.2218	0.76947	85
Training and Education	4.3305	0.70478	85

Adoption of ICT in GVT Hospitals is the dependent variable while the Training and Education is the independent variable. The results in Table 10 indicate the descriptive statistics for the indicated variables on IV and DV. The means for Adopting ICT in

GVT Hospitals and Training and Education based on the 5-likert scale respectively are 4.2218 and 4.3305 with the corresponding standard deviation of 0.76947 and 0.70478.

Inferential Statistical Analysis

Pearson's correlation analysis was done to get the strength of the relationship between the independent variable (Training and Education) and dependent variable (Adoption of ICT in GVT Hospitals) based on the hypothesis stated.

Hypothesis

Null hypothesis: There is no significant relationship between Training and Education and Adoption of ICT in GVT Hospitals

Results in Table 11 reveal that the Pearson correlation coefficient is 0.965 and a p-value of 0.000. This shows a strong, positive and statistically significant relationship since the asymptotic level of significance (0.000) is less than the predetermined level of confidence (0.05). Hence, the null hypothesis was rejected. Therefore, it was concluded that a significant relationship exists between Training and Education and Adoption of ICT in GVT Hospitals.

Table 11: Correlations

		Adoption of ICT in GVT	Training and Education
Adoption of ICT in GVT Hospitals	Pearson Correlation	1	.965(**)
	Sig. (2-tailed)		.000
	Sum of Squares and Cross-products	49.735	43.944
	Covariance	.592	.523
	N	85	85
Training and Education	Pearson Correlation	.965(**)	1
	Sig. (2-tailed)	.000	
	Sum of Squares and Cross-products	43.944	41.724
	Covariance	.523	.497
	N	85	85

** Correlation is significant at the 0.01 level (2-tailed).

Table 12: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.965(a)	.931	.930	.20397

a Predictors: (Constant), Training and Education

Results in Table 12 indicate that the contribution from the training and education to the Adoption of ICT in GVT Hospitals is 93.1%. This means that training and education is responsible for Adoption of ICT in GVT Hospitals by 93.1% while other factors fall under (or account) the remaining 6.9%.

Now, since there exist a significant relationship, we can use a regression analysis to find a model that relates the independent variable (Training and Education) and dependent variable (Adoption of ICT in GVT Hospitals) based on the hypothesis stated.

Table 13: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B B	Std. Error	Beta	B	Std. Error
1	(Constant)	-.339	.139		-2.447	.017
	Training and Education	1.053	.032	.965	33.352	.000

a Dependent Variable: Adoption of ICT in GVT Hospitals

Results in Table 13 indicate the coefficients for the independent variable (Training and Education) and the constant of the model. The model equation is given as :

Adoption of ICT in GVT Hospitals = 1.053***Training and Education** – 0.339 (2)

The results are significant since P-values < 0.05.

Table 14: ANOVA

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	46.282	1	46.282	1112.387	.000(a)
	Residual	3.453	83	.042		
	Total	49.735	84			

a Predictors: (Constant), Training and Education
b Dependent Variable: Adoption of ICT in GVT Hospitals

Results in Table 14 shows that the overall model equation in equation (2) is statistically significant (p-values < 0.05)

ICT Infrastructure

Table 15: Descriptive Statistics

Variable	Mean	Std. Deviation	N
Adoption of ICT in GVT Hospitals	4.2218	0.76947	85
ICT Infrastructure	4.2958	0.72508	85

Adoption of ICT in GVT Hospitals is the dependent variable while the ICT Infrastructure is the independent variable. The results in Table 15 indicate the descriptive statistics for the indicated variables on IV and DV. The means for Adopting ICT in GVT Hospitals and ICT Infrastructure based on the 5-likert scale respectively are 4.2218 and 4.2958 with the corresponding standard deviation of 0.76947 and 0.72508.

Inferential Statistical Analysis

Pearson's correlation analysis was done to get the strength of the relationship between the independent variable (ICT Infrastructure) and dependent variable (Adoption of ICT in GVT Hospitals) based on the hypothesis stated.

Hypothesis

Null hypothesis: There is no significant relationship between ICT Infrastructure and Adoption of ICT in GVT Hospitals

Table 16: Correlations

		Adoption of	ICT
Adoption of ICT in GVT Hospitals	Pearson Correlation	1	.993(**)
	Sig. (2-tailed)		.000
	Sum of Squares and	49.735	46.520
	Covariance	.592	.554
	N	85	85
ICT Infrastructure	Pearson Correlation	.993(**)	1
	Sig. (2-tailed)	.000	
	Sum of Squares and	46.520	44.162
	Covariance	.554	.526
	N	85	85

** Correlation is significant at the 0.01 level (2-tailed).

Results in Table 16 reveal that the Pearson correlation coefficient is 0.993 and a p-value of 0.000. This shows a strong, positive and statistically significant relationship since the asymptotic level of significance (0.000) is less than the predetermined level of confidence (0.05). Hence, the null hypothesis was rejected. Therefore, it was concluded that a significant relationship exists between ICT Infrastructure and Adoption of ICT in GVT Hospitals.

Table 17: Model Summary

Model	R	R	Adjusted R	Std. Error of the Estimate
1	.993[a]	.985	.985	.09390

Results in Table 17 indicate that the contribution from the ICT Infrastructure to the Adoption of ICT in GVT Hospitals is 98.5%. This means that Availability of Funds is responsible for Adoption of ICT in GVT Hospitals by 98.5% while other factors fall under (or account) the remaining 1.5%.

Now, since there exists a significant relationship, we can use a regression analysis to find a model that relates the independent variable (ICT Infrastructure) and dependent variable (Adoption of ICT in GVT Hospitals) based on the hypothesis stated.

Table 18: Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta	B	Std. Error
1	(Constant)	-.303	.062		-4.927	.000
	ICT Infrastructure	1.053	.014	.993	74.549	.000

a Dependent Variable: Adoption of ICT in GVT Hospitals

Results in Table 18 indicate the coefficients for the independent variable (ICT infrastructure) and the constant of the model. The model equation is given as:

Adoption of ICT in GVT Hospitals = 1.053***ICT Infrastructure** – 0.303 (3)

The results are significant since P-values < 0.05.

Table 19: ANOVA

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	49.003	1	49.003	5557.570	.000(a)
	Residual	.732	83	.009		
	Total	49.735	84			

a Predictors: (Constant), ICT Infrastructure

b Dependent Variable: Adoption of ICT in GVT Hospitals

Results in Table 19 shows that the overall model equation in equation (3) is statistically significant (p-values < 0.05)

4.4 Discussion of the Findings

This section discusses the key findings as considered under each objective.

4.4.1 Influence of Availability of Funds on Adoption of ICT

On effects of cost of equipment and training, the study established that the cost of ICT training materials is considered to be among the problems that negatively affects the implementation of ICT in most health facilities. Enormous amount of funds is required to acquire equipment and on training. The study further revealed that medical equipment management involves other essential activities which ensure that equipment is effectively planned and budgeted for, procured, and operated. Human factors engineering is used to influence medical device procurement decisions in hospitals. The process ensures that the safest, most efficient and effective devices are purchased. The study findings are in line with Oliver (2005) that compared to traditional forms of

hospital treatments technology facilitated has proven to be quite expensive in all areas of consideration.

4.4.2 Influence of Training on Adoption of ICT

The study revealed that staff in various hospitals are lacking in specialized IT knowledge and technical skills in most public hospitals in FCT, Abuja. If employees in health institutions have more knowledge of information systems, then they will be more likely to adopt the information systems. The study further revealed that training and adoption of electronic medical records in public hospitals can support medical professionals in their decision-making and also improve operating efficiency, thus improving medical care quality. Other systems such as decision support systems have been seen to reduce medical errors in applications such as drug order entry. E-Health in public hospitals has shown that it can be one solution to provide better access to healthcare facilities for patients and healthcare professionals, improve collaboration between different governmental bodies, and increase care quality.

The study further revealed that, in order to facilitate the successful implementation of ICT system in hospitals, the government should provide employees with computer education and training courses. Potential and competency of the ICTs for improving hospitals services cannot be realized unless staffs are well trained and retrained in the pedagogical use of technology in the hospital premises. Doctors and hospital staffs in FCT, Abuja should be trained on basic IT skills such as; file management, word processing, spreadsheet, email and internet use since they will play a key role in developing requisite human health which is paramount in ensuring attainment if vision 2030 and knowledge economy.

The study findings are in line with Apulu & Latham (2009), hospitals in developed countries continue to implement electronic medical records to lower costs and to improve quality of care. With the adoption of electronic medical records, patient information will be electronically captured in any care delivery setting.

4.4.3 Influence of ICT Infrastructure on Adoption of ICT

On the influence of ICT Infrastructure on adoption of ICT, the study revealed that installation of ICT infrastructure is a major drawback to the adoption of ICT. Computers phones are in use in all the teaching hospitals but not much Internet connectivity was available, meaning that most of the medical experts used external. The study further revealed that developments in ICT technological infrastructure in hospitals have drastically influenced the competitive business environment in health sector as proved by the emergence and strengthening of the global economy, and the transformation of industrial economies to knowledge-and-information-based service economies. The study findings are in line with Eysenbach & Wyatt (2002), that ICT infrastructure is a major issue that stands as an impediment to access of information, most people are not able to access digital information due to lack of the necessary infrastructure.

The study further revealed that Lack of adequate ICT infrastructure has hampered provision of efficient and affordable ICT services in public hospitals in FCT, Abuja. There is therefore need to put more emphasis on provision of support infrastructure, such as, connectivity, supporting software development and assembly of ICT equipment and accessories and Provision of incentives for the provision of ICT infrastructure in major hospitals. The study findings are in line with Eysenbach & Wyatt (2002), that technological infrastructure is a major issue that stands as an impediment to access of information, most hospital staffs are not able to access digital information due to lack of the necessary infrastructure. This has left a bigger part of the population unable to access the digital information hence discouraging the adoption of ICT. Health institution needs to enhance and upgrade current technical architectures to accommodate digital materials especially with the rapid changes in technology.

4.4.4 Influence of ICT Staff Attitude on Adoption of ICT

On the influence of ICT staff attitude on ICT adoption, the study established that ICT adoption has been perceived to challenge the traditional management hierarchy and change both the location and the nature of decision making in most public hospitals.

The effectiveness and success of ICT systems seems to depend not only on the technology itself, but also on the ways in which the users are introduced to the concept because some staffs tend to be resistant to change. The support of hospital staffs in introduction of new innovations is highly dependent on the type of innovation as well as the employees‟ perception to the inventions to be introduced.

The study further revealed that the way people perceive the usefulness and ease of use of a given ICT is impacted by the existing national culture where the medical teams in many hospitals as well as the support staff together with the common practices, artefacts, espoused values and underlying assumptions of the developer(s) in an organization affect ICT adoption. The study findings concur with (Apulu & Latham, 2009), that in the developed nations, doctors use computers to send live video, sound and high-resolution images between two distant locations as well as examining patients in clinics that may be thousands of miles away. These technologies are being rolled over to developing countries due to their immense abilities in reducing healthcare costs but most staffs do not adopt these changes.

5. CONCLUSION AND RECOMMENDATIONS

The study set out to establish the factors influencing adoption of ICT in public hospitals in FCT, Abuja; and to determine the influence of training, infrastructure, availability of funds, and the influence of ICT staff attitude on the adoption of ICT in those hospitals. The study population consisted of ICT managers, record keepers, clerks, cashiers and laboratory technologists in seven targeted public hospitals in the city. The data collected was analysed using descriptive statistics (measures of central tendency and measures of variations), correlation coefficient and linear regression, with SPSS version 20. The findings of the study are that: the cost of ICT training materials is considered to be among the problems that negatively affects the implementation of ICT in most health facilities; medical equipment management involves other essential activities which ensure that equipment is effectively planned and budgeted for, procured, and operated; deficient ICT infrastructure is a major drawback to the adoption of ICT; developments of ICT technological infrastructure in hospitals have drastically influenced the competitive business environment in the health sector as proved by the emergence and strengthening of the global economy, and the transformation of industrial economies to knowledge-and-information-based service economies; and that ICT adoption has been perceived as being a challenge to the traditional management hierarchy and changes both the locations and the nature of decision making in most public hospitals. The study recommends that the ministry of health should improve the current ICT status for health sector. The Sector should attain tangible and observable ICT diffusion levels. The government should increase the ICT budget to address adoption challenges in public hospitals in FCT, Abuja, as the survey found that high cost of funding ICT programmes is immensely influencing ICT adoption. It is recommended that the government should increase the ICT budget to address adoption challenges in public hospitals in the FCT; adequate ICT budget should be provided to empower the operations of Ministry of Information and Communication as well as the Ministry of Health with a focus to bringing down the cost of Internet connectivity. It is also recommended that public hospitals management should train their employees on the information systems prior to the ICT adoption. This will ensure that the staff will easily understand the functionality of information systems and will also serve to reduce resistance to information systems.

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QUESTIONNAIRE

Instructions:
Kindly answer the following questions fully by either ticking the appropriate response in one of the boxes provided. Do not write your names anywhere in this questionnaire. Please be as honest as possible.

Section A: Complete The Following
HOSPITAL:
_____
_
NO OF WORKERS:
_____
DEPARTMENT:
_____
POSITION:
_____
_
DATE: _____ SIGN:
_____

Section B: Demographic Information
1. Gender Male ( ) female ( )
2. Please indicate the highest level of education attained? (Tick as applicable)
College Diploma [ ]
Undergraduate [ ]
Master [ ]
Others (specify) ……...
3. Indicate your period of service in this institution
Below 2 years ( ) 3 to 5 years ( ) 6 to 8 years ( ) 9 years and above ( )

Section C: Factors Influencing Adoption of ICT
4. Indicate your level of agreement with the following statements relating to the Level of ICT Adoption in Government Hospitals in Nigeria. Use a scale of 1-5, where (1= Strongly Disagree, 2= Disagree, 3= Moderately Agree, 4= Agree, 5= Strongly Agree)

S/N	COST OF EQUIPMENT AND TRAINING	1	2	3	4	5
1	The cost of ICT training materials is considered to be one of the problems that negatively affects the implementation of ICT in most health facilities					
2	The migration to electronic medical records is necessitated by savings in expenditure.					
3	Paper-based systems in hospitals have limited functionality; many people cannot easily view the same record at the same time, thereby reducing productivity and efficiency of employees.					
4	Electronic medical records, support medical professionals in their decision-making leading to improved medical care quality					

5	E-Health can be one solution to provide better access to healthcare facilities for patients					
6	The availability of skilled personnel will boost quality healthcare					
7	Government policies positively affect E-Health adoption in Government owned hospitals in the FCT					
8	The level of industry support will positively influence the adoption of ICT in Government owned hospitals in FCT, Abuja					

5. To what extent do you agree with the following statements on training and adoption? Use a scale of 1-5, where (1= strongly disagree, 2= disagree, 3= moderately agree, 4= Agree and 5= strongly Agree)

S/N	**Training and Adoption**	**1**	**2**	**3**	**4**	**5**
1	Members of the institutions are lacking in specialized IS knowledge and technical skills.					
2	The higher IS capabilities the staff have, the higher their potential in the use of information systems					
3	In order to facilitate the successful implementation of information system in hospitals, the government should provide employees with computer education and training courses.					
4	The lack of knowledge on how to use technology affects the adoption of ICT in hospital.					
5	Many public hospital are lacking technical abilities on the adoption of ICT					
6	Public hospital are lacking management skills on the adoption of ICT					
7	If employees in health institutions have more knowledge of information systems, then they will be more likely to adopt the information systems.					

6. To what extent do you agree with the following statements on ICT Infrastructure? Use a scale of 1-5, where (1= strongly disagree, 2= disagree, 3= moderately agree, 4= Agree and 5= strongly Agree)

S/N	**ICT Infrastructure**	**1**	**2**	**3**	**4**	**5**
1	Despite the immense benefits of ICTs as a means of delivering quality health care services, the potential of ICTs have not been fully harnessed by health professionals					

2	Communication for health purposes has shifted from the largely manual or physical documentary method to digital communication					
3	Internet has become an important component of the electronic services in health institutions.					
4	In spite of the potential contributions of ICTs to the activities of health workers, some constraints exist that prevent their widespread utilization					
5	Physical access to ICT is a major constraint to public hospitals.					
6	Cost of installation of ICT infrastructure is a major drawback to the adoption of ICT.					
7	That computers phones were in use in all the teaching hospitals but not much Internet connectivity was available, meaning that most of the medical experts used external					

7. To what extent do you agree with the following statements on ICT staff attitude? Use a scale of 1-5, where (1= strongly disagree, 2= disagree, 3= moderately agree, 4= Agree and 5= strongly Agree)

S/N	ICT Staff Attitude	1	2	3	4	5
1	The impact of staff attitude is extensive in health institutions where it is manifested in concepts such as the way things are done					
2	The attitude of the developer of the ICT that is used in an organization affects the performance of organizations					
3	The attitudes of the user of ICT in the hospitals affect the performance of the organization(s).					
4	ICT adoption attitude is shared by the employees of a health institution involved in information activities.					
5	ICT adoption attitude resist technologies which threaten to change the working habits, especially when they employees violate some of the groups‟ shared values.					
6	The way people perceive the usefulness of a given ICT will be impacted by the existing national attitude					
7	IS culture is more or less compatible with certain forms of IT; when that is the case, the result can be resistance to IT changes					

Design and Installation of an Affordable Water Level Controller; A Way Out to Uganda Water Crisis

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Abstract: Water remains the most crucial nutrient that can sustain life. This research provides a mechatronics design to control drinking water wastage in Uganda. The drinking water crisis in Uganda is reaching a distressing rate with the water income increasing annually as a means of generating revenue. The drinking water scarcity could get to the stage of the national crisis in a jiffy. Hence, it is of paramount importance to preserve water for human sustainability and in turns justify the huge amount of money invested by the Uganda government in the water sector. There is unneeded wastage of water in many houses due to overflow in overhead tanks couple with the fact that the cost of drinking water is unduly high in Urban and not available in the rural area of Uganda. A rise in water wastage can impair access to improved water which in turn can lead to poor sanitation and contamination of water. Contaminated water has been proved to be the leading cause of death each year. When water is not properly cared for, it could lead to an outbreak of diseases such as diarrhea, cholera, dysentery and worm infection. Automatic Water Level controller and indicator can be a solution to this problem. The operation of water level indicator works on the electrolytic nature of water (conducts electricity due to the presence of hydrogen and hydroxyl ions). The float is used to switch **OFF** /**ON** the motor pump as the water level rises/falls by pushing up the electric contact which returned and anchored by a string.

Keywords: Mechatronics, water, design, affordable, crisis, float, Uganda.

1. Introduction

Access to clean and safe water with enhanced sanitation facilities and practices results in better health, these are crucial investments in human capital and thus have a direct and immediate impact on the quality of life. Therefore, contributing to the long-term socio-economic development of the country and eventual elimination of poverty. Uganda's freshwater resources are considered to be a critical strategic resource, essential for sustaining life, promoting development and maintaining the environment [1–3]. Various health organisations recommend that drinking water ranging from 10-20 litres is consumed by an individual in a day when supplied by a standard pipe in the neighborhood. The quantity of water required for drinking and eating is the most water crisis indicator. Thus, drinking water requirements entail essential hygiene and cooking routines [4-5].

2. Drinking Water Supply and Management in Uganda

It has been appraised that the total volume of water available on Earth is 1.4 billion cubic kilometres, sufficient to cover the planet with a layer of about 3 km. About 95% of the Earth's water is in the oceans, which is unfit for human consumption. About 4% is locked in the polar ice caps, and the rest 1% constitutes all freshwater found in rivers, streams, and lakes which are suitable for our consumption [6–8].

Table1: Uganda Water and Environment Sector Performance Indicator 2018 report [9]

Performance Indicators (n/a = not applicable, ND = No data)		2015/16	2016/17	2017/18
Water Supply				
1. Basic water: Percentage of population using an improved drinking water source	Rural	67%	70%	70%
	Urban	71%	71%	77%
2. Safely managed water: Percentage of population using safely managed drinking water services located on premises	Rural	n/a	ND	ND
	Urban	n/a	ND	20%
3. Percentage of villages with a source of safe water supply	Rural	n/a	64%	66%
	Urban	n/a	ND	ND
4. Percentage of towns with pro-poor facilities where people pay less or equal to the house connection tariff in the service area	STs	n/a	ND	38%
	NWSC	n/a	ND	83%
5. Functionality: rural: % of water sources functional at time of spot-check	Rural	86%	85%	85%
urban: % piped water service availability	STs	n/a	92%	93%
	NWSC	n/a	ND	ND
6a. Management - rural: % of water points with actively functioning Water & Sanitation Committees	Rural	87%	88%	89%
6b. Management – piped schemes: % of piped water schemes with formal contract-based management structure	STs	n/a	ND	ND
7a. % Non-revenue water (piped schemes)	STs	n/a	ND	42%
	NWSC	28%	31.3%	30.7%
7b. Customer satisfaction: NSWC's customer satisfaction index	NWSC	88%	84%	85%
8. Financial Sustainability: Ratio between total revenue collection and O&M costs	STs	n/a	ND	158%
9. Per Capita Investment Cost: Average cost per beneficiary of new water and sanitation schemes (USD)	Rural	32	32	68
	Urban	65.5	54	58
10. Drinking water quality: % of water samples taken that comply with national standards (Point water sources / Piped schemes)	Rural	43%	59%	64%
	STs	n/a	ND	89%
	NWSC	99%	98.6%	99.3%
Sanitation and Hygiene				
11. Basic sanitation: Percentage of population using an improved sanitation facility not shared with other households	Rural	n/a	ND	ND
	Urban	n/a	ND	36.3%
12. Safely managed sanitation: Percentage of population using safely managed sanitation services	Rural	n/a	ND	ND
	Urban	n/a	ND	26%
13. Open defecation: Percentage of population practicing open defecation	Rural	n/a	ND	8%
	Urban	n/a	ND	12.6%
14. Hand washing: Percentage of population with hand washing facilities with soap and water at home	Rural	36%	37%	36.5%
	Urban	39.1%	40%	39.6%
Schools: Percentage of pupils enrolled in schools with basic hand washing facilities	Schools	34%	35%	40%

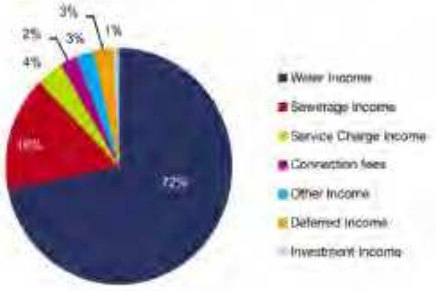

Figure1: Operating Income2009/10[10]

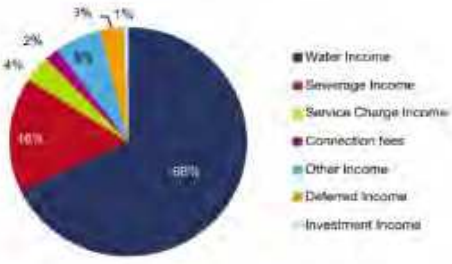

Figure2: Operating Income 2008/09[10]

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Uganda water and environment sector performance report 2018 shows that the percentage of the population using an improved drinking water source in both rural and urban area from 2015/18 are 67%-70% and 71-77% respectively while 20% of the urban populations enjoy safely managed drinking water in 2018 as shown in table1[4-5, 8–11]. For the past ten years, funding for water sector by Uganda government has been smoothly increased, being one of the crucial priority sectors, has benefitted noticeably from the poverty action fund (PAF) to which government has funded. The financial commitment to water resource development and environmental management can increase per capita GDP by 9% in 2040 in which water resources developments contribute 45% to the increment [8- 9, 11].

The percentage of water income increased yearly and also has the highest among other operating income in Uganda as depicted in figure1-3.

Kampala enjoys the highest water supply while the water distributions in other parts of Uganda are nothing to write home about as shown in figure 4.

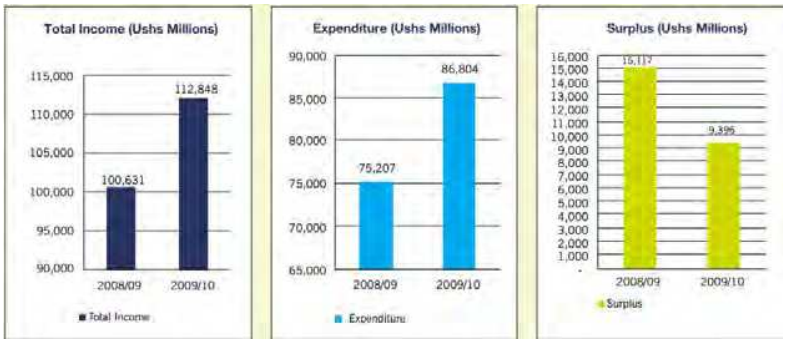

Figure 3: Financial Performance comparison 2009/10[10]

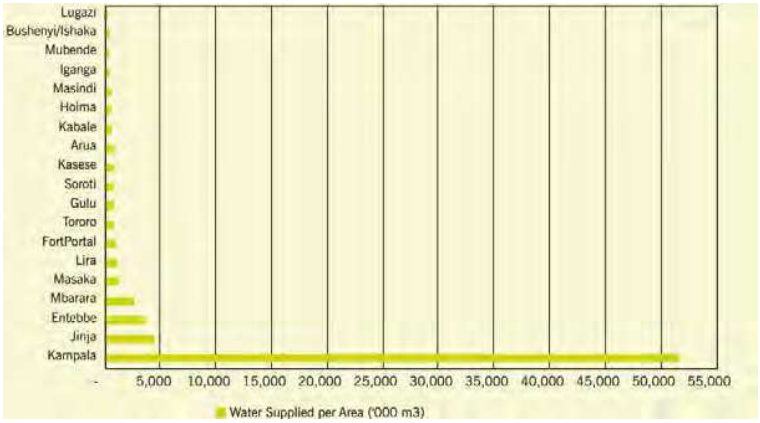

Figure 4: Water produced/supplied per Area 2009/10 [10]

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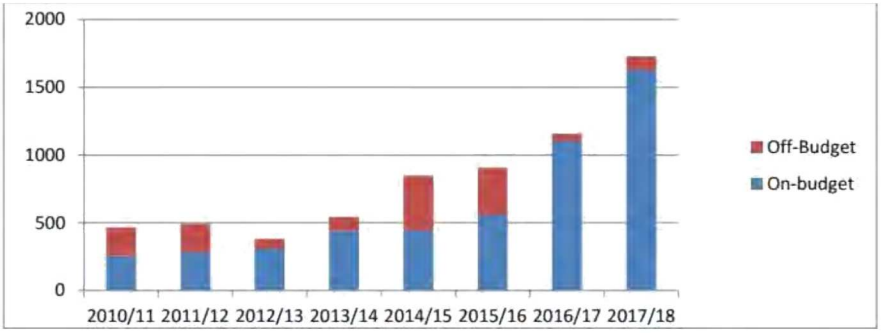

Figure 5: Trends in Sector Funding throughout 7years.(2011/12-2017/18)[9]

Figure 5 shows the 2018 Uganda water and environment sector performance report; the government investment on water was increasing annually.

3. Design Methodology

Figure 6 shows the design innovation of the system. The following components were used for the experimental design: LED, 22O ohm resistor, Centrifugal pump,9v battery, Float, Plastic Pipes, Water Tank, Automatic switch, Single phase wires, Ports and String. The design and installation of all components which are used in the system with required modification and the pumping system are mechanically operated. The problem of opening the tank to remove seals to see the water level is time-consuming, this problem was eliminated by using this electronic display (LED) and the mechanically operating switch to supplement water level through the pump operation. The 9v is supplied to the water through contact. The glowing LED depends on the water level in the tank. When the water level reaches the minimum detectable point, the float will pull the switch hence completing the pump circuit with the aid of the string.

As the tank gets full, the float rod will push the switch hence breaking the circuit.

The float

9v Battery

220 ohms resistor

The Pump

The LED

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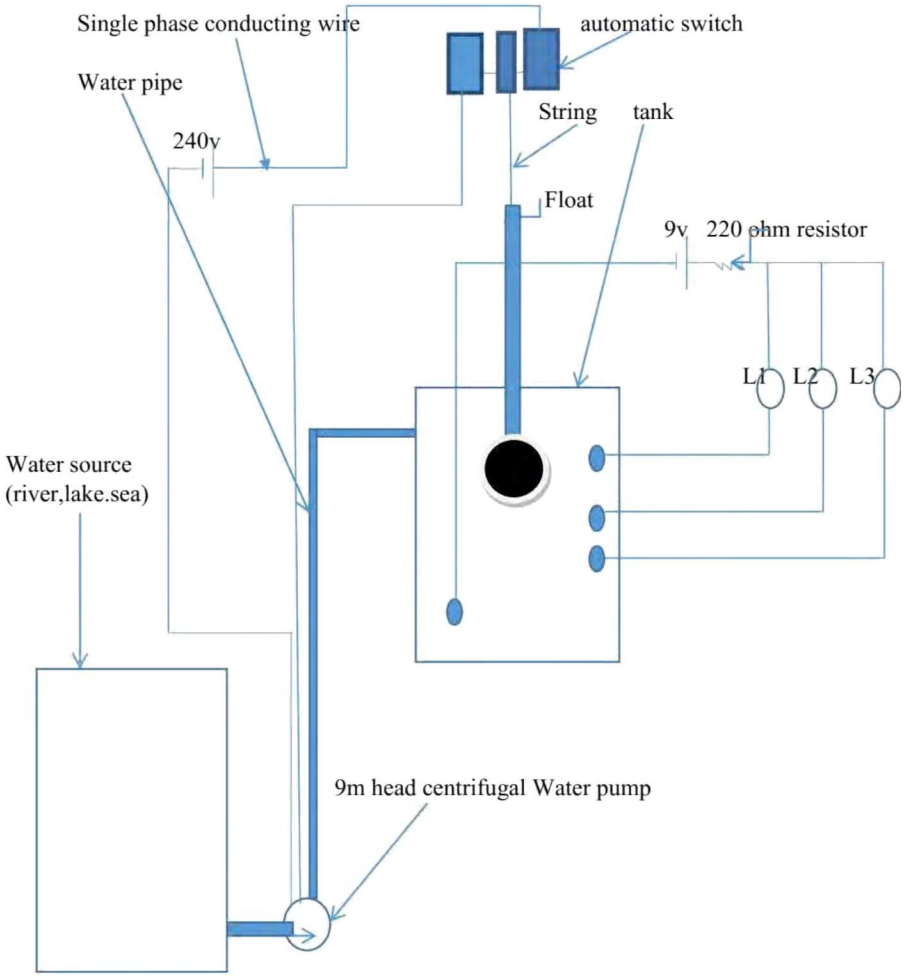

Figure 6.The innovated water level controller with indicator incorporated with a pump.

4. Results and Discussion

Figure 7 shows the result of the experiment, as the water rises the led1 (green) lit up followed by the others as the water got to the prescribed locations for indication. The float rod moved up via the pipe and trip off the electrical contact.

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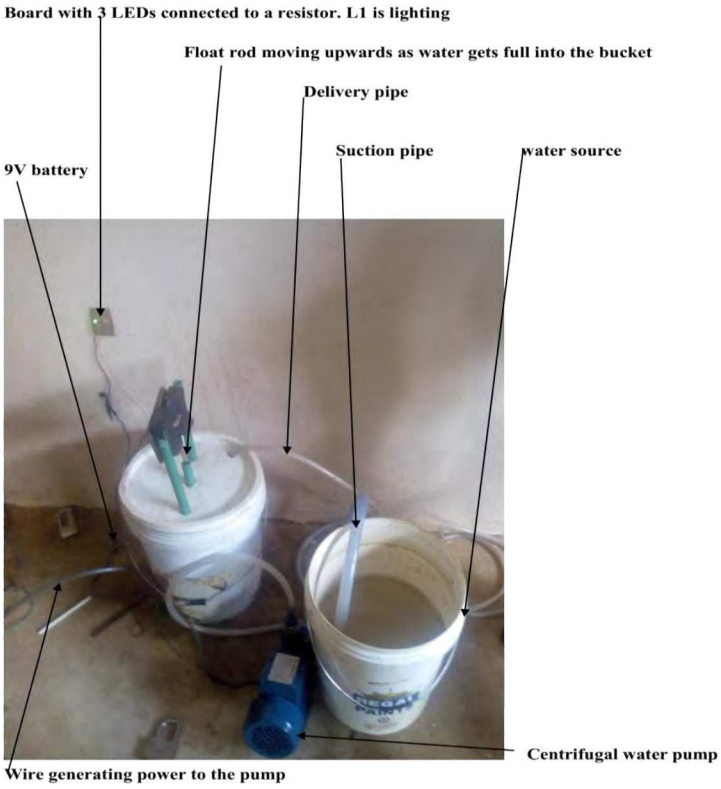

Figure 7.Assembled working diagram for the experiment.

5. Conclusion

The float provided the switching force due to the upthrust, while the light emitting diode (LED) indicated the various levels of the water. The designed system was done successfully without the use of transistor and microprocessors and affordable for the masses in Uganda. With this design, drinking water can be conserved and channeled to other rural areas in Uganda. However, this can also be integrated into hotel toilets, factories, commercial apartment drainage, the liquid level in huge tanks and fuel level indicator in the vehicle.

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Adoption of Free and Open Source Software in teaching and learning of STEM subjects in high schools using R-programming: A pilot study of selected schools in the Kingdom of Eswatini

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Abstract

Globally, there is a gross shortage of professionals in Science, Technology, Engineering and Mathematics (STEM) field due to several factors including scarcity of graduates with STEM skills, lack of qualified technicians, loss of high skilled STEM professionals, untapped pools of STEM talent at primary and secondary school level, limited STEM training infrastructure and lack of human capital in learning institutions and limited funding on STEM subjects. The purpose of this study was to investigate the adoption and use of Free and Open Source Software in teaching and learning R-programming language in high schools. The questionnaire was used to collect quantitative data and results were analyzed using the Statistical Package for Social Sciences. The findings of the study revealed the following: i) the availability of computers in private and public schools will assist in the adoption of FOSS ii) the popular use of commercialized/proprietary software in high schools will affect the adoption of FOSS iii) the interest of high school students in computer programming will expedite the adoption of FOSS iii) lack of personal computers at home in schools will have a negative effect on the adoption of FOSS. Therefore, the study seeks to recommend the use of Free and Open Source Software to teach computer programming in the primary and secondary school to incentivize STEM innovation, and inspiring STEM culture, thereby equipping pupils and students with software programming skills. The teaching and learning of computer programming in secondary school curriculum should be a joint and collective effort between all interested stakeholders including the government authorities, the Ministry of Education and Training, teachers, learners, higher learning institutions and also captains of the industry to ensure smooth adoption and implementation.

Keywords: STEM, E-learning, Free and Open Source Software, Teaching and Learning, Blended learning.

1.0 Introduction

Technology is incessantly changing drastically, its adoption in teaching and learning is inevitable especially in the educational sector. According to**1**, teaching is defined as the concerted sharing of knowledge and experience, which is organized within a discipline and more generally, the provision of stimulus to the psychological and intellectual growth of a person by another person or artifact. **2** defines learning as a process of acquiring information, knowledge and skills through either self-exploration or teaching. Learning is an active engagement process that results in knowledge transfer if properly supported with conducive and enabling environment between the learner and the educator. However, **3**argues that teaching is a difficult, complex process and often subtle activity particularly in Science, Technology, Engineering and Mathematics (STEM) subjects in primary and secondary schools as well as higher education. Such difficulties are associated with inherent challenges faced by the learning institutions, educators and learners. STEM subjects are overwhelmingly becoming the most popular subjects in the modern world as drivers of the solution to the current global challenges. For instance, addressing Sustainable Development Goals (SDGs) **4**, climate change issues**5**, world economy recession challenges, global social and environmental problems caused by the burgeoning world population, all depend on well-educated global population in Science, Technology, Engineering and Mathematics to build a better and more sustainable future for all through Free and Open Source Software (FOSS), humanitarian computing and computing education. Education in STEM subjects is accentuated as a critical global need. Globally, there is a massive shortage of professionals in STEM areas **6**, evident by critical STEM skills positions remain unfilled in both emerging and developed countries. According to **6**, the sub-Saharan Africa region faces a crippling shortage of 2.5 million more engineers to address the continent's gravest development problems. Such shortages are attributed by several challenges including scarcity of graduates with STEM soft skills, lack of qualified technicians, loss of high skilled STEM professionals, untapped pools of STEM talent, limited STEM training infrastructure and human capital in learning institutions and limited funding of STEM subjects**7**. **8** states that Africa's future depends on STEM education but the continent does not have a robust strategic plan on STEM policies, a clear framework for implementing and standardizing the STEM curriculum. Therefore, to counter these challenges, the sub-Saharan countries must invest in STEM education and training in order to realize social, economic, and infrastructural transformation. A tentative step towards such transformation is to infuse computer programming in the primary and secondary curriculum to incentivize STEM innovation and inspiring STEM culture, thereby equipping pupils with software programming skills. For instance, South Korea as one of the most successful stories of economic development through STEM managed to increase STEM students' enrolment and graduates through STEM educational programs and initiatives**9**. STEM education supports logical and conceptual connections across different STEM fields which allow curriculum and pedagogical coherence across different STEM subjects. In support of STEM education, the University of California developed a full option science system and free and open source software**4** to improve learning and teaching of science. Free and open source software (FOSS) is computer software that allows the source code to be available to the general public for free and for use-as-is and code reuse**10**.

Such educational technology advancement can be explored in the primary and secondary curriculum as it supports customization of instructional materials at different levels of learning as well as different learning cognitive styles to adapt to student responses. If appropriately adopted and supported, FOSS has the potential to

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provide multifarious computer programming learning and teaching experiences such as online instruction, online simulations, collaborative virtual classes, innovative pedagogical strategies and online tutoring videos as well examples. These experiences help learners and educators to simulate real-world content and scenarios, and to provide them with hands-on lab simulations that probably stimulate students' passion and engagement in the STEM field. Such experiences pose unprecedented opportunities in STEM-related content for learners to comprehend how the STEM disciplines work together in addressing community problems for sustainable development. This can be achieved through the infusion of computer programming in primary and high schools as part of the schools' curriculum. Computer programming is a necessity and becoming paramount important to address the rapidly increasing gap between the need and availability of programmers**11**.For instance, in some parts of the world such as England (leading pack), Finland, Estonia, Bulgaria, Cyprus, Czech Republic, Denmark, Greece, Ireland, Italy, Lithuania, Poland, Portugal and Australia computer programming(coding) and digital literacy has become an essential element of modern education in primary and high schools **12**. Computer coding is introduced to primary schools for all children between the ages of 5 and 16 to culminate them in learning simple Boolean logic and computer operations **11**, **12**.This helps learners to build mastery in sequencing skills, programming skills**13**, counting, problem-solving, logical thinking, cause and effect, critical thinking and to stimulate their passion in STEM subjects at a tender age.

R is an interactive programming language for statistical analysis, data science, machine learning, graphical representation and reporting. R-programming language was developed at the University of Auckland in New Zealand by Ross Ihaka and Robert Gentleman**14**. R is the important open-sources software used to solve difficult issues arising from various fields including computational statistics and hard sciences. Unlike other programming languages which contain abstract concepts, challenging syntax and semantics**15**, R has more 5,000 packages (libraries of functions) which assist learners to simulate several codes at a beginners level**16**. R is platform independent, easy to use, solely free and open source which means anyone can contribute and fix bugs. The introduction of R-programming in high schools helps learners to accept computer programming as scientific doable subject and stimulate them to pursue computer programming as a carrier. Its integration in the high school curriculum at early stages is considered valuable in laying sound programming foundation using robust and ease of use programming languages such as R. This helps learners to stimulate their passion because computer programming is perceived as a difficult subject**1718** and results in low self-efficacy**19**.

1.1 Research Context

The study was conducted in the Kingdom of Eswatini through the Ministry of Education and Training (MoeT). A policy from the Ministry of Education and Training **20** state that the country's education and training system is divided into categories namely: early childhood care and development (ECD), primary education, secondary and tertiary education. The study focuses on secondary education which is divided into two categories namely; junior secondary education to the end of Form3 and senior secondary education from Form 4 to completion- lays the foundation for entry into appropriate vocational and tertiary paths**21**. STEM subjects are rigorously taught at the secondary level to provide equitable access for all learners to quality secondary education that adequately prepares them for further technical, vocational and tertiary education. According to**22**, the curriculum in high schools follows the University of Cambridge's International General Certificate of Secondary Education (IGCSE) standards and the Eswatini International General Certificate in Education (SIGCE) standards to measure students' performance.

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University of Eswatini (UNESWA) established a Centre for Community Services (CCS) to facilitate the provision of quality and relevant community services and the integration of community services as a core function of UNESWA. The Department of Computer Science (DCS) in collaboration with the Centre for Community Services support the integration of community service learning programmes and curricula in Science, Technology, Engineering and Mathematics (STEM). They are using the ICT community outreach programme to support learners and teachers in high schools by providing R-programming training through the state-of-the-art simulation environment (First National Bank Cyberspace). As a way of complimenting the idea, several programming activities have been established such as the Lego League Robotics Challenge (LLRC) and Girls Got Game Coding Camp through STEM Foundation, GLOW Eswatini and Information and Communication Technology (ICT) Fair event to promote, spread and creation of STEM awareness throughout the country especially in rural areas to bridge existing technological disparity between rural and urban schools **23**, **24**. The aim of this study is to investigate the adoption and use of Free and Open Source Software in teaching and learning R-programming language in high schools. The objectives of the study are to assess the benefits and challenges encountered by learners and educators when using FOSS in learning and teaching computer programming languages in high schools and to investigate factors influencing the adoption of FOSS in learning and teaching computer programming languages in high schools.

2.0 Literature Review

Computer programming has been found to be a very difficult subject for beginners**17**. The adoption of computer programming is increasing exponentially with constant practices. Programming teachers usually provide learners with several programming exercises and assignments to enable them to have more practical knowledge. Manual inspection of programming lines of code on paper is notoriously inefficient and error-prone. Thus, the assessment of programming exercises and assignments becomes very tedious. However, this practice is academically disadvantageous since students have to wait for a while before getting a response from the teacher. In order to ensure real-time engagement of students and teachers,**25** developed an automated web-based programming assignment assessment system (PASS) to improve teaching and learning of computer programming. Lecturing and learning computer programming is demanding but a thoroughly planned method and mode of teaching could make the teaching effective. Nevertheless, the conventional way of teaching creates some restrictions on knowledge and skills transfer. In addition to this, some teaching and learning methods are strenuous to apply when teaching computer programming in a standard classroom, therefore, learners probably find it difficult to grasp advanced programming model except with constant practice. To counter that, blended learning merges several teaching and learning methods to increase learner's knowledge while capacitating educators and learners through the provision of conducive teaching and learning environment online or offline. For instance, PASS allows courses to be blended so as to facilitate effective and productive learning and teaching computer programming. Moreover, it is relatively hard to supervise or observe each student's improvements in conventional teaching mode since most programming classes are usually large. PASS offers resourceful and helpful information on student's performance, slow learners can be easily identified and helped. In programming, instructors inspired exceptional students to render help to their colleagues, which helps other students to improve themselves.

Blended learning is a superset of e-learning and face-to-face learning as shown in Figure 1. E-learning comprises of both network-based learning (online learning, In-

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ternet-based learning, and Web-based learning) and non-network-based learning (computer-based learning).

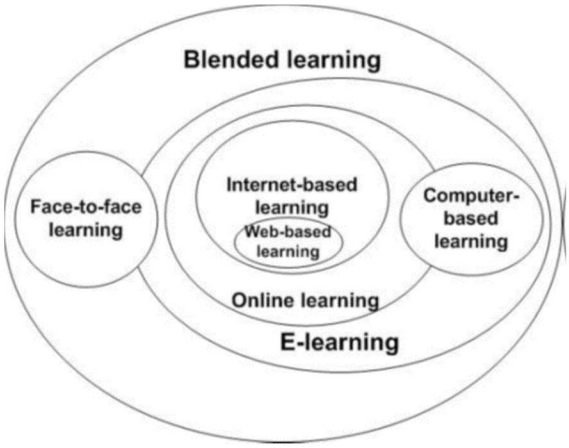

Figure 8: Components of Blended Learning

Blended learning can be used for teaching programming based on the use of learning theories, educational design framework and through blended learning teaching platforms tools. Some researchers employ a collaborative learning approach to improve the teaching of programming from a programming perspective**26**,**27**. As there is an increasing need for blended learning systems, efforts have been continuously devoted to the research of blended learning**25**. Globally, a number of blended learning platforms have been developed to support collaborative learning, remote access to learning material, self-paced independent study, live virtual classrooms and real-time assessment of students' performance. Blackboard academic suite, Moodle and Web Course Tools are well-developed blended learning platforms that have been widely used and extensively adopted by various educational institutions to facilitate interactions between students and educators, and to create a dynamic learning environment while reducing geographical barriers **28**,**29**,**30**. Blended learning provides tremendous benefits including minimization of paper usage, ability to improve students' creativity, remote access to learning material, online code testing and online real-time simulations. However, many students drop out from online courses due to some factors such as lack of motivation, instructional design-related factors and mismatch of learning cognitive styles, time conflicts with other commitments, organizational support and lack of follow-up.

E-learning platforms are interactive learning system designed for learners, teachers, collaborators and researchers who want to learn, teach, communicate, collaborate and grade tasks automatically with feedback via the internet with intelligent support for the learning process. E-learning platforms are commonly viewed from two perspectives namely; e-learning assessment and teaching platforms. There are many studies on e-learning assessment platform for programming pedagogy but few studies on e-learning teaching platform**31**,**32**.Some researchers believed that programming skills should not only be acquired by computer scientists and computer science students but should also be taught at primary and high school**33**. In the field of computer science, the teaching of programming is widely achieved through the use of constructivism than cognitivism and behaviourism**33**. Teaching computer programming is considered to be difficult and often ineffective. For this reason, various approaches were proposed and tried with lack of convincing success **34**,**35**. They included computer games as the subject of programming to augment the involvement of students, either at an initial**36** or later stage of course.

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Computer programming is a complex subject that cannot be taught through explanation alone, and several constructivist approaches to teaching the discipline have been implemented. One such approach is Wiki **37**, which places the onus on the student to learn through practical experimentation and in collaboration with peers. Lecture-style teaching is reduced to a minimum and the tutor's role defined as a "guide on the side". The e-learning teaching tools that have been used for teaching programming are Nooblab, code academy, Colab, Khan Academy, Treehouse, Code School, Udacity, USACO, j-LATTE, CPP-tutor, APT**32**,**38**. Macedonia Electronic competitions and National Olympiads (MENDO) system are also designed for teaching programming and data structures with the ability for teachers to add practical interactive features infinitely and automated grading for programming tasks in Macedonia**38**. According to**39**, Codeacademy is the only e-learning teaching platform specifically for computer programming with gamification features.

According to **40**, e-learning assessment tools for programming assessment are web-based platforms, and the most commonly used is the Automated Assessment Tools (AATs). The AATs are used for grading or assessing students' source code or computer program based on criteria given by the instructor or the teacher or lecturer. AATs also provide automatic qualitative feedback on programming style such as the validity of a variable name, the proper use of comments, indentations and so on. The AATs tools are very useful in a scenario where the student's computer programs are many to be graded. The benefits of AATs include speed, availability, consistency and objectivity assessment. Examples of AATs are PASS, ASAP, TRY, ASSYST, BOSS, RoboProf, Course Marker and WebCAT**33**.

3.0 Methodology

The pilot study used quantitative methodology to conduct the research. The sampling method used was the stratified random sampling to divide schools into strata, and then randomly select students in each strata to participate in the study. Three schools participated in the study are Ka-Zakhali Private school, Swazi National High school and Lozitha High school. A sample size of 38 high school students in Form1 to Form 5 in both public and private schools participated in this study. A closed-ended questionnaire was used to collect quantitative data from the sample through the help of teachers and the principals of the three schools. The Statistical Package for Social Sciences (SPSS) was used to analyse quantitative data and findings are presented in form of tables with the following descriptions.

4.0 Potential benefits of FOSS

According to**41**, reliability, cost, scalability, accessibility, education, research and security are the paramount benefits of FOSS in teaching and learning. The major driving force behind integrating FOSS in teaching and learning computer programming is to reduce the cost of buying and maintain commercialized software. In support of FOSS in application development, **42**,**43** state that FOSS-based application development model increases productivity and security and risk, ultimately reducing the cost of purchasing commercialised licensed software development platforms. FOSS supports customisation and location of teaching material to suit the needs of the learners and educators. FOSS also plays an important role in bridging the digital divide by providing low-cost applications that have the ability to localize content, particularly in developing countries. FOSS bridges digital divide between the urban areas, rural areas and underserved schools by providing low-cost applications especially in developing countries where there is gross inequitable access to computing devices, lack of enough STEM human capital due to brain drain and misdistribution of ICT infrastructure between public and private schools**444546**

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4.1 Results Analysis

Demographic Information

The study sought to establish the demographic information of the respondents in terms of gender distribution, school name and types of school as in Table 1 to 3.

Table 1: Gender distribution

Gender	Frequency	Percentage
Male	22	57.9
Female	16	42.1

Table 1 shows that the respondents were mainly males (51.9%), though a good number of females (42.1%) participated in the survey.

Table 2: School Distribution

Name of School	Frequency	Percentage
Ka-Zhakali High School	14	36.8
Lozitha National High School	8	21.1
Swazi National High School	16	42.1

Table 2 shows that the respondents were from three schools and 36.8% are from Ka-Zhakali High School while 21.1% and 42.1% are from Lozitha and Swazi national high school respectively that participated in the survey.

Table 3: Types of School distribution

Type	Frequency	Percentage
Private	14	36.8
Public	24	63.2

Table 3 shows that the respondents were mainly students from public schools (63.2%) while the remaining 36.8% are from the private school that participated in the survey.

Table 4: Mean Distribution

Attributes	Mean
Gender	1.4211
Name of school	2.0526
Type of School	1.3684

Table 4 shows that the mean for the three attributes considered in the demographics for respondents were 1.4211 for gender, 2.0526 for the name of school and 1.3684 for the type of school participated in the survey.

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4.2 REGRESSION

Table 5: Model Summary

Model	R	R Square	Adjusted R Square	Std. The error of the Estimate
1	.871(a)	.758	.585	.28256

a Predictors: (Constant), Q15E, Q15C, Q15D, Q15B, Q15A

Results in Table 5 indicate that the availability of enough computers in private and public schools for teaching and learning computer programming will enhance the Adoption of FOSS for STEM subjects' by75.8%. Now, since there exists a significant relationship, we can use a regression analysis to find a model that relates the independent variables (student's competence in programming skills, student's motivation in computer programming, student's eagerness to pursue STEM subjects, students higher order and student's thinking skills) and dependent variable (Availability of enough computers for teaching and learning computer programming) based on the hypothesis stated.

Table 6: ANOVA(b)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.749	5	.350	4.381	.040(a)
	Residual	.559	7	.080		
	Total	2.308	12			

a Predictors: (Constant), Q15E, Q15C, Q15D, Q15B, Q15A

b Dependent Variable: Q6

Results in Table 6 shows that the overall model equation in equation (1) is statistically significant (p-values < 0.05)

Table 7: Coefficients (a)

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta	B	Std. Error
1	(Constant)	-1.875	.980		-1.913	.097
		.279	.170	.382	1.648	.143

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	Q15A					
	Q15B	-.102	.196	-.111	-.518	.620
	Q15C	.697	.280	.597	2.487	.042
	Q15D	-.042	.211	-.042	-.197	.850
	Q15E	.134	.168	.158	.799	.451

a Dependent Variable: Q6

Results in Table 7 indicate the coefficients for the independent variables (student's competence in programming skills, student's motivation in computer programming, student's eagerness to pursue STEM subjects, students higher order and student's thinking skills) and the constant of the model.

Availability of enough computers for teaching and learning computer programming=AECTL
Students' competence in programming skills=SCPS
Students' motivation in computer programming=SMCP
Students' eagerness to pursue STEM subjects=SEPSS
Students' higher order=SHO
Students' thinking skills=STS

The model equation is given as:
AECTL=0.279*SCPS - 0.102*SMCP+0.697*SEPSS -0.042*SHO+0.134*STS -1.875 (1)
The results are significant since P-values < 0.05.

Table 8: Model Summary

Model	R	R Square	Adjusted R Square	Std. The error of the Estimate
1	.779(a)	.607	.326	.70196

a Predictors: (Constant), Q15E, Q15C, Q15D, Q15B, Q15A

Results in Table 8 indicate that the use of the commercialized/proprietary software is common in private and public schools for teaching and learning computer programming and this will not enhance the Adoption of FOSS for STEM subjects by 60.7%. Now, since there is no significant relationship existing, we can use a regression analysis to find a model that relates the independent variables (student's competence in programming skills, student's motivation in computer programming, student's eagerness to pursue STEM subjects, students higher order and student's thinking skills) and dependent variable (use of commercialized/proprietary software for teaching and learning computer programming) based on the hypothesis stated.

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Table 9: ANOVA(b)

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	5.320	5	1.064	2.159	.172(a)
	Residual	3.449	7	.493		
	Total	8.769	12			

a Predictors: (Constant), Q15E, Q15C, Q15D, Q15B, Q15A

b Dependent Variable: Q7

Results in Table 9 shows that the overall model equation in equation (2) is not statistically significant (since p-values are not less than 0.05)

Table10:Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta	B	Std. Error
1	(Constant)	-.418	2.435		-.172	.869
	Q15A	-.363	.421	-.254	-.861	.418
	Q15B	1.359	.487	.764	2.790	.027
	Q15C	.421	.697	.185	.605	.564
	Q15D	-.194	.525	-.100	-.370	.723
	Q15E	-.542	.417	-.329	-1.300	.235

a Dependent Variable: Q7

Results in Table 10 indicate the coefficients for the independent variables (student's competence in programming skills, student's motivation in computer programming, student's eagerness to pursue STEM subjects, students' higher order and student's thinking skills) and the constant of the model.

Use of commercialized/proprietary software =UCPS
Student's competence in programming skills=SCPS

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Student's motivation in computer programming=SMCP
Student's eagerness to pursue STEM subjects=SEPSS
Student's higher order=SHO
Student's thinking skills=STS

The model equation is given as:

UCPS = -0.363*SCPS + 1.359*SMCP+0.421*SEPSS -0.194*SHO - 0.542*STS -0.418 (2)

The results are not significant since P-values are not less than 0.05.

Table 11: Model Summary

Model	R	R Square	Adjusted R Square	Std. The error of the Estimate
1	.812(a)	.660	.417	.21182

a Predictors: (Constant), Q15E, Q15C, Q15D, Q15B, Q15A

Results in Table 11 indicate that the interest in computer programming in private and public schools will enhance the Adoption of FOSS for STEM subjects by 66%. Now, there is no significant relationship existing, we can use a regression analysis to find a model that relates the independent variables (student's competence in programming skills, student's motivation in computer programming, student's eagerness to pursue STEM subjects, students higher order and student's thinking skills) and dependent variable (interest in computer programming) based on the hypothesis stated.

Table 12: ANOVA (b)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.609	5	.122	2.714	.113(a)
	Residual	.314	7	.045		
	Total	.923	12			

a Predictors: (Constant), Q15E, Q15C, Q15D, Q15B, Q15A

b Dependent Variable: Q8

Results in Table 12 shows that the overall model equation in equation (3) is not statistically significant (since p-value is not less than 0.05)

Table 13: Coefficients(a)

Mod		Unstandardized	Standardized	t	Sig.

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el		Coefficients		Coefficients		
		B	Std. Error	Beta	B	Std. Error
1	(Constant)	-1.520	.735		-2.068	.077
	Q15A	.002	.127	.005	.018	.986
	Q15B	.090	.147	.156	.613	.559
	Q15C	.427	.210	.579	2.032	.082
	Q15D	.173	.158	.274	1.094	.310
	Q15E	.109	.126	.203	.863	.416

a Dependent Variable: Q8

Results in Table 13 indicate the coefficients for the independent variables (student's competence in programming skills, student's motivation in computer programming, student's eagerness to pursue STEM subjects, students higher order and student's thinking skills) and the constant of the model.

Interest in Computer Programming =ICP
Student's competence in programming skills=SCPS
Student's motivation in computer programming=SMCP
Student's eagerness to pursue STEM subjects=SEPSS
Student's higher order=SHO
Student's thinking skills=STS

The model equation is given as:

ICP = 0.002*SCPS + 0.090*SMCP+0.427*SEPSS + 0.173*SHO + 0.109*STS -1.520 (3)

The results are not significant since P-value is not less than 0.05.

Table 14: Model Summary

Model	R	R Square	Adjusted R Square	Std. The error of the Estimate
1	.475(a)	.226	-.328	.43270

a Predictors: (Constant), Q15E, Q15C, Q15D, Q15B, Q15A

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Results in Table 14 indicate the use of a personal computer at home or in school in private and public schools for computer programming is far below 50%(22.6%), so it will have a negative effect on the Adoption of FOSS for STEM subjects. Now, there is no significant relationship existing, we can use a regression analysis to find a model that relates the independent variables (student's competence in programming skills, student's motivation in computer programming, student's eagerness to pursue STEM subjects, students higher order and student's thinking skills) and dependent variable (use of personal computer at home or in school for computer programming) based on the hypothesis stated.

Table 15: ANOVA (b)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.382	5	.076	.408	.830(a)
	Residual	1.311	7	.187		
	Total	1.692	12			

a Predictors: (Constant), Q15E, Q15C, Q15D, Q15B, Q15A

b Dependent Variable: Q9

The results are not significant since P-value is not less than 0.05.

Table 16: Coefficients (a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta	B	Std. Error
1	(Constant)	2.242	1.501		1.494	.179
	Q15A	.266	.260	.424	1.023	.341
	Q15B	-.142	.300	-.182	-.473	.651
	Q15C	-.366	.429	-.366	-.852	.422
	Q15D	-.081	.323	-.094	-.250	.810
		-.017	.257	-.024	-.067	.948

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	Q15E					

a Dependent Variable: Q9

Results in Table 16 indicate the coefficients for the independent variables (student's competence in programming skills, student's motivation in computer programming, student's eagerness to pursue STEM subjects, student's higher order and student's thinking skills) and the constant of the model.

Use of Personal Computer at home or school =UPCHS
Student's competence in programming skills=SCPS
Student's motivation in computer programming=SMCP
Student's eagerness to pursue STEM subjects=SEPSS
Student's higher order=SHO
Student's thinking skills=STS

The model equation is given as:

UPCHS = 0.266*SCPS - 0.142*SMCP-0.366*SEPSS - 0.081*SHO + 0.017*STS +2.242 (4)

4.1 Factors influencing the adoption of FOSS in learning and teaching computer programming languages in high schools

Lack of computing infrastructure and equipment such as computers, laptops and tablets in both public and private schools in developing countries is a major drawback to make FOSS a success. Many schools in developing countries do not have adequate computers if not none, to teach pupils modern computing technologies including computer programming**47**. **48** further highlighted that the cost associated with acquiring computing infrastructure is very high in developing countries.

Unavailability of electricity in some rural areas influences the adoption and use of FOSS for teaching and learning purposes. Even though students are willing to pursue computer programming but without electricity to power up computers it would not be successful. The adoption and use of computer programming remain elusive since some schools are not yet powered in developing countries despite the apparent benefits of FOSS**4950**. The cost of acquiring power and electrification equipment is relatively high**51**, and it can affect the implementation of FOSS in teaching and learning computer programming in schools.

Unavailability of internet access in schools can be detrimental to FOSS since it supports collaborative learning through virtual classrooms online. Computer programming reading material should be readily accessible online to help students to study and practice programming anytime**5253**. To ensure that all schools get access to the internet, the authorities can advocate for free access to the internet to schools located in resource-constrained areas and then charge a relatively low-cost to schools located in urban areas to avoid digital divide and imbalance access to knowledge. Lack of FOSS training programs to train educators to teach computer programming can be a major to the adoption of FOSS in schools. Computer programming languages evolve, therefore, frequent training of teachers is needed to ensure that they upgrade computer programming skills to avoid resistant to change.

Incorporating computer programming in high school curriculum is another paramount factor that needs to be considered when adopting FOSS in teaching and learning computer programming. Teachers also need to learn appropriate pedagogies for delivering STEM subjects, particularly in those aspects of computer science that relate to algorithms, programming and the development of computational thinking skills**54**. The Ministry of Education and other interested stakeholders can make an effort to incorporate computer studies in the primary and secondary curriculum to

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stimulate pupils to pursue STEM subjects, thereby upgrading Eswatini's education and training policy. According to **55**,**56**, all stakeholders need to be consulted and participate in policy debate to increase the chances of making a successful policy. Consultations of regulatory authorities and potential stakeholders can increase chances of supporting the idea by knowing the views, perceptions and attitudes of the concerned stakeholders. Once computer studies are included in the curriculum, then computer programming will be included in the syllabus.

5.0 Conclusion

Computer programming is an important skill in the digital world and it is changing drastically and irrevocably especially in STEM subjects. Besides the factors influencing the adoption of computer programming using FOSS, students in high schools have passion to pursue and incorporate computer programming in learning STEM subjects. The introduction of computer programming in secondary school curriculum should be a joint and collective effort between all interested stakeholders including the government authorities, the Ministry of Education and Training, teachers, learners, higher learning institutions and also captains of the industry to ensure smooth adoption and implementation. STEM teachers should be properly trained to upgrade their programming skills and to avoid resistance to technology adoption. According to**57**, teachers' feelings, knowledge and attitudes influence the adoption and use of ICT in teaching. Teachers and schools need support from the government authorities especially MoeT to provide them with ICT infrastructure**2021** to make the adoption and use of Free and Open Source Software in teaching and learning of STEM subjects in high schools using R-programming a success.

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QUESTIONNAIRE

Instructions:

Kindly answer the following questions fully by either ticking the appropriate response in one of the boxes provided. Do not write your names anywhere in this questionnaire. Please be as honest as possible.

Section A: Complete The Following

HOSPITAL: _____

NO OF WORKERS: _____

DEPARTMENT: _____

POSITION: _____

DATE: _____ **SIGN:** _____

Section B: Demographic Information

2. Gender Male ( ) female ( )

2. Please indicate the highest level of education attained? (Tick as applicable)

College Diploma [ ]

Undergraduate [ ]

Master [ ]

Others (specify) ……...

3. Indicate your period of service in this institution

Below 2 years ( ) 3 to 5 years ( ) 6 to 8 years ( ) 9 years and above ( )

Section C: Factors Influencing Adoption of ICT

4. Indicate your level of agreement with the following statements relating to the Level of ICT Adoption in Government Hospitals in Nigeria. Use a scale of 1-5, where (1= Strongly Disagree, 2= Disagree, 3= Moderately Agree, 4= Agree, 5= Strongly Agree)

S/N	COST OF EQUIPMENT AND TRAINING	1	2	3	4	5

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1	The cost of ICT training materials is considered to be one of the problems that negatively affects the implementation of ICT in most health facilities					
2	The migration to electronic medical records is necessitated by savings in expenditure.					
3	Paper-based systems in hospitals have limited functionality; many people cannot easily view the same record at the same time, thereby reducing productivity and efficiency of employees.					
4	Electronic medical records, support medical professionals in their decision-making leading to improved medical care quality					
5	E-Health can be one solution to provide better access to healthcare facilities for patients					
6	The availability of skilled personnel will boost quality healthcare					
7	Government policies positively affect E-Health adoption in Government owned hospitals in the FCT					
8	The level of industry support will positively influence the adoption of ICT in Government owned hospitals in FCT, Abuja					

5. To what extent do you agree with the following statements on training and adoption? Use a scale of 1-5, where (1= strongly disagree, 2= disagree, 3= moderately agree, 4= Agree and 5= strongly Agree)

S/N	Training and Adoption	1	2	3	4	5
1	Members of the institutions are lacking in specialized IS knowledge and technical skills.					
2	The higher IS capabilities the staff have, the higher their potential in the use of information systems					
3	In order to facilitate the successful implementation of information system in hospitals, the government should provide employees with computer education and training courses.					

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4	The lack of knowledge on how to use technology affects the adoption of ICT in hospital.					
5	Many public hospital are lacking technical abilities on the adoption of ICT					
6	Public hospital are lacking management skills on the adoption of ICT					
7	If employees in health institutions have more knowledge of information systems, then they will be more likely to adopt the information systems.					

6. To what extent do you agree with the following statements on ICT Infrastructure? Use a scale of 1-5, where (1= strongly disagree, 2= disagree, 3= moderately agree, 4= Agree and 5= strongly Agree)

S/N	ICT Infrastructure	1	2	3	4	5
1	Despite the immense benefits of ICTs as a means of delivering quality health care services, the potential of ICTs have not been fully harnessed by health professionals					
2	Communication for health purposes has shifted from the largely manual or physical documentary method to digital communication					
3	Internet has become an important component of the electronic services in health institutions.					
4	In spite of the potential contributions of ICTs to the activities of health workers, some constraints exist that prevent their widespread utilization					
5	Physical access to ICT is a major constraint to public hospitals.					
6	Cost of installation of ICT infrastructure is a major drawback to the adoption of ICT.					
7	That computers phones were in use in all the teaching hospitals but not much Internet connectivity was available, meaning that most of the medical experts used external					

7. To what extent do you agree with the following statements on ICT staff attitude? Use a scale of 1-5, where (1= strongly disagree, 2= disagree, 3= moderately agree, 4= Agree and 5= strongly Agree)

S/N	ICT Staff Attitude	1	2	3	4	5
1	The impact of staff attitude is extensive in health institutions where it is manifested in concepts					

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	such as the way things are done					
2	The attitude of the developer of the ICT that is used in an organization affects the performance of organizations					
3	The attitudes of the user of ICT in the hospitals affect the performance of the organization(s).					
4	ICT adoption attitude is shared by the employees of a health institution involved in information activities.					
5	ICT adoption attitude resist technologies which threaten to change the working habits, especially when they employees violate some of the groups‟ shared values.					
6	The way people perceive the usefulness of a given ICT will be impacted by the existing national attitude					
7	IS culture is more or less compatible with certain forms of IT; when that is the case, the result can be resistance to IT changes					

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Learning Management Systems: The Nigerian Students Experience

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Abstract — This study focuses on trying to understand the Nigerian student's experience of using an eLearning application called Canvas. This study focuses on three main elements, course quality, technological aspects and instructor influence as factors that influence Nigerian student's experience of using Canvas. A paper-based survey was used to collect responses from 12 students participating in an Information Systems course. The results showed that all three elements contribute towards the student's positive experience in using the system and that the students rated the instructor's influence as the most significant contributor towards their use of the application. The functionality of the system (technology aspect) was the next significant factor followed by the course content. The study contributes to the existing body of knowledge of eLearning use by students in developing countries specifically in Nigeria. The results from this study can be used by educators and administrators of Nigerian higher education institutions as a guide for policies and best practices.

***Index Terms*—Learning management systems, students experience, eLearning, Nigeria.**

INTRODUCTION

The internet and its associating technologies have brought about new methods of education and training which aim at enabling learners to efficiently and effectively achieve learning outcomes. These technologies facilitate access to resources as well as assist in the management of the learning process.

The use of technology for teaching and learning is known as eLearning. eLearning leverages on the internet to facilitate access to learning curriculum and also to support pedagogies such as blended learning and the flipped classroom. There are numerous benefits to be gained by students and instructors by using eLearning systems, easy access to resources, reduced costs, efficiency, and flexibility are some of the identified benefits of adopting eLearning. eLearning is an important tool as it has the potential to restructure the traditional teaching and learning methods, especially in developing countries.

In developed countries like the United Kingdom and the United States of America, the use of technology for teaching and learning has evolved. In a bid to keep up with the recent trends in teaching and learning, developing countries introduce these technologies which can result in a culture shock to both instructors and students; this eventually leads to rejection and misuse of the technologies.

This study focuses on trying to understand the student's experience of using an eLearning application called Canvas. A paper-based survey distributed to a single class of a private university in Nigeria, the responses once collated, were used to inform this study on some of the perceptions that the students have about the use of eLearning for their studies. The study focuses on three important factors (course quality, instructor's influence, and technology aspects) that can affect the students learning experience. This research aims at contributing to the existing body of

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knowledge within the context of eLearning in developing countries and specifically in Nigeria.

Literature Review

eLearning is simply the use of technology for teaching and learning. It involves various types of technology that can be used to aid instruction and learning.

ELearning tools include 1) eLearning technologies, 2) learning content management systems (LCMS) also known as learning management systems (LMS), and 3) eLearning authoring tools. ELearning technologies comprise of a group of devices and services that can be used aid instruction and learning. Examples are Projectors, Laptops, Cloud Services, Mobile Devices, and the Internet. The authoring tool and LMS usually rely on these technologies for their functionality. Án LMS is a software application that enables schools to administer courses online. It allows for resource distribution, discussions, students testing and progress tracking. Authoring tools as the name implies are used to develop and publish content to be used for eLearning. Authoring tools work together with LMS' as the LMS provides a platform to host the developed content. The focus of this study is based on a learning management system known as Canvas.

There have been very few studies that have investigated eLearning in Nigeria. The few studies identified fall into two categories. Category 1 highlights the challenges faced by universities in implementing eLearning [1] and category two studies the factors that affect the adoption of eLearning, see [2] and [3]. Thus there is a need for further literature on the challenges and experience with regards to the use of eLearning in Nigerian universities.

According to Gilbert, Morton, and Rowley [4], there are

Table 1. Grouping of factors derived from IS theories.

Original factors derived from IS theories	Theory	Corresponding factors in the context of eLearning systems	Groupings
Facilitating conditions/ Service Quality	UTAUT/DeLone and McLean IS Success Model	Facilitating conditions	Technology Aspects
Effort Expectancy/Perceived Ease of Use	UTAUT/TAM	Effort Expectancy/Perceived Ease of Use	
Performance Expectancy/ Perceived Usefulness	UTAUT/TAM	Performance Expectancy/ Perceived Usefulness	
System Quality	DeLone and McLean IS Success Model	System Quality	
Information Quality	DeLone and McLean IS Success Model	Course Quality	Course Quality (Content and Design)
Social Influence	UTAUT	Instructors Influence	Instructors Influence

a few frameworks used to inform eLearning practice, and these frameworks identify factors that contribute to providing quality eLearning experiences. Some of these factors include technology and pedagogy [5, 6, 7], instructor quality and course content [8]. Other factors such as social influence [9], [10], and [11], perfor-

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mance expectancy and effort expectancy [3] have all been proven to influence student's usage of eLearning systems.

The factors mentioned above are derived from prominent theories used to explain the acceptance of technology. Theories such as the unified theory of acceptance and use of technology (UTAUT) [12, 13], Technology acceptance model (TAM) [14], and the DeLone and McLean Information Systems Success models [15, 16] have been used extensively in the study of students' acceptance of eLearning systems.

Yakubu and Dasuki [3] and Lwoga [17] both adapted the DeLone and McLean Information Systems Success models to try and understand the factors responsible for the acceptance of eLearning systems by students. Similarly, UTAUT has been used by several researchers in the study of student's acceptance of learning management systems see [18, 19, 9, 10, 20]. TAM, being one of the most applied theories in the domain of technology acceptance, has been applied to different types of technologies. In the context of eLearning systems, TAM has also been used extensively see:
[21, 11, 23, and 24].
Based on a review of literature, Table 1 shows, the factors derived from IS theories and used in the context of eLearning acceptance by students. They can be grouped into three categories, i.e., technological aspects, course quality, and instructors influence. These factors are the collection of an individual's perceptions of the use of the technology being studied. Social influence as defined as "the degree to which an individual perceives that important others believe he or she should use the system" [13]. Cheng [17] identified instructors or tutors as having a great influence on the use of technology for learning. Similarly, Lwoga [17] showed that the impact of instructors on

students significantly influences their perceived usefulness of a learning system. The instructor's influence is therefore grouped under the social influence category. Information quality is a measure of the information systems output [15]. It corresponds to course quality as used by several authors in the context of eLearning systems by replacing the information quality construct derived from the DeLone and McLean IS success model [25, 26, 27]. The technological aspects include the applicable properties of quality software as defined by Jalote [28]. These qualities include functionality, reliability, usability, and efficiency

Majority of the studies that adopted these theories were based on a quantitative approach and as such did not provide an in-depth reason as to why students use eLearning systems. Yakubu and Dasuki [20] called for either a qualitative a mixed method approach to provide a better understanding of the acceptance of the systems by students.

METHOD

The data collected in this research was obtained from students participating in a single section of a course at the American University of Nigeria. All the students were at the same level, i.e., 1st-year undergraduate students (first-year students) and participated in the same course named: Principles of information systems. The choice of using one class was to ensure that responses to the questions about the influence of the instructor were not affected by the differing views students have towards different instructors.

Responses were collected using a paper-based survey. As the freshmen are all new to the University, it is very likely that this is their first time using an eLearning system. Thus the survey was administered towards the end of the semester to ensure that the students have gained some experience using Canvas LMS.

The survey was distributed to the students by the staff of the office of institutional

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research and effectiveness as part of their end of semester faculty course evaluation to ensure that teaching activities meet the university's target of academic excellence. During the assessment process, the instructor is asked to leave the classroom to ensure anonymity and to make sure that the students are not influenced as they fill in the assessment forms.

The survey was made up of a mixture of open-ended questions and Likert-scale type questions. The questions were grouped into four sections which aimed at gathering responses related to the functionality and quality of the LMS application (Canvas LMS), the course content and design, the instructor's influence on the students in using the LMS application. The final question tries to capture general feedback from the students on their use of the LMS.

Tabular and graphical representations were used to analyze the qualitative data while content analysis was used to interpret the responses from the open-ended questions.

Technology Aspects Questions

With regards to the questions relating to the technology used by the students, i.e., Canvas LMS, three questions were asked. The first question asked the students to list the most useful functions of the LMS in their studies while the second question required the students to list the least useful functions of the LMS to their studies. The final question was open-ended and asked the students what is it about the LMS that makes it enjoyable to use.

Course Quality Questions

Course quality assesses the learning resources with an emphasis on relevance, up-to-date content, and flexibility. There were three questions relating to the course design. The first question asked the following three sub-questions about the modules that made up the course:

1. The modules used in the course are well arranged.
2. I followed the module step by step as arranged by the instructor.
3. The content in the modules was up to date and relevant

These questions were structured in a 5 point Likert scale format with the following responses: strongly agree, moderately agree, neutral, moderately disagree, and strongly disagree.

Similarly, the second question in the content and design section used a Likert scale to gather responses about the students' use of the learning objectives. The questions were"

1. Approximately how much of the learning objectives within the modules did you study thoroughly?
2. Approximately how much of the learning objectives within the modules did you print out or download?

The available responses were: none, very few, some, most and all.

The final question about the course quality section was open-ended and asked the students what aspects of the course structure and resources did they like?

Instructors Influence Questions

There were three questions related to the instructor's influence on the student's use of the LMS. The students were expected to rate the instructor based on response times and the level of support via the LMS as guided by prior research [8, 17].

1. How would you rate your instructor based on response time to your queries?
2. How would you rate your instructor based on the level of support you received during the course?
3. How has your instructor improved your learning experience using Canvas?

The options available for selection for the three questions were excellent, good, satisfactory, and poor.

General Questions

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The general questions section contained two questions. The first question asked the students to order the factors that influence the students to use Canvas LMS. Selecting 1 for most influential and 3 for least influential, the options given were:

- Canvas functionality and quality
- Course content and design
- Instructors influence

The second question asked the students for any general comments on their experience that might not have been covered by the questions previously asked.

All responses were analyzed by aggregating the responses for each question and summarizing the responses as presented in the results section. The open-ended questions were analyzed using content analysis technique.

Results

There were 19 surveys distributed which corresponded to the number of students in the class. Only 12 completed forms were returned, resulting in a 63.2% return rate.

The results from the survey are organized below according to the questions asked in the survey. Selected comments from the students are also included to explain and clarify certain observations.

Technology Aspects

Table 2 indicates that the majority of the students reported that the grading, syllabus section, and the dashboard were the most useful aspects of the LMS for their studies. These three functionalities of the Canvas application assist the student to track and monitor the students' progress and also to notify them of deadlines and activities.

The results also indicate that most of the students found the LMS to be useful to their studies in almost all of the identified aspects.

For the open-ended questions, the responses were categorized into themes as shown in table 3.

The themes were generated by analyzing the responses from the students and grouping the responses based on the software qualities as identified by Jalote [28], i.e., functionality, reliability, usability, and efficiency. Table 3 indicates that almost all the students enjoy using the LMS for their studies due to its usability. Usability of software means that it is easy to be understood, learned and used [36].

Course Quality

The course quality section contained three main questions. The first question enquired about the student's perception of the content of the course module. The second question asked about the use of the learning objectives document. The final question in this section was an open-ended question asking the students what aspects of the course structure and resources did they like.

Table 2. Responses for the Canvas LMS functionality.

Aspects of Canvas LMS	Useful aspects of Canvas LMS	Aspects that can be improved on
Assignment	3	2
Interface	1	1
Grading	8	2
Syllabus	7	0
Announcement	2	2
Calendar	2	1

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Dashboard	4	0
Courses and Groups	2	1
Quizzes	1	0
Discussion Forum and Threads	1	3
Turnitin Integration	1	2
Folder and Files Section	1	1

Figure 1 shows the student responses on the content of the modules.

The responses show that most of the students believe that the courses are arranged logically and are up to date and relevant.

The second question was related to the learning objectives document, which highlights the knowledge and skills that the student is expected to acquire.

Figure 2 shows that at least all of the students went through the learning objectives and all of them downloaded or printed the at least a few of the learning objectives for the module.

There were nine responses to the third question in the course quality section. This question tried to determine the student's perception of the design and contents of the course. The responses were categorized into three themes as shown in table 4.

Table 3. Themes generated from Q3.

Theme	Student Count	Example of students comments
Usability	11	*The layout is simple and user-friendly.*
Functionality	4	*The system is practical and easy to use.*
Reliability	3	*The system is useful for my studies, user-friendly an always available.*
Efficiency	1	*The system is very fast.*

Instructors' influence

The students were also asked to rate the response and support given by their instructor to determine how the instructor influences the student's experience using the Canvas LMS. Three questions were asked in this section; the first question asked for the students to rate the instructor response times to student's queries while the second question asked about the support given by the instructor on using the Canvas LMS.

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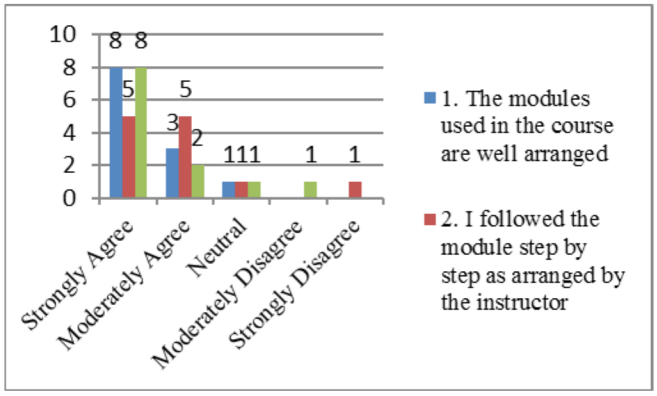

Fig. 1. Student's responses on the module content

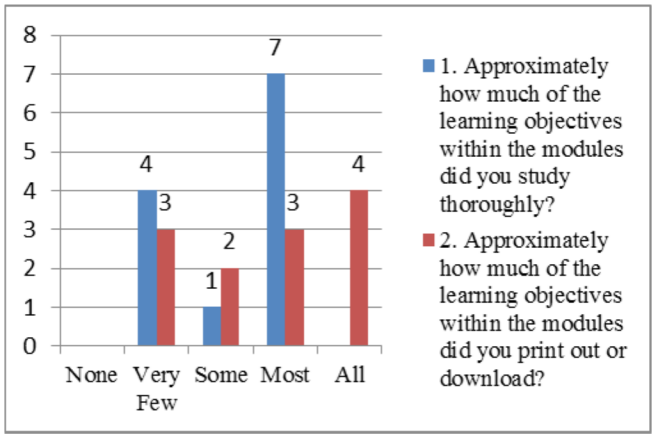

Fig.2. Students responses on the learning objectives

Figure 3 shows the responses by the students for the two questions. It indicates that all the students believe that their instructor responded to queries promptly and supported them in the use of the LMS.

Table 4. Themes generated from Q6.

Theme	Student Count	Example of students comments
Course Resources	5	*I can always download the lecture slides*
Course Design	3	*The modules are arranged logically*
Course Activities	1	*I like the discussions and quizzes sections as they make the course interesting*

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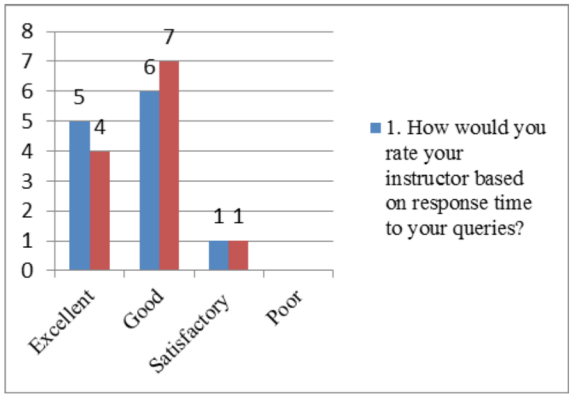

Fig. 3. Students responses to the instructors' influence

General Comments

In the general comments section, there were two questions. The first tried to determine which of the three factors (technology aspects, course quality, and instructor influence) improves the student's experience in using the LMS by rating them in order of priority. Figure 4 is a summary of the results. Half of the class indicated that the instructor was the most significant factor to influence their experience in using the LMS, the functionality of the LMS followed this. Only two students thought that the course content was more important than the other two factors. Half the class agreed that the course content was the least factor to affect their experience in using the LMS.

For the second question general comments were sought from the students. A thorough review extracted the following comments which were identified as unique and vital to improving the student learning experience in using the LMS:

- *Stop locking assignments and modules*
- *There is no feedback from my assignments*
- *A phone application for Canvas would be a good idea*

Discussion

This study focuses on three factors as contributors to student's experience in using an LMS, 1) the influence of the instructor, 2) the quality and functionality of the technology and 3) the course content quality and design. The results show that usability was the most significant technological factor in using the Canvas system. The grading aspect, the syllabus and the dashboard section of Canvas were identified by the students as the features they find the most useful. Thus the students find it easy to use the Canvas software to track their progress on the course.

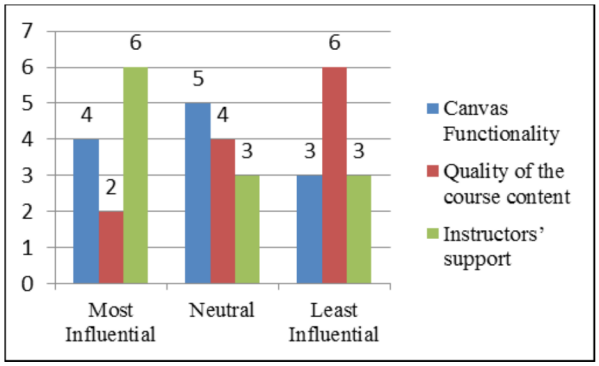

Fig. 4. Students rating of influential factors

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With regards to the course quality, the majority of the students believed that the modules of the course were arranged logically and that the course content was up to date and relevant for their studies. Also, all of the students went through the learning objectives and felt that they were important enough to download or print. This indicates that the students were interested in understanding the skills and knowledge to be acquired from the modules. The open-ended question in the course quality section revealed that the resources available for the course as well as the design of the course influence the student's learning experience. Almost half of the class mentioned the relevance or availability of resources used in the modules as aspects of the course quality they liked. 3 of the students mentioned the design/layout of the course and one student indicated the activities in the class as reasons to why they like the course.

The instructor response time and support towards the students were rated as above satisfactory by the majority of the class. The instructor is very experienced in using technology for instruction and has been teaching using the LMS for over 12 years in the university. This study believes that the experience of the instructor contributed to the excellent ratings by the students. Based on the open-ended question, most of the students indicated that the instructor was supportive of the use of the LMS.

Considering that this study was carried out on freshmen (1st-year students) who have most likely not been exposed to using an LMS, the results show that the LMS is easy to use and the students will find it even easier to use with further usage. The content is a very important aspect of the learning process in both the way and order it is presented. Documents such as the learning objectives and the syllabus are also important for students to use as a guide to their studies. Also, the instructor has an important role to play in supporting and responding to their students. The students attributed the influence of the instructor as the most significant factor that contributes towards the learning experience using the LMS.

Finally, the general comments showed that some students would like access to all of the course material for a more flexible learning experience as opposed to being restricted by following the modules sequentially. A few comments also identified the need for a mobile application for the LMS; this shows that some students prefer to use their mobile devices for learning.

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Designing Optimal PicoGrids for Non-Smart Phones: Sufficient Mathematical Conditions

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Abstract. This paper presents sufficient conditions for designing magnetic circuit wireless picogrids for non-smartphones to mitigate user inconveniences due to flexibility, safety and reliability issues. The work demonstrates flexibility and safety by efficiency regulation over generalized coordinates and conformance to IEEE standards on electromagnetic field exposure respectively.

KEYWORDS: Picogrid, Wireless Power, Magnetic circuit, Langrangian

1 Introduction:

Generally, power systems for mobile phones are expected to function with optimal quality of experience (QoE). [8] stated that a near ideal power supply system should ensure that its operations does not affect the functions of the connected loads. Additionally, it should operate with minimal maintenance effort and higher degree of safety. At present, the architecture for loads such as non-smartphones cannot achieve such a power supply system. [23] wrote that to this day, powering non-smartphones does not allow free movement of the device because of conventional recharging methods. For instance, when recharging non-smartphones, users may require an important call failure to which translates into inconvenience. Repeated inconveniences result in frustrating user experience and diminished market turns. Another area of concern on wired charging methods is one of reliability. Repeated charging requires frequent plugging and unplugging of the charger on the device. The contacts wear out and are eventually damaged. This reduces the overall safety and reliability of the wired charging method. Simultaneous occurrence of a discharged mobile phone and a damaged charger creates a second degree of inconvenience especially during maximum requirement times. The replacement or repair in this case attracts unwanted financial cost. Consequently, improved picogrids for such devices are necessary as per discussions on cost minimization need in service systems of [25].

Our objective herein this work is to design a WPT[1] system (picogrid) for non-smartphones devoid of the limitations above as a remedy for conventional wired power supply systems known for these devices. This kind of WPT system to the best of our knowledge does not exist in the literature and the industry to date. Designing such a picogrid then will improve the performance of mobile devices both in QoE and markets. Our main contributions to literature on WPT system designs could be summarized as follows:

1. Providing architectural design and system process for such a picogrid.
2. Identifying requisite generalized coordinates needed for designing such a picogrid.
3. Proving sufficient mathematical conditions and testings given these coordinates for real time design.

[1] Wireless Power Transfer

The rest of the work is organized as follows: In section 2, a review of related literature on WPT systems is carried out. Section 3 provides basic architecture and assumptions needed for designing such a picogrid. In section 4, the design process involving power flow throughout the entire architecture is explained. Section 5 presents sufficient mathematical conditions such a picogrid must satisfy in real time design. Additionally, numerical simulations, discussions and testing of the picogrid in question relative to flux and range, efficiency and rotation and finally, efficiency and range are carried out. The work concludes in section 6 with summaries and remarks on the performance of the picogrid over existing international standards.

2 Literature Review:

One problem of designing flexible picogrids for mobile phones is demand management. [26] investigated power consumption in mobile phones. A relationship between power consumption and quality of user experience was established. It was shown that higher power consumption reduces the device availability and consequently reduces the user`s QoE. [1] studied strategies for improving QoE and their impact on power consumption. It was indicated that high performance processors, memory devices and peripheral devices are used in design to improve QoE. However, these additional components result in higher power consumption. From experience, it is known that short battery life degrades user`s QoE due to the need for frequent charging. [5] noted that resultant higher power consumption reduces battery life. In this regard, [11] proposed that the battery life and consequently, the QoE can be improved by designing mobile phone applications for real time power management. [13] compared usage in smart phones and non-smart phones. It was found that smartphones consume more power and generate more network traffic than non-smartphones. Thus, one can envisage that the use of advanced feature phones will simplify demand management in picogrids for mobile phones in support of [21] and [24] who indicated that such phones offer some similar capabilities to smart phones but at lower power consumption levels.

[22] discussed an approach to dealing with power consumption issues which uses WPT to provide flexible power supply. It was shown that magnetic induction based WPT systems can improve mobile phone user`s QoE by robust powering experience. However, a survey reported by [10] highlighted some limitations of existing magneto-induced WPT systems such as charging pads. Existing charging pads to date require perfect alignment of the phone with the pad. Thus, limiting the mobility of the phone and negatively affecting the QoE. Also, charging pads may interfere with other magnetic materials in their vicinity. Moreover, the costs of procuring existing charging pads approach the cost of the mobile phone itself. In this respect, [14] highlighted that the newest trend in mobile phone use is that, users are moving away from smartphones to feature phones due to power consumption issues. This trend is not unconnected with power demands due to electromagnetic interference and high device utilization levels. More flexible power supply systems on advanced feature phones will mitigate these challenges. It turns out that the problem is that of identifying requisite governing equations of a picogrid with a non-smartphone as load.

From the literature reviewed and many others, it can be seen that a lot of work has been carried out on conventional wired power and WPT systems for special loads such as mobile phones. A common feature of existing WPT models is that they do not consider the interaction of WPT systems with external realities. Essentially, in resonant systems of [28], [27], [4], [22], [6], [7] and [19], this interaction is considered negligible. There are cases such as in switching converters where high frequency electric circuit resonates at operating frequency of the WPT system. Under such conditions, the amount of electromagnetic interference becomes significant and needs to be considered in model design of WPT systems. Additionally, WPT systems applied to mobile phones need to deal with power demands due to electromagnetic interference and high power consumption levels while maintaining minimal costs to users. High power consumption levels can be mitigated by the use of advanced non-smartphones which are more energy efficient. To the best of our knowledge, WPT designs covering this class of phones are not explored in the literature.

3. Basic Architecture and Assumptions:

Consider a magnetic induction system with one Tx and multiple (at least two) Rx with basic system architecture as in figure 1 below. The architecture consists of a power source, the input driver and two crossed dipole coils Tx and Rx. In addition, there is a load driver and the load which in this case is a non- smartphone. The Tx and Rx coils are setup in a crossed dipole coil structure to ensure flexibility of power supply to the non-smartphone. The dimensions of the Tx are such that the evanescent near field dominates and radiated fields are negligible. The Tx is fixed such that the magnetic near field produced covers a spherical control volume and sources of external influences on the magnetic field follow a finite distribution. Under this condition, the external influences can be quantified. The open loop system process is given by the process diagram in figure 2 below.

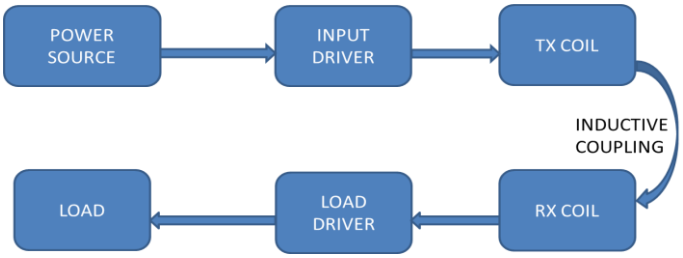

FIG. 1: BASIC DESIGN ARCHITECTURE

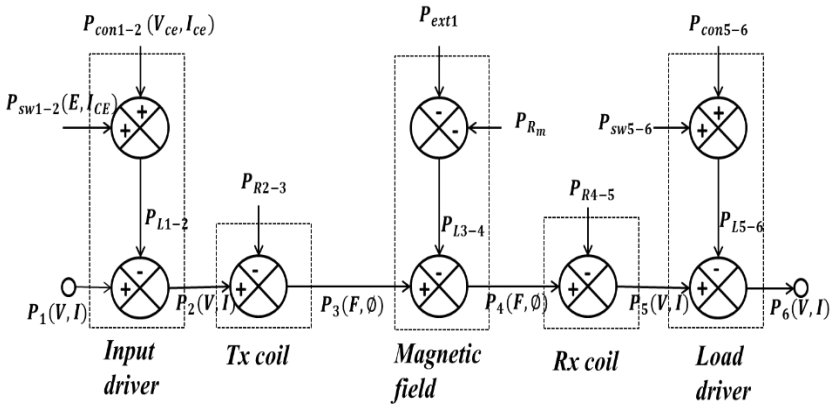

FIG. 2: DESIGN PROCESS DIAGRAM

For the purpose of designing this picogrid, the system process is broken down into series of power transfers across the constituent modules between the power input and the load so that module number *i* represents a stage of the system process with efficiency η_i . The overall efficiency is then the total of the efficiencies at each stage. The following subsections describe step by step analysis of power transfers across the picogrid designed in this work.

3.1. Power Conversion in the Input Driver:

Suppose the proposed picogrid receives an a.c. input at a nominal frequency f_1 such that the input undergoes a power conversion within the driver from a low frequency a.c. signal at power $P_1(V, I)$ to a high frequency a.c. signal at power $P_2(V, I)$. The converter topology is chosen such that power is converted from the low frequency a.c. to d.c. and then from d.c. to high frequency a.c.[2] Denote the output frequency by f_2 and set the one-dimensional near field limits to coincide with the range of the proposed picogrid. Then f_2 can be determined by applying the three-region model of electromagnetic fields. The

[2] The input driver is an a.c. to a.c. converter with d.c. link.

range of the field *l* is such that $l = \lambda/2\pi$ which is constant. If a solar photovoltaic (PV) input is introduced in the d.c. link of the input driver to improve the reliability of the system, then from the law of conservation of energy, it follows that the algebraic difference between P_1 and P_2 is the sum of power losses $P_{L1\text{-}2}$ in the input driver and power input $P_{PV1\text{-}2}$ from the PV system. Mathematically, we have

$$P_1(V,1) - P_2(V,1) = P_{L1-2} - P_{V1-2} + P_{Stored1-2} \quad (1)$$

In this case, $P_{stored1\text{-}2} = 0$. By [24], we have

$$P_{L1-2} = P_{con1-2} + P_{sw1-2} \quad (2)$$

Where Pcon1-2 is the conduction losses and Psw1-2 is the switching losses. By [24] again, these losses are given by

$$P_{con1-2} = f_{sw1-2} \int_{t=0}^{\frac{1}{f_{sw1-2}}} (V_{ce1-2} I_{ce1-2}(t) + \gamma(t))dt \quad (3)$$

and

$$P_{sw1-2} = f_{sw1-2} \left(\sum E_{on1-2} I_{ce1-2} + \sum E_{off\,1-2} I_{ce1-2} + \upsilon \right) \quad (4)$$

3.2. Power Conversion within the Tx Coil:

Within the Tx coil, there is a transition between states P_2 (V, I) in the electrical domain to P_3 (F, ϕ) in the magnetic domain. The power output P_3 in this case is given by

$$P_3 = V_{L2-3} I_{2-3} = I_2 X_{L3} \quad (6)$$

Where X_{L3} is the inductive reactance of the Tx coil. The power output in terms of F and ϕ is given by

$$P_3(F,\phi) = \frac{F\phi}{s} \quad (7)$$

Where, s is a Laplace parameter such that $s \downarrow 0$ as P_3 attains a maximum. The power losses $P_{L2\text{-}3}$ in the Tx coil are resistive losses, hence measurable. The efficiency η_{2-3} of the Tx coil is

$$\eta_{2-3} = \frac{I^2 X_{L3}}{I^2 X_{L3} + I^2 R_3} \quad (8)$$

3.3. Power Conversion within the Magnetic Field:

The power output P_3 is transferred to the Rx across a magnetic field. In this case, the power transition is from P_3 (F, ϕ) to P4 (F, ϕ). If the flux paths from Tx to Rx are replaced by their lumped reluctances z_μ (i); i = 1, 2, 3,… where i is a point in a field, then it is possible to describe the power flow paths as a network of reluctances leading to a magnetic circuit. Since the external interferences are measurable coupled impedances, then there exists a finite distribution that quantifies the density of these external interactions. Under this condition, it is possible to model the interferences as a series complex reluctance. The net power loss due to external interference denoted by Pext3-4 can be estimated. With known values of F3 and the reluctances in the magnetic circuit,

one can apply circuit theory to obtain the mmf at the Rx and the power P_4 (F, ϕ) received at the Rx. The efficiency of power transfer across the magnetic field can be calculated by applying known equations for efficiency in the sense of power transfers under conduction and switching losses**.**

3.4. Power Conversion within the Rx:

The power output of the magnetic field is converted within the Rx from magnetic signals P_4 (F, ϕ) to electrical signals, P_5 (V, I). The output power P_5 is then obtained by transforming F to I and ϕ to V using flux equations for a current carrying conductor. Here, the power loss $P_{L4\text{-}5}$ in the Rx is due to coil resistance; [9] so that the efficiency η_{4-5} of the Rx coil can then be calculated similar to those indicated above.

3.5. Power Conversion within the Input Driver:

The power output P_5 from the Rx is a high frequency a.c. which can be converted to d.c. by the load driver subject to switching and conduction losses similar to that from P_1 (V, I) to P_2 (V, I) because of generality. The expression for efficiency η_{5-6} in this case can also be computed similar to η_{1-2} described above.

3.6. The Overall Efficiency:

To calculate the efficiency η_{system} of the picogrid proposed in this work, we apply the efficiency model in [3]. Specifically, let $\eta_j; j = 1, 2, 3, \ldots$ denote the component efficiencies for a given system with *j* components. Then the overall system efficiency is given by

$$\eta_{system} = \prod \eta_{j-k}, \quad j = 1, 2, \ldots, n-1 \quad k = j+1 \tag{9}$$

4. Sufficient Mathematical Conditions:

In designing a picogrid for non-smartphone, seven (7) generalized coordinates are required. These coordinates are; time coordinate *(t),* space coordinate *(A),* frequency coordinate *(f),* displacement coordinate *(l),* rotation coordinate (ϕ) voltage coordinate *(V),* and load magnitude coordinate (Z_L). The following mathematical conditions (presented as lemmas) are sufficient for designing such picogrids.

Lemma 1.
The effective range *(l)* for such a picogrid is given by

$$l = \frac{\frac{\rho_m}{\pi}\phi^2{}_{3-4}t + \frac{1}{2\pi\mu}\phi^2{}_{3-4}}{\frac{N\varepsilon\pi}{2}\phi^2{}_{3-4}} \tag{10}$$

Additionally, the angle of rotation θ is at π.

Proof:

If one applies the selection criteria of [12] on the identified coordinates above then, the degrees of freedom *d* can be computed using

$$d^2 = [(A_i - A_j)^2 + (f_i - f_j)^2 + \ldots + (Z_i - Z_j)^2] \tag{11}$$

At unit design level, one obtains that 4 generalized coordinates are required for such a picogrid. The power transfer process of figure 2 is represented as a magnetic circuit using the formulation of [16]. The energy balance of the magnetic circuit is given by

$$R_m \dot{\phi}^2_{3-4} t + \frac{L_m \phi^2_{3-4}}{2} + \frac{\phi^2_{3-4}}{2C_m} + \dot{\phi}^2_{3-4} Z_{L_m} t + \alpha = P_3 \qquad (12)$$

Where

$\alpha = P_{ext1} = \dot{\phi}^2_{3-4} Z_{L_m} t$ *and* $P_3 = F_3 \phi_{3-4}$. In terms of the chosen generalized coordinates, (12) becomes

$$\frac{\rho_m}{\pi l \cos^2\theta} \dot{\phi}^2_{3-4} t + \chi + \frac{\phi^2_{3-4}}{2\mu\pi l \cos^2\theta} + \psi + \alpha = P_3 \qquad (13)$$

In this case,

$\chi = \frac{N\varepsilon\pi l \cos^2\theta}{2} \phi^2_{3-4}$ *and* $\psi = \frac{\phi^2_{3-4} N^2}{Z_{L_{4-5}}} t$. The Langrangian equation of motion for the system in (13) is the coupled system below

$$-a_1 \dot{\phi}^2_{3-4} l^{-2} t \cos^{-2}\theta + a_2 \phi^2_{3-4} \cos^2\theta - A_* = 0 \qquad (14)$$
$$A_* = a_3 \phi^2_{3-4} l^{-2} \cos^{-2}\theta$$
$$-a_1 \dot{\phi}^2_{3-4} l^{-1} t \cos^{-3}\theta \sin\theta - a_2 \phi^2_{3-4} A^* + A_3 = 0 \qquad (15)$$
$$A^* = \cos\theta \sin\theta \text{ and } A_3 = a_3 \phi^2_{3-4} l^{-1} \cos^{-3}\theta \sin\theta$$

Solving (14) and (15) simultaneously for *l* and θ ends this proof.

Lemma 2.
The power factor (pf) for the picogrid is

$$pf = \cos\left(\frac{-4\frac{\rho_m}{\pi l}}{\frac{1}{\pi l} - N\varepsilon\pi} \right) \qquad (16)$$

Proof:
In view of (12), the inductive coupling stage power output P_4 for the picogrid in question is given by

$$P_4 = \frac{\dot{\phi}^2_{3-4} N^2}{Z_{L_{4-5}}} \qquad (17)$$

Solving for ϕ_{3-4} in (13) and substituting into (17), we have

$$P_4 = \frac{4N^2}{Z_{L_{4-5}}} \frac{\rho_m}{\frac{1}{\mu} - N\varepsilon\pi^2 l} \exp\left(\frac{-4j\rho_m}{\frac{1}{\mu} - N\varepsilon\pi^2 l} \right) \qquad (18)$$

Comparing (18) with the general form of complex power,

$$\vartheta = \frac{-4\frac{\rho_m}{\pi l}}{\frac{1}{\pi l} - N\varepsilon\pi} \qquad (19)$$

The lemma holds upon taking the cosine of ϑ .

5. Simulations and Discussions:

To obtain the efficiency of the picogrid presented, a load profile of [2] in [15] was considered. Additionally, θ of [7], drivers of the Qi standards and the coupled interference impedance of [18] were adopted. The following computations of average power demand P_6 for some non-smartphones are tabulated as

Non Smartphones	$\mathbf{P_{ON}}$	$\mathbf{P_{LOW}}$	$\mathbf{Z_L}$
Samsung GT-C3262	0.275	0.005	77.79
Samsung neo duos	0.236	0.006	90.00
Samsung Rex 70 S3802	0.254	0.005	84.09

TABLE 1: Z_L for sampled non-smartphones

The efficiency of the design was evaluated by applying the Z_L of the sampled non-smartphones to (12) and solving in MATLAB. The flexibility of the design was measured as the efficiency regulation over rotation, range and load magnitude.

REMARK 1: EFFICIENCY VS ROTATION:

The picogrid is flexible over alignment.

This is in view of the efficiency range over rotation as in figure 3. One can see that the system maintains its performance with rotation up to 60 degrees. Maximum performance is also obtained from 120 degrees to 180 degrees similar to the performance of the design by [7] and [20] over variation in the angle of rotation θ. However, the maximum efficiency variation is less than 1%. This is an improved parameter regulation when compared with [7], and [19] in which the parameter variations were 31% and 6% respectively.

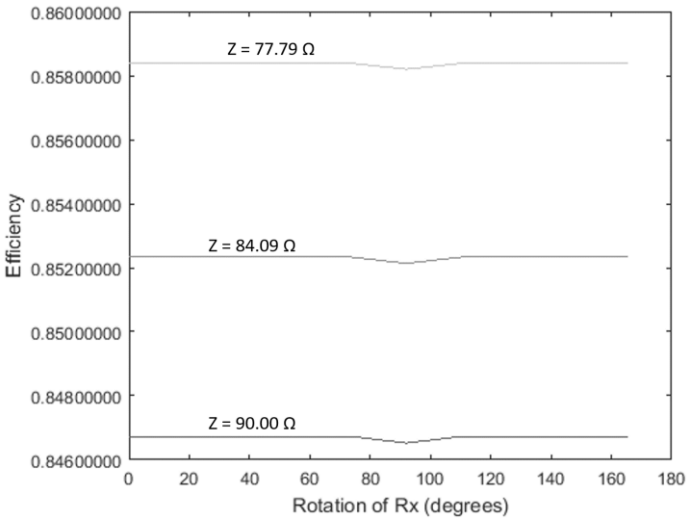

FIGURE 3: EFFICIENCY VS ROTATION FOR Z AT L= 4M

REMARK 2: EFFICIENCY VS RANGE:

The picogrid is flexible over location.

In figure 4, it can be seen that the efficiency is maintained with little variation over range up to 4.5m. Thus, the picogrid can efficiently power devices within 4.5m range from the Tx. This is an improvement on the range of the system designed by [7] which showed significantly diminished performance at 1m away from the Tx.

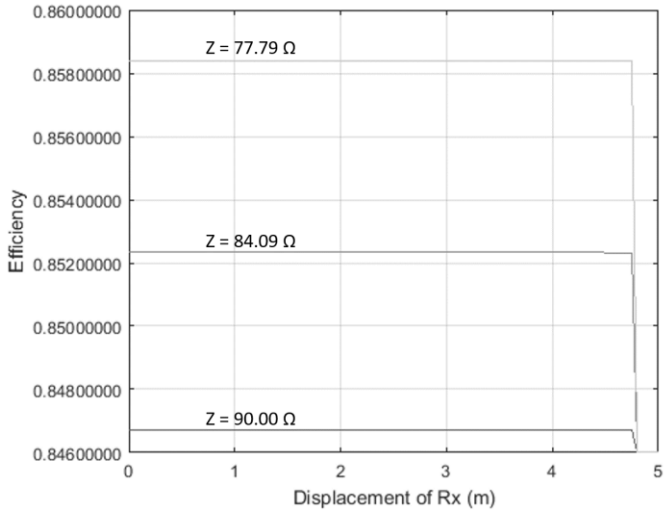

FIGURE 4: EFFICIENCY VS RANGE AT $Z \leq 90\ \Omega$, $\theta = 180$.

REMARK 3: EFFICIENCY VS LOAD IMPEDANCE:

The picogrid is flexible over load impedance.

This can be seen from figure 5. The efficiency varies by 6% for changes in the load impedance from 25Ω to 90Ω. Thus, the system is able to power different non-smartphones with different impedance characteristics. Additionally, this is similar to the performance of the design in [19].

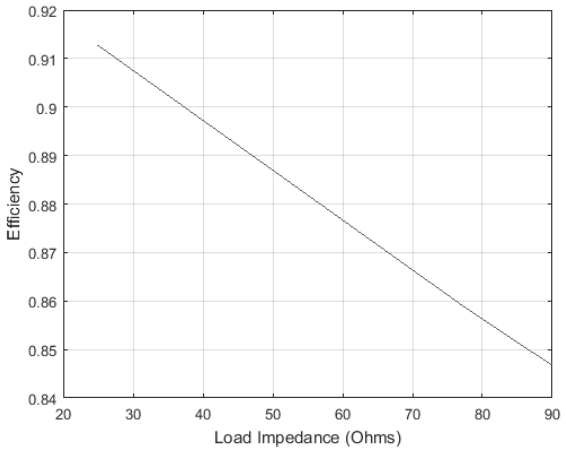

FIGURE 5: EFFICIENCY VS IMPEDANCE, l = 4m, θ =180.

REMARK 4: FLUX VS RANGE:

The picogrid is safe for human living spaces.

It can be observed from figure 6 that within a range of 1.5m flux in the WPT space is less than the maximum permissible limits set out in the IEEE standards on Electromagnetic fields exposure (IEEE Std C95.1-2005) in [17].

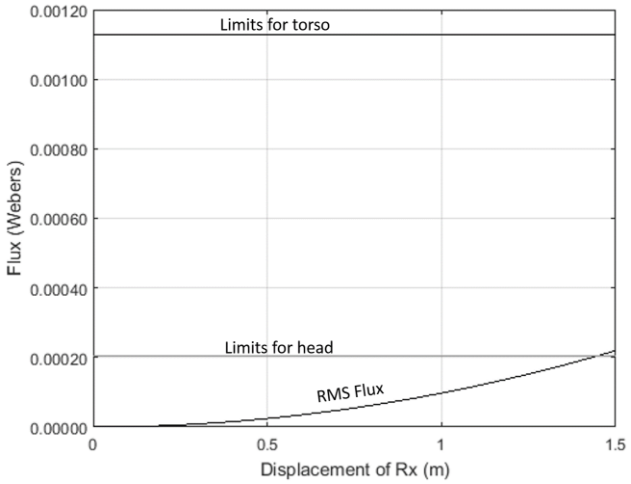

FIGURE 6: FLUX VS RANGE FOR SELECTED Z AT $\theta = 180$.

6. Simulations and Discussions:

We have shown that a picogrid for non-smartphones like that of smartphones is realistic. Application of our design and coordinates ensures that non-smartphones receive continuous power supply within the range of a Tx. The Tx can be set up in homes and offices for continuous powering of mobile phones. Thus, eliminating user inconveniences associated with power supply systems. Furthermore, since efficiency varies inversely with the load magnitude; figure 5, low-power non-smartphones will experience better performance and vice versa. Finally, such a picogrid conforms to IEEE standards on electromagnetic field exposure as in figure 6. As an emphasis, presently, there is no physical prototype of this picogrid in the industry.

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Naïve Bayes and k-Nearest Neighbour Data Mining Algorithms: A Comparative Analysis

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Abstract

Several techniques exist for data mining but some are more suitable for certain datasets than others. The suitability in terms of best performance of a particular algorithm or technique for a specific dataset depends on certain criteria. This paper attempts to evaluate the performance of the k-nearest neighbour (k-NN) and the Naïve Bayes classification algorithms using Knime Analytics Platform. The performance parameters include classification accuracy, speed, and level of interpretability. Liver-disease dataset and the fertility dataset obtained from the UCI Machine Repository were used in the analyses. The datasets were split into two for training and testing, 70% 30% and 60% 40% respectively. The classification accuracy performance of the k-NN is seen to be better than the Naïve Bayes on the two datasets. It was observed that the time of execution taken by the two algorithms differ across datasets: the k-NN took approximately 0 seconds on the fertility dataset but took a longer time on the liver disorder dataset. On the other hand, Naïve Bayes took a lesser time for execution on the liver-disorder dataset than the k-NN. The level of interpretability offered by the k-NN is higher on the liver-disorder dataset than that offered by the Naïve Bayes algorithm. The k-NN outperforms the Naïve Bayes algorithm in terms of higher level of interpretability and greater classification accuracy, especially with small dataset sizes. In terms of speed, on the fertility dataset, the k-NN and Naïve Bayes algorithms performed at almost equal time, but, on the liver-disorder dataset, the Naïve Bayes outperformed the k-NN, however, the k-NN performance decreases as the number of samples increases.

Keywords: *Naïve-Bayes, k-nearest neighbour (k-NN), Classification accuracy, Execution time, Interpretability*

1 Introduction

The overall goal of data mining process is to extract interesting patterns of information from a dataset and transform it into a structured form for further understanding [1]. Data mining has been described as the process of analysing and extracting useful information from huge sets of data and a procedure of mining knowledge from data; it is also known as knowledge discovery in databases (KDD) [2]. Data mining is defined as the nontrivial extraction of implicit, previously unknown and potentially useful information from data in databases [3]. In most cases, KDD and data mining are taken as synonymous, while in actual fact, data mining is the core part of the KDD process. It is important to researchers in machine learning, pattern recognition, databases, statistics, artificial intelligence, knowledge acquisition for expert systems, and data visualization. The unifying goal of the KDD process is to extract knowledge from data in the context of large databases. It does this by using data mining algorithms to extract (identify) what is deemed necessary knowledge, according to the specifications of measures, using a database along with any required pre-processing, sub-sampling, and transformations of that database. A typical knowledge discovery process adopted in [4] include data integration, data selection, data cleaning, data transformation, data mining, pattern evaluation, knowledge presentation.

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2 Literature Review

In this section, we look at some previous literature on the subject matter.

2.1 Data Mining Techniques

There are various methods and techniques by which interesting patterns can be identified in datasets. Data mining techniques are generally divided into three: supervised, unsupervised and semi-supervised learning [5]. In supervised learning, a model is built prior to analysis, this works with a set of examples with known labels. The algorithm is applied to this model in order to determine parameters. Common examples of supervised learning include classification, decision trees, Bayesian classification, and neural networks[6]. In unsupervised learning, no model is created prior to analysis, the labels of the examples in the dataset are unknown. The algorithm is applied directly to the dataset and grouping is done according to their attribute values; a common example of this type of learning is clustering [6]. The semi-supervised learning is applied to a combination of small subset of labelled example with a large number of unlabelled example [5].

2.2 Classification

Classification is a classic data mining technique based on supervised machine learning technique [7]. It is mainly used to analyse a given dataset and takes each instance of it and assigns this instance to a particular class in such a way that the classification error is minimized. It is used to extract models that accurately define important data classes within the given dataset. Classification follows a two-step process, first, the model is created by applying classification algorithm on training dataset, and second, the extracted model is tested against predefined test dataset. This is to measure the trained performance and accuracy of the model [8].

Naïve Bayes Algorithm

Naïve Bayes Algorithm is based on the Bayes Theorem and mostly used when dimensionality of the input is high. It assumes that every feature in a class is highly independent; this means that the appearance of a feature in a certain category is not related to any other feature. It is a probabilistic classifier based on prior probability and likelihood of the tuple of a class [2]. The algorithm provides a way to calculate the posterior probability $\boldsymbol{P}(\boldsymbol{c}|\boldsymbol{x})$, from $\boldsymbol{P}(\boldsymbol{c})$, $\boldsymbol{P}(\boldsymbol{x})$, and $\boldsymbol{P}(\boldsymbol{x}|\boldsymbol{c})$, given by Equation (1):

$$Posterior = \frac{(Likelihood).(Proposition\ prior\ probability)}{Evidence\ prior\ probability}$$

$$P(c|x) = \frac{P(x|c)P(c)}{P(x)} \quad (1)$$

Where:

$P(c|x)$ is the posterior probability of class (target) given predictor (attribute) of class.

$P(c)$ is called the prior probability of class; it can be estimated from the frequency of the class in the training examples.

$P(x \vee c)$ is the likelihood which is the probability of predictor of given class.

$P(x|c)$ is the prior probability of predictor of class; it can be estimated if there is an availability of training examples.

In a machine learning classification algorithm, there are multiple features and classes that can be denoted as $C_1, C_2, \ldots, C_k$. The Naïve Bayes algorithm aims to

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calculate the probability of an object with a feature vector $x_1, x_2, \ldots, x_n$ belonging to a particular class C_1 as given in Equation (2).

$$P(C_i|x_1, x_2, \ldots, x_n) = \frac{P(x_1, x_2, \ldots, x_n|C_i) \cdot P(C_i)}{P(x_1, x_2, \ldots, x_n)} \quad for\ 1 \leq i \leq k \qquad (2)$$

Based on the assumptions that features are independent, we have Equation (3):

$$P(C_i|x_1, x_2, \ldots, x_n) = \prod_{j=1}^{j=n} P(x_j, C_i) \qquad (3)$$

The expression $P(x_1, x_2, \ldots, x_n)$ is constant for all classes, we can therefore say that $P(C_i|x_1, x_2, \ldots, x_n)$ is directly proportional to

$$\prod_{j=1}^{j=n} P(x_j, C_i) \cdot P(C_i) \quad for 1 \leq i \leq k$$

Formally, a Naïve Bayesian classifier, or simply Naïve Bayes is defined by Equation (4) as:

$$C_j(E) = \arg\max p(c) \prod_{i=1}^{j} p(x_i|c) \qquad (4)$$

k Nearest Neighbour

In the *k* nearest neighbour (k-NN) (or closest neighbour), the nearest neighbour is computed based on the estimation of *k* that indicates how many nearest neighbours are to be considered to characterize class of a sample data point [9]. It uses more than one closest neighbour to determine the class in which the given data point belongs to and consequently, it is called k-NN. These data samples must be in the memory at runtime, hence they are referred to as memory-based technique. The problem of k-NN is the computational complexity and memory requirements because the training examples are stored during training time which can slow down the process. The nearest neighbours are found and based on the voting of neighbours, the majority neighbourhood class is assigned to the test samples. During prediction time, the Euclidean distance (if the values are continuous) of a test sample *x* to the training samples is calculated. By doing this, we find the *k* training examples $(x_1, x_2), \ldots, (x_k, y_k)$ that are closest to *x*. The probability of assigning a sample X to that of a class C is based on the number of neighbours considered, denoted as k, the probability of to a class is given by Equation (5).

$$C = \sum_{i=1}^{k} \frac{distance(c, c(y_i))}{k} \qquad (5)$$

k-NN algorithm does not build a model using a training set until a query of the dataset is performed; furthermore, all computations are done after classification [10]. k-NN stores all available cases and classifies new cases based on similarity measure.

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A case is classified by a majority vote of its neighbours, with the case being assigned to the class most common amongst its *k* nearest neighbours measured by a distance function. If k=1 then the case is assigned to the nearest neighbour. For continuous variable, the distance can be measured by using the functions in Equations (6) to (8):

Euclidean: $\sum_{i=1}^{k}(Xi - Yi)_2$ OR (6)

Manhattan: $\sum_{i=1}^{k}(Xi - Yi)$ OR (7)

Minhowski: $Xi - Yi \vee \sum_{i=1}^{k}$ $^{q}]^{1/q}$ (8)

For categorical variables, the Hamming distance given in Equation (9) is used:

$$D_k = \sum_{i=1}^{k}(X_i - Y_i): x = y, d = 0: x \neq y, d = 1 (9)$$

Given a training set *D* and a test object $x = (\mathbf{x}^*, y^*)$, the algorithm computes the distance (or similarity) between *z* and all the training objects $(\mathbf{x}, y) \in D$ to determine its nearest-neighbour list, *Dz*, (**x** is the data of a training object, while *y* is its class. Likewise, **x*** is the data of the test object and *y** is its class.) Once the nearest-neighbour list is obtained, the test object is classified based on the majority class of its nearest neighbours, the majority voting is obtained by Equation (10):

$$y = argmax \sum_{x_i, y_i \in D_z} I(v = y_i) (10)$$

Where *v* is a class label, y_i is the class label for the *i*th nearest neighbours, and *I* (·) is an indicator function that returns the value 1 if its argument is true and 0 otherwise. In general, a large value of *k* is more precise but historically, the optimal *k* for most datasets has been between 3 and 10.

2.3 Performance parameters

Predictive/Classification Accuracy: This refers to the ability of the algorithm to correctly predict the class label of new or previously unseen data. The classification accuracy A_c of a classifier *c* depends on the number of samples correctly classified and is evaluated by Equation (12):

$$A_c = \frac{t}{n} * 100 (12)$$

Where *t* is the number of sample cases correctly classified, and *n* is the total number of sample cases.

Speed: refers to the computation cost involved, in terms of running time of the algorithms on the various datasets.

Interpretability: the level of understanding, interpretability and insight provided by the model determined by the Cohen's kappa.

Tools: analysis was implemented using the Knime (Konstanz Information Miner) Analytics Platform v 3.5.2.

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3 Materials and Methods

3.1 Datasets and Attributes

Measuring the interpretability of the algorithm is done using the Cohen's kappa, *k*, a measure of agreement between two categorical variables X and Y, where X and Y are attempts by two individuals to measure the same thing. X is the selection column and Y is class k-NN as they attempt to measure the classification of each row. The Cohen's kappa, k, varies thus:

0 = agreement equivalent to chance;
0.1 to 0.2 = slight agreement;
0.21 to 0.4 = fair agreement;
0.41 to 0.60 = moderate agreement;
0.61 to 0.80 = substantial agreement;
0.81 to 0.99 = near-perfect agreement;
1 = perfect agreement.

A negative value indicates that agreement is less than chance. There are two sets of datasets used in this study: the Fertility dataset and the Liver diseases dataset. The Liver disease dataset is a collection of specific attributes on plants donated by Forsyth .S Richard, created by the BUPA Medical Research Ltd. on May 15, 1990 and obtained from the UCI Machine Repository [11].

Relevant Information: The first 5 variables are all blood tests which are thought to be sensitive to liver diseases that might arise from excessive alcohol consumption.

Number of instances: 345 instances of the data with seven (7) attributes, namely:

1. mcv: mean corpuscular volume
2. alkphos: alkaline phosphotase
3. sgpt: alamine aminotransferase
4. sgot: aspartate aminotransferase
5. gammagt: gamma-glutamyl transpeptidase
6. drinks: number of half-pint equivalents of alcoholic beverage drunk per day
7. selector: field used to split data into two sets

Missing values: none

The confusion matrices presented in Figures 1 & 2 contain the classification accuracy and Cohen's Kappa of k-NN for the two data splits, while the confusion matrices of Naïve Bayes for the same data splits are presented in Figure 3 & 4.

Table 1: Summary Statistics for liver-disease dataset

	MIN	MAX	MEAN	S.D
Mcv	65	103	90.16	4.45
Alkphos	23	138	69.87	18.35
Sgpt	4	155	30.41	19.51
Sgot	5	82	24.64	10.06
Gammagt	5	297	38.28	39.26
Drinks	0	20	3.46	3.34
Selector	1	2	1.58	0.494

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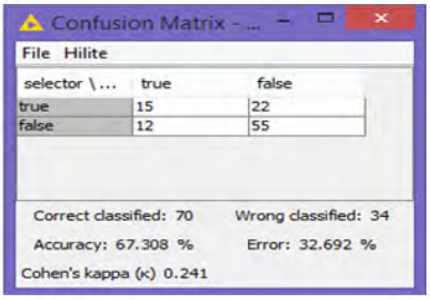

Figure 1 Confusion matrix for k-NN 70% 30% data

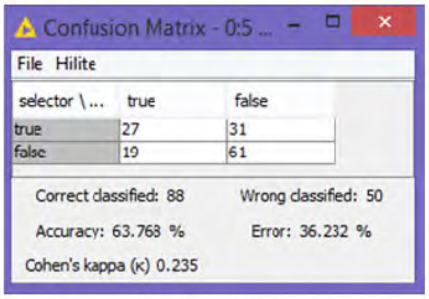

Figure 2 Confusion matrix for k-NN 60% 40% data

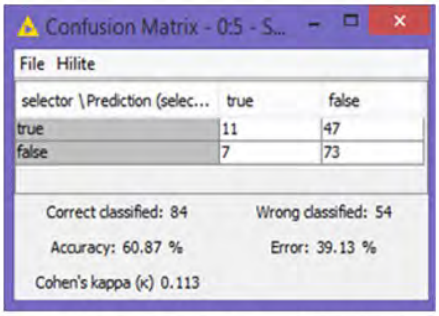

Figure 3 Confusion matrix for Bayes 60% 40% data

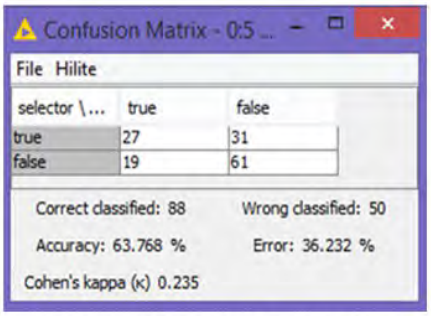

Figure 4 Confusion matrix for Bayes 70% 30% data

The fertility dataset is a collection of semen sample provided by 100 volunteers and analysed according to WHO 2010 criteria [12]. Sperm concentrations are related to socio-demographic data, environmental factors, health status and life habits. 60 instances of the data were used with 10 (ten) attributes and no missing values.

Attribute Information:

Number of Instances: 100

Number of Attributes: 10

Missing Values: N/A

i. Season in which the analysis was performed: (i) Winter (-1), (ii) Spring (-0.33), (iii) Summer (0.33), (iv) Fall (1).
ii. Age at the time of analysis: 18-36 years (0, 1)
iii. Childish diseases (i.e., chicken pox, measles, mumps, polio): (i) yes (1), (ii) no (0).
iv. Accident or serious trauma: (i) Yes (1), (ii) No (0).
v. Surgical intervention: (i) Yes (1), (ii) No (0).
vi. High fevers in the last year: (i) Less than three months ago (-1), (ii) More than three months ago (1), (iii) No (0).
vii. Frequency of alcohol consumption: (i) Several times a day (0), (ii) Every day (0.2), (iii) Several times a week (0.4), (iv) Once a week (0.6), (v) Hardly ever (0.8) (iv) Never (1).
viii. Smoking habit: (i) Never (-1), (ii) Occasional (0), (iii) Daily (1).
ix. Number of hours spent sitting per day: 1-16 (0, 1)
x. Output Diagnosis: (i) Normal semen (N), (ii) Altered semen (O), [12] and [13] .

Summary Statistics

Table 2: Summary Statistics for Fertility dataset

	MIN	MAX	MEAN	S.D

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Season	-1	1	0.168	0.819
Age	0.5	1	0.66	0.107
Child Disease	0	1	0.833	0.376
Accident/Serious Trauma	0	1	0.45	0.502
Surgery	0	1	0.55	0,502
High Fevers	-1	1	0	0.451
Alcohol consumption Frequency	0.2	1	0.833	0.177
Smoking Habit	-1	1	-0.383	0.844
Sitting Hours	0.13	0.88	0.414	0.172

The confusion matrices showing the classification accuracy and Cohen's Kappa of k-NN for the two data splits are presented in Figures 5 & 6, those of Naïve Bayes for the same data splits are presented in Figures 7 & 8.

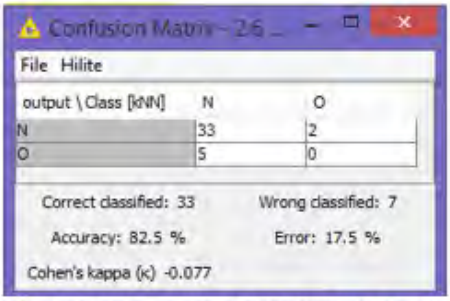

Figure 5 Confusion matrix for k-NN 60% 40% data split

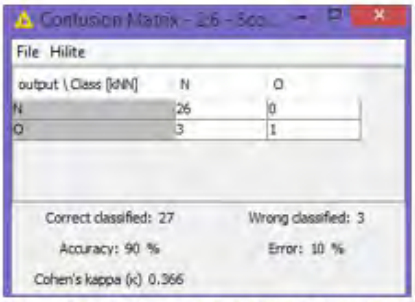

Figure 6 Confusion matrix for k-NN 70% 30% data split

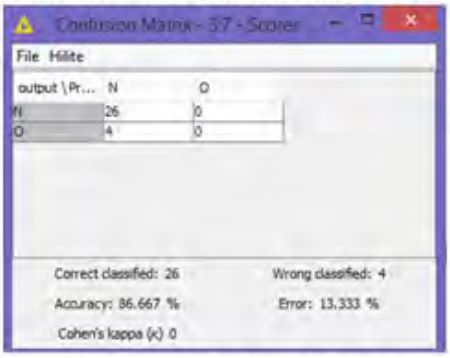

Figure 7 Confusion matrix for Bayes 70% 30% data split

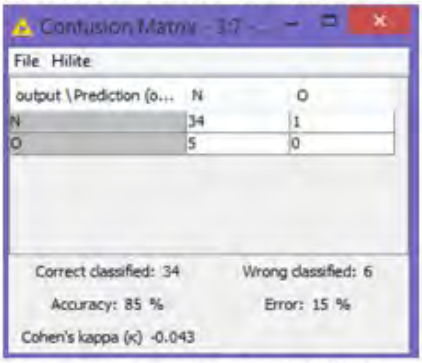

Figure 1 Confusion matrix for Bayes 60% 40% data split

4 Results and Discussion

The summary of the results obtained from the analyses are presented in Table 3. From Table 3, it was observed that for both fertility and liver-disease datasets, the classification accuracy of the k-NN algorithm is higher in the 70% 30% data split. The interpretability of the k-NN algorithm is fair for both datasets at 70% 30% data split and 60% 40% in liver-disease dataset but negative for 60% 40% fertility dataset. This implies that the Naïve Bayes allows for a lower level of interpretation than k-NN. The time of execution taken by the two algorithms differ across the datasets; the k-NN took approximately 0.002 seconds on the fertility dataset but took a longer time on the liver-disease dataset 70% 30% data split. On the other hand, Naïve Bayes took about 0.003 seconds on 70% 30% data split of fertility dataset while it took much longer (0.2 seconds) on 60% 40% split. Naïve Bayes performed slower on both splits of the liver-disease dataset, however, it was faster on the 70% 30% split. On the average, k-NN ran faster on the fertility dataset while Naïve Bayes was faster on the liver-disease dataset.

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Table 3: Comparison of k-NN and Naïve Bayes on Fertility and Liver-Disease Datasets

	k-Nearest Neighbour		Naïve Bayes	
Fertility dataset	**70%**	**60%**	**70%**	**60%**
Execution Time	0.002	0.002	0.003	0.200
Classification	90.00	86.67	82.50	85.00
Interpretability	Fair	Negative	Zero	Negative
Liver-disease	**70%**	**60%**	**70%**	**60%**
Execution Time	0.420	0.002	0.183	0.263
Classification	67.31	63.043	60.57	60.87
Interpretability	Fair		Fair	Slight

5 Conclusions

In this study, the k-NN algorithm was compared to the Naïve Bayes algorithm based on speed of execution, classification accuracy, and level of interpretability offered by the model. Execution time or speed varies across the dataset; on the fertility dataset, k-NN performed better with a reduced execution time while on the liver-disease dataset, the Naïve Bayes performed better. One of the major disadvantages of k-NN, according to [14] is its inefficiency for large scale datasets. For the level of interpretability offered by the algorithms on the various datasets, k-NN performed better than the Naïve Bayes algorithm. We observed that, the k-NN has low performance rate on large scale datasets and a better performance on the 70% 30% data split. Secondly, the Naïve Bayes algorithm performed better on its 60% 40% data split, which means that a higher number of testing datasets should be considered in future works. Furthermore, in this study, the performance of k-NN and Naïve Bayes algorithm were compared based on only three parameters, namely: execution time, classification accuracy and level of interpretability. Other parameters such as scalability, robustness, etc. were left out but can be evaluated in future works.

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Multidimensional Wireless Power Transfer Using Inductive Triffid Antennas

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Abstract. In this paper, a multidimensional triffid antenna is designed and tested. It is used in a wireless power transfer cube for increased power-delivery efficiency in capsule endoscopy systems as presented. The cubical structure creates a triffid power pattern. The proposed antenna can be integrated into an implant device including hearing aid devices. The new design consists of six conical coils constructed in a cubical shape. The design transfers power wirelessly in Omni-directional manner. Therefore, it provides a high efficient wireless power transfer in multiple directions for wireless powered devices.

Keywords: Wireless power transfer cube, Multidimensional triffid antenna, Triffid power pattern.

1 Introduction

Most biomedical transceiver coils in use to deliver efficient power wirelessly for devices such as implants, capsules and hearing aids are affected by the orientation of such transmitter and/or the receiver magnetic antennas. Many designs have been developed to help increase the capability of wireless power transfer receivers to detect larger amounts of magnetic field lines [1][2][3]. Similarly, many kinds of transmitters have been developed to transmit wireless power to large and multi dimensional areas [4][5][6].

Wireless rechargeable biomedical devices allow clinicians to directly use magnetic energy for treating patients. For example, viewing gastrointestinal tract can be easier by using endoscopes than conventional methods which are obtrusive to the patient [7].Transferring power to recharge the battery of pacemakers devices need to be efficient between the primary and secondary coils that are implanted inside the body [8]. The same requirement is desirable for implantable hearing devices [9].Poor wireless connectivity in some positions is more likely to occur for these devices on account of several problems, such as orientation and movement. Some researchers [10] have used a strongly coupled magnetic resonance with high frequency to address this problem. Unfortunately, inductive coupling with high frequency can cause harmful effect to body tissues [11]. Some other researchers [12] used a multi-coil system to overcome orientation misalignment contact problem. The system in [12] can capture the magnetic field lines in different orientations. However, it fails to capture the magnetic field lines when movement occurs, because the orthogonal structure of the coils required it to be perpendicular to the transmitter most of the time.

In [13] a design configuration of three-coils has been used to reduce the influence of receiver random movements. It should be noted that in this design the three-coil

receiver is surrounded by the transmitter coil. It means that the receiver is swimming in a huge number of uniform magnetic field lines. Thus, the system can be useful for some applications such as capsule endoscopes where the patient body is covered by a large transmitter coil. In the case of hearing problems patients using implantable hearing devices require rechargeable systems for the device battery with no movement constraints. In general the design of an efficient wireless power transfer system to implantable devices requires not only accurate shape and size but also a safe frequency range to avoid harmful effects. These three factors are related. For example, coil sizes of most implantable devices are usually a few mm long and wide. Minimizing the coil size of such devices requires high frequency which can reach up to the GHz range [14] [15]. The square receiver coil used in [14] has been sized to be 2mm x 2mm on each side. As a result, a frequency range from 1 to 2 GHz has been optimally used to achieve a power gain of about -30dB. The team in [16] proposed a four-coil strongly coupled magnetic resonance to improve wireless power transfer in the same manner as [14]. In their work they achieved a power gain of -26dB. Then, in [17] they improved the previous design to achieve a power gain of about -20dB by optimizing the receiver coil in size to be 110μm x 110μm, which is a lot smaller than the receiver coil in [14]. As a result, a frequency of 5.8 GHz was used to improve the power gain by about 7dB over the conventional two-coil system.

In this paper, a novel method for optimization and design of wireless power transfer systems for biomedical devices is proposed. The trade off between power improvements, frequency range, transceiver size and coverage path is the major design challenge. Thus, in this paper these challenges are resolved through a design framework which relies on designing the magnetic field pattern. The rest of the paper is arranged as follows. Section 2 introduces the design framework adopted in this paper. Simulation and construction of a prototype are presented in section 3. Results are also discussed in this section. Conclusions are drawn in section 4.

2 System Design

The wireless power transfer system consists of six conical coils forming a cube. The conical coil have been designed and studied in a previous work which inserted in [1][2].The conical coil built in the same manner of the previous work. Fig. 1 shows the diagram of the conical coil design. The large radius of the coil indicates as r1 and the smaller radius indicates as r2 while θ indicates the obtuse angle of the coil.

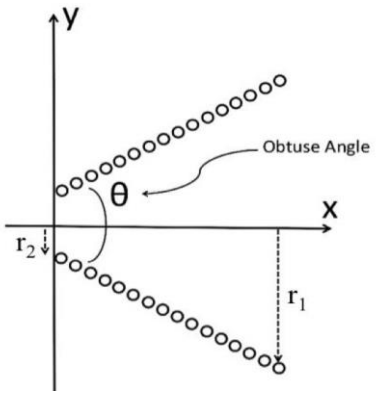

Fig.1. A basic design of conical coil inductor

Table 1 lists the parameters of conical coils that are used in the proposed system. The chosen of 45° angle to built a symmetrical shape of the cube. It can be any angle of interest as long as the choice made based on the better controllable of flux and voltages as inserted in [18].

Table 1. The geometrical parameters of all coils.

Number of turns	Wire thickness (mm)	Large radius (cm)	Small radius (cm)	Obtuse angle (degree)
25	0.85	3.6	0.7	45

The cube coils are created from the same inductor but segmented to support many directive power transfer. Example of building this design has been introduced in a previous work [5] where transceivers of six coils have been discussed. Coils of conical design are sharing the same concept. Each two coils sharing a common axis can be developed as Helmholtz coils design. In this manner conical coils are wound in equal number of turns and radius. They are individually wound to carry the same current and to resonate as a one inductor. Hence, they produces uniform magnetic field along their common axis. In the cubical design proposed in this paper, multiple pairs of Helmholtz coils are employed to design a 'triffid' power transfer pattern. The equivalent circuit of the transmitter coil is shown in Fig. 2. Each side of the cube has a conical coil of small radius positioned at the center of the cube. In this way, the other end of the conical coil which have the larger radius point along the major axis of the cube surface as seen in Fig. 3.

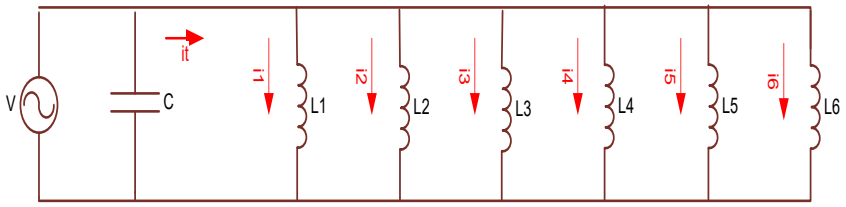

Fig.2. The equivalent circuit of the cube coil

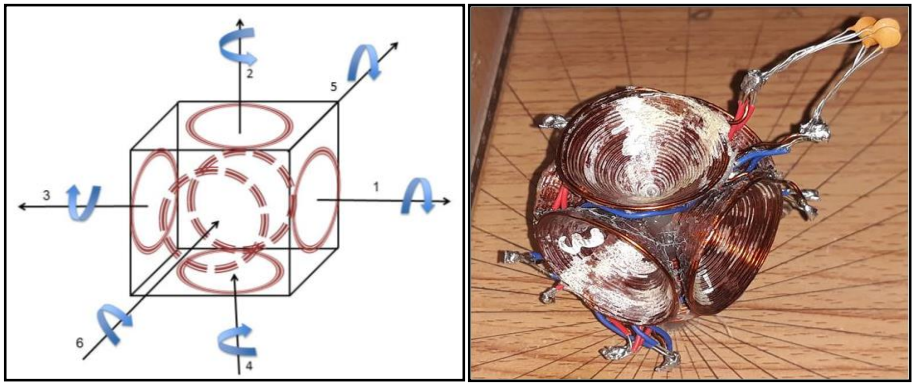

Fig.3. The cube coils structure

The alternating current of the design drives the induced flux in many directions direction. Therefore, changes in the direction of the current of a loop results to a change in the induced flux in that loop. This concept has been used previously for a multi-dimensional coil system in [4] which describes the relation between source winding and current direction. Fig. 4 shows an example of the flux direction in

relation to the direction of current. Each two coils facing each other carry the same currents of the same magnitude and direction. Crosstalk created by the pairs of coils is almost zero because they are connected together with one capacitor. Thus, the whole cube resonates at the same frequency and therefore interference in this study is neglected. The same method is discussed in [5].

The (+) mark indicates a flux pointed out of the loop and (.) mark indicates a flux diving into the loop. Observe that the magnetic field that point out of the loop comes from the larger frame and that they point into of the loop goes through smaller frame of the conical. This is achieved because of the connection used between the conical loops and the related currents flowing through them as shown in Fig. 4.

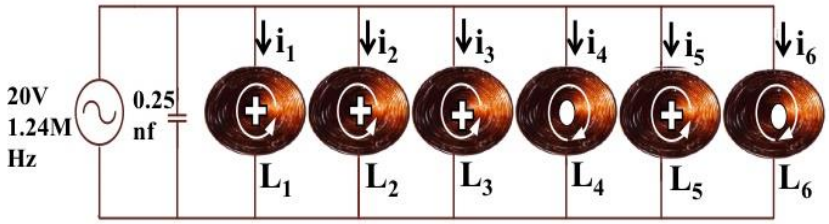

Fig.4. Configuration number 1

In this model, all coils are connected in parallel with one capacitor, and therefore the source current is divided into six values. To verify the influence of the flux direction factor, two more configurations were constructed. Coils in the first configuration are connected in parallel in a way that all of them have the same flux direction out of each loop (see Fig. 5). Opposite direction of the flux into each loop is achieved by using the configuration in Fig. 6.

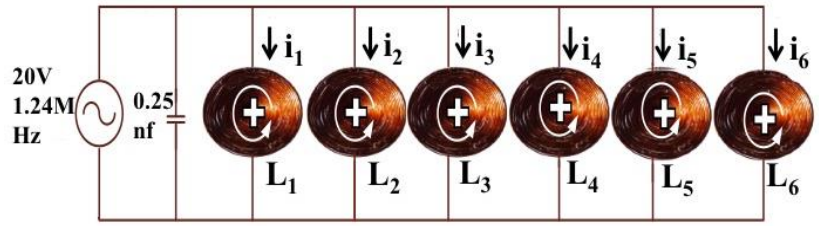

Fig.5. configuration number 2

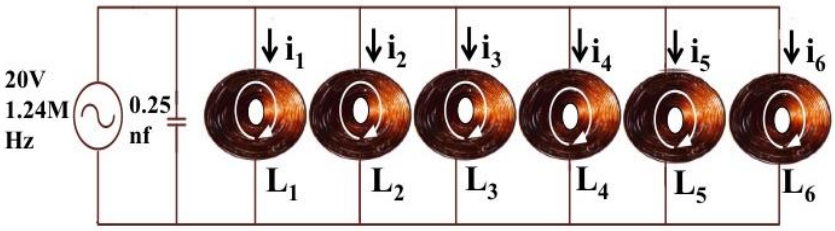

Fig.6. configuration number 3

The equations governing the design of the coils are simple since all the coils are in parallel. Kirchhoff's current law shows that the applied current is divided into the six cube coils. Let L_T be the parallel equivalent value of the inductors. This is

$$L_T = \frac{1}{\sum_{j=1}^{N} \frac{1}{L_j}} \quad (1)$$

Then the resonant frequency obtained from the configuration is still

$$f_0 = \frac{1}{2\pi\sqrt{L_T C}} \quad (2)$$

3 Results and Discussions

The wireless power transfer performance of these three configurations has been experimentally tested. All configurations operate at the same resonant frequency of 1.34MHz.A circular receiver coil with radius the same as the larger radius of the conical coils have been used to detect the wireless power transfer voltage. It is placed at a distance of 5cm from the designed cube with x-axis lying in the same plane of the conical from any sides of the cube loops. The wireless voltage transfer of all six loops of the cube have been tested and recorded in Table 2. The total inductance of the parallel connection of the cube is equal to 55.92μH. Each loop of the cube has an inductance of 9.32μH. All coils of the design resonates using one capacitor which is equal to 0.25nf.

Table 2. Measured wireless voltage transfer of all six conical loops.

	Coil order of the cube	1	2	3	4	5	6
Wireless voltage level (V)	Configuration of Fig 3	6	4.8	7.2	4	6.8	7.6
	Configuration of Fig 4	2.5	2	5	4	6	8.5
	Configuration of Fig 5	0.36	0.24	0.9	3	5	10

Table 2 shows the difference between configurations. Configuration described in Fig 6 shows the worst connection case of conical coils with the flux direction going into the conical loops. Although coils number 5 and 6 has higher level of the voltage transfer, the ability to transfer the voltage by coils 1, 2 and 3 is very weak. This case is not applicable for medical devices and for many of other applications that requires a stable wireless power transfer from each side of the cube. In contrast, the configuration described in Fig 4 shows the very acceptable voltage levels on all coils of the cube. Therefore, the level of the voltage transferred is more stable than other configurations. Less flux conflicts in this case due to the reverses of coils number 4 and 6 in which their flux direction is opposite to the other coils in the same cube. The results are drawn in Fig. 7.

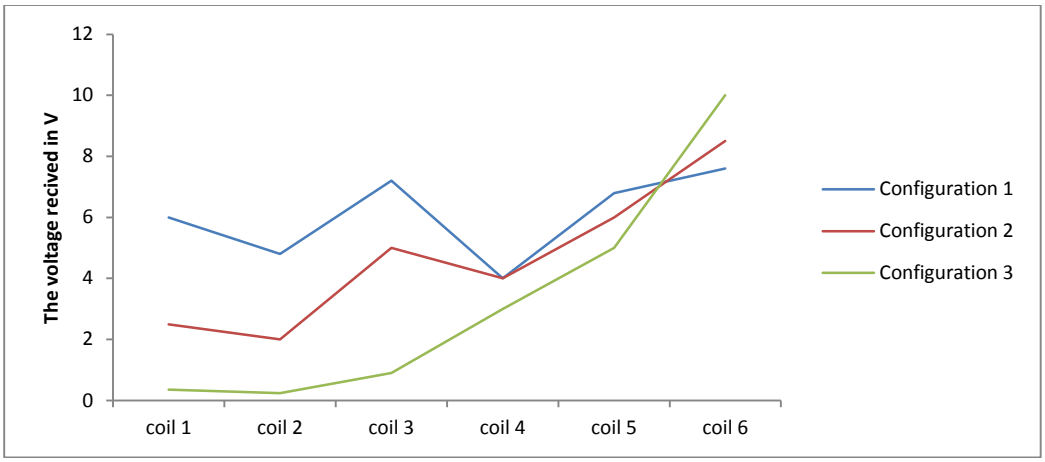

Fig.7. The comparison of the voltage delivery between configurations.

3.1 A. The magnetic field of the design:

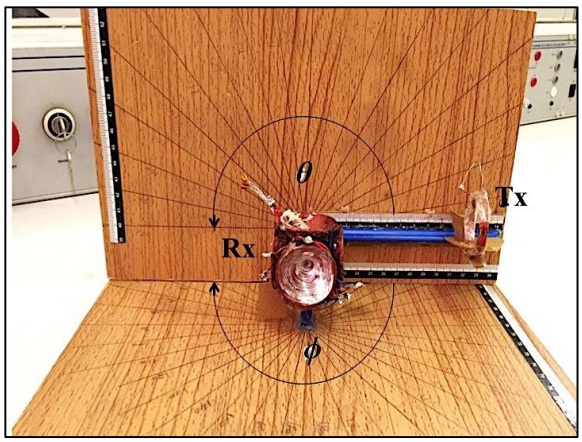

Fig. 8. The method of drawing the magnetic field pattern.

The method of drawing the magnetic field pattern in this design has been proposed in [1][4][5] and includes the design expressions. The distance between transmitter and the receiver probe was set at variable as the probe moved around a spherical area nearby the transmitter. Then a value of measured points at adjusted distance where the voltage is diminished to be 1 V is recorded. In this way a consistent edge of the flux pattern can be plotted. The set up in Fig 8 have been created for measuring the wireless transfer voltage of the cube from all angles. It shows the horizontal and vertical anglesθ and ϕ as used in the measurements. The radiating angles from the cube show at what angles measurements were taken. Therefore, the whole area around the hemisphere of the design is covered and recorded.

Table 3. The distance in (cm) between transmitter and receiver at angles θ and ϕ

ϕ°/θ°	10	20	30	40	50	60	70	80	90	10
0	2.7	2.3	2	4.1	3.2	3.4	5.2	4	4.6	5.7
10	2.6	2.2	2	4.1	3	3.2	5.2	4	4.6	5.7
20	2.4	1.6	2.1	3.4	3	3	5.2	4	4.6	5.7
30	1.6	2.7	2.4	3.6	2.5	3	5.2	4	4.6	5.7
40	2	3.2	2.6	3.9	2.9	3	5.2	4	4.6	5.7
50	1.3	3	2.8	3.5	3	2.9	5.2	4	4.6	5.7

60	1.7	2.5	2.4	3.4	3.2	3	5.2	4	4.6	5.7
70	1	2.1	1.7	3.4	2.6	3	5.2	4	4.6	5.7
80	1.8	2.1	1.3	3.1	2.1	3	5.2	4	4.6	5.7
90	2	2.1	1.3	2.7	1.8	3	5.2	4	4.6	5.7

In Table 3, power transfer is measured in terms of the adjusted voltages of 1V at various angles and distance from the transmitter. The angular coordinates at which voltages were measured are shown in Table 3. The movement angle θ is in the vertical plane and the ϕin the horizontal plane. Due to the symmetric shape of the design transmitter, the results have been recorded from 0° to 90° for both angles as shown in Table 3. The rest of the measured distance from 90° to 360° degrees was assumed to be the same in four quadrants as providing by the angular coordinates. The results indicated in Table 3 are plotted in three dimensions as shown in Fig 9. The magnetic field pattern and hence the power transfer voltage for the design shows the ability of covering magnetic field in multi directional manner. As appear in Table 3 that between angles 10 to 90 degrees the measured voltages are about equal proving that the cubical structure is suitable for uniform power multi-dimensional power transfer and charging in wireless power transfer systems. Comes to the figure, the maximum distance at which the circular coil received voltage is 1 V from the side of the cube coil transmitter is about 5.7 cm or 11.4 (end to end) along the axis. The measurements were taken at a discrete set of angles (at 0°, 10°, 20°, 30° ...), and therefore sharp peaks and drops at the figure were introduced. The objective is to design a multidimensional power pattern. The result shows another type of pattern that called a triffid power pattern. Further study of pattern design is to be obtained as all set of angles are taken. This is more difficult to be examined practically unless a simulation is involved.

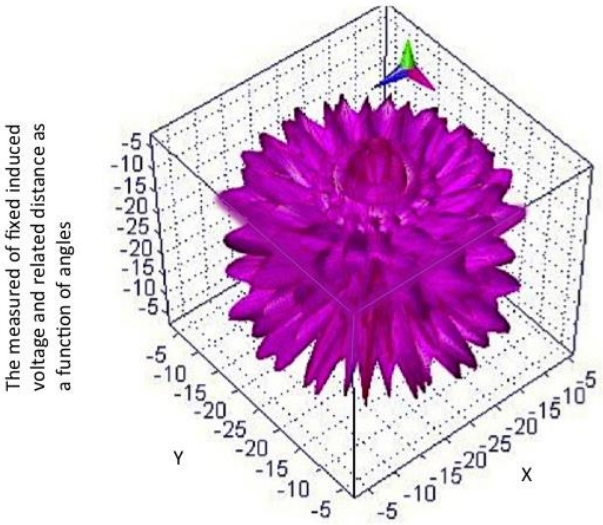

Fig. 9. The three dimensions magnetic field pattern of the cube.

For biomedical devices suffering from loss in connectivity when used as a conventional receiver design to recharge their battery, the cube receiver is more applicable to enhance the connection in all directions. The performance of the cube is summarized in the wireless power transfer stability compared with other coils. It can be observed that this design outperforms others in terms of uniform multidimensional power transfer. For example wireless power distribution in homes or places where medical devices is involved, capsule endoscopes, hearing aids and industrial settings is facilitated by this design. At this point, notes that the design has been tested as a

transmitter side to obtain the multidimensional pattern. Therefore, the same design will receive the power from any side of its structure without orientate it, if it is used as a receiver. Further more, suitable frame works for multi-power transfer/receive to biomedical devices and between homes is made possible by this design.

4 Conclusions

In this paper we have presented the design and implementation of a multi-dimensional antenna. It has a 'triffid' power transfer pattern and called the 'triffid' power transfer pattern, named after the triffid sea food. The antenna is created as a cubical-shaped inductive antenna. The current design has a resonant frequency of 1.34MHz. Current directions in the cubical-antenna determine the shape of the power transfer pattern. It was determined through measurements that the best configuration is one in which some of the currents in the loops flow in opposing directions where leakage magnetic fields are cancelled. The antenna can be miniaturized into an embedded antenna in biomedical devices and also useful for recharging such devices.

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Application of Cloud Computing to Improve Library Services: A study

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Abstract:
Technology advancement has been greatly felt in every sphere of human society and libraries are also not spared from it. Cloud computing is one amongst such advancements in technology that facilitates computing services over the Internet to offer faster innovation, flexible resources and economies of scale. It helps in saving substantial capital costs without spending on in-house server storage and application needs. Cloud computing is expected to act like a boon for libraries as it provides various opportunities to connect their services with clouds. The present paper will highlight the possible applications of cloud computing in enhancing library services. The study also discusses the characteristics, models, advantages and disadvantages, types of cloud storage, need and usage of cloud computing.

Keywords: Cloud computing, IaaS, PaaS, SaaS, Interoperability, Models of cloud computing.

1. Introduction:

"Are the money spent on libraries yielding value in economic terms?", "do maintenance of libraries still matters?" the existence of libraries is being frequently questioned by the administrators and policy makers (funding agencies) these days (Neal, 2011). Tenopir (2010) also revealed that libraries are facing increasing calls for accountability that means libraries need to justify the amount being spent on them. That enforces libraries to execute their resources in more systematic and strategic manner and libraries have to plan their strategies with minimum resources.

The applications of information and communication technology (ICT) and its use in libraries brought changes with respect to storage, process, arrangement and dissemination of information. Whereas, in terms of information format, the shift from print to electronics along with features like simultaneous access to electronic resources irrespective of location and time. The libraries have been moved towards strengthening electronic or digital collection (Durant and Horava, 2015). The use of information technology and its newly emerged concepts have been adding to ease the library systems and services. Similarly, the Cloud Computing technology is expected offer great advantages for libraries to connect their services promptly with flexibilities of new information formats. The libraries are adopting computing resources and services that need not to own by the libraries to serve end user (Scale, 2009).

2. Objective of the study:

The objective of this study is to review the use of cloud computing in academic libraries and how we can motivate in the use of the technology in library services.

3. What is cloud computing?

Cloud computing has revolutionized the way enterprises manage, scale and process large-scale applications and derive value from data. It is a computing technology which facilitates in sharing the resources and services over the internet rather than having the services on local server. It transform the way systems are built and services delivered, providing libraries with an opportunity to extend their impact. The concept emerge way back in the 1960s, when John McCarthy opined that computation may someday be organised as public utility "Wikipedia" according to NIST (National Institute of Standards and Technology) (2011) "Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (eg. Networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction."

Kaushik and Kumar (2013) stated that cloud computing contains features of different technologies, like web2.0, semantic web, utility, unified and grid computing, etc. Now, it has emerged as one of the most popular virtual technology for libraries to effective delivery of services. Gartner (2018) define cloud computing "a style of computing in which massively scalable and elastic IT-enabled capabilities are delivered as a service to external customers using Internet technologies."Buyya (2009) defined 'Cloud computing is a parallel and distributed computing system consisting of a collection of inter-connected and virtualized computers that are dynamically provisioned and presented as one or more unified computing resources based on Service Level Agreements (SLA) established through negotiation between the service provider and consumers'. Romero (2012) defined cloud computing as the 'cloud', a highly scalable platform promising quick access to hardware and software over the Internet. It can be easily managed and accessed by non-expert users as well. Mitchel (2010) highlighted some challenges for the libraries in adoption for cloud computing. One of the challenges is training to the professional staff. As information literacy or training to the staff become essential in view of ease in experimenting on new services and security of data is the another prominent challenge while using cloud computing in the libraries.

4. Essential of cloud computing in libraries:

Information technology plays a vital role in equipping library resources right from collection development to storage, organization, processing and analysis to dissemination. Library faces many challenges but the addition of the new concepts and technology ease the practices. Cloud computing is completely a new technology that the library professional should be aware of it and also the application in library services. Academic libraries are still not able to take the advantages rather they are stuck with the server based Integrated Library System. But the popularity of cloud computing cannot be ignored in libraries. Some of the activities at the library with cloud computing are:

- Automation of library activities using LMS;
- 24*7 access of library;
- Creating Digital library to link the online databases using IP, institutional repositories, free resources, e-learning and training materials, question papers, and archives uploading;
- Library portal for new book request, queries, feedback, newsletter;
- Creating group e-mails to the users;

- Web OPAC, online renewal, reservations etc…
- Federated searching;
- Large number of documents can be stored in a public server using cloud;
- Online attendance monitoring, student's records maintenance, fine collections etc…
- Creating and uploading newsletter, new arrivals and forthcoming events for user community (CAS);
- Creating alerts to the user community based on SDI.

5. Models of cloud computing:

5.1 Service Models:

There are many types of cloud computing models but the service models widely used for delivering the different cloud based services are described as follows:

i) IaaS (Infrastructure as a Service)
ii) Paas (Platform as a Service)
iii) SaaS (Software as a Service)
iv) RaaS (Recovery as a Service)

5.1.1. IaaS (Infrastructure as a Service):

It is the lowest level of cloud solution. It is a basic layer in cloud computing model and one of the three main categories of cloud computing services. It is a fully-outsources service. Organizations can be developed entire infrastructure on demand. For example, Amazon web services, Google based services etc.

5.1.1.1 Benefits of IaaS solutions:

- Reduces cost of ownership and capital expenditures;
- Users pay only for the service;
- Users can scale up and down based on their requirements;
- Most flexible cloud computing model;
- Allows for automated deployment of storage, networking, servers, and processing power;
- Hardware can be purchased based on consumption;
- Gives clients complete control of their infrastructure;
- Resources can be purchased as-needed;
- Is highly scalable.

5.1.2.(PaaS) Platform as a Service:

It is similar to IaaS but is more advanced. It helps in generating the computing platforms to run the software and other tools over the internet without managing the software and hardware at the end of user side. Such models are mostly used by companies. For example, Windows Azure, GoGrid, etc.

5.1.2.1 Benefits of PaaS Solutions:

- Community;
- No more upgrades;
- Lower cost;

- Simplified deployment;
- Makes the development and deployment of apps simple and cost-effective
- Scalable;
- Highly available;
- Greatly reduces the amount of coding;
- Automates business policy;
- Allows easy migration to the hybrid model.

5.1.3. (SaaS) Software as a Service:

Software as a Service, also known as cloud application services is the most commonly used option for business in cloud market. SaaS utilizes the internet to deliver applications to its users, which are managed by a third party vendor. For example – Gmail services, online storage facilities etc.

5.1.3.1 Benefits of SaaS Solutions:

- Rapid Scalability;
- Accessibility from any location with Internet;
- Eliminates infrastructure concerns;
- Custom levels of service offerings;
- Bundled maintenance and support;
- **Gain access to sophisticated application;**
- **Pay only for what you use;**
- **Use free client software;**
- **Mobilise your workforce easily;**
- **Access app data from anywhere.**

5.1.4. Recovery as a Service (RaaS):

Recovery as a Service refer as Disaster Recovery as a Service (DRaaS) is a category of cloud computing used for protecting an application or data from a natural or human disaster or service disruption at one location by enabling a full recovery in the cloud. RaaS solutions helps companies to replace their backup, archiving, disaster recovery and business continuity solutions in a single, integrated platform. RaaS providers protect and can help companies recover entire data centers, servers (OS, applications, configuration and data), and data (files and databases). It helps businesses to reduce the impact of downtime when disasters happen.

1.1.1 5.1.4.1. Benefits of RaaS Solutions

- Prevent temporary or permanent loss of critical company data;
- Prevents permanent loss of physical infrastructure, including IT infrastructure;
- Cost-effective way of recovering data;
- Enables faster recovery while maintaining accuracy;
- Offer greater flexibility on the type of backup required.

5.2. Deployment Models:

There are four types of cloud deployment models that have been defined in the cloud community. The details of the models are discussed as follows:

5.2.1. Private cloud:

This are dedicated to one organization and often have much specific controls. It is provisioned for exclusive use by a single organization comprising multiple consumers (e.g., business units). Using private cloud storage allows to control highly sensitive data by meeting regulations and industry based criteria whether that be medical records, trade secrets, or other classified information.

5.2.2. Community cloud:

This is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be owned, managed, and operated by one or more of the organizations in the community, a third party, or some combination of them, and it may exist on or off premises

5.2.3. Public cloud:

This is open for use by the general public. It may be owned, managed, and operated by a business, academic, or government organization, or some combination of them. It exists on the premises of the cloud provider. Resources are shared by hundreds or thousands of people.

5.2.4. Hybrid cloud:

The cloud infrastructure is a composition of two or more distinct cloud infrastructures (private, community, or public) that remain unique entities, but are bound together by standardized or proprietary technology that enables data and application portability. Hybrid cloud solutions are a blend of public and private clouds. This is a more complex cloud solution in that the organization must manage multiple platforms and determine where data is stored.

6. Use of Cloud Computing in Libraries:

Cloud computing offers interesting options for libraries to reduce technology cost and increase capacity reliability and performance for library automation activities. It has a large potential for libraries. They can put more content into the cloud computing and access it anytime, anywhere.

The possible fields identified for cloud computing application in libraries are discussed below:

6.1 Institutional Repository/Digital Library:

Libraries are developing and maintaining an institutional repository to share its in-house publications like reports, working papers, annual reports, newsletters etc. To create institutional repository Dspace and Fedora are used for building digital libraries and repositories. Dura cloud provides complete solutions for developing digital

libraries and repositories with standard interface and open source codes for both software.

6.2 File Storage:

To store heavy files the libraries can avail the facilities of cloud computing services which are offering storage space, such as dropbox, google doc, flicker, skydrive etc.

6.3 Data Sharing:

The cloud computing offers easy sharing of common data stored on the cloud. The services such as Union catalogue, copy cataloguing facility and converting bibliographical records in MARC format etc. can be available with the help of cloud computing. OCLC World Cat is one of the examples of this service.

6.4 Library Automation:
Library management software like Libris, OSS and some KOHA development groups are offering cloud based services of library automation. This SaaS approach service of the cloud computing save libraries from investing in hardware used in automation purpose.

6.5 Community Power:

The cloud computing also offers to establish community network within the library and out of the library as well. The service like Researchgate is one of the key examples of services for academic community. The Facebook, Twitter are the examples of social community services being executed over cloud.

6.6 Website hosting:

Website hosting is one of the basic service of cloud computing. Google Site facility is one of the examples of free website hosting that are commonly being used in libraries.

7. Advantages and disadvantages of Cloud computing in library services: Cloud computing in libraries service has its advantages and disadvantages like other technology.

7.1. Advantages:

- Cost saving;
- Scalability;
- Easy on installation and maintenance;
- Increased storage;
- High speed;
- Transparency;
- Availability anytime anywhere;
- Cloud OPAC
- Better security and accessibility.

7.2. Disadvantages:

- Data security and privacy;
- Low bandwidth;
- Incompatibility;
- **Denial of Service;**
- **Lack of due diligence;**
- **Weaknesses of shared technology;**

8. Conclusion:

Libraries are moving towards cloud computing technology. Although Cloud computing is still in the initial stage the impacts carried by cloud computing are obvious. Libraries are taking advantages of the cloud based services to have a new leap in the near future. Libraries need to improve their services and relevance. Cloud computing can help libraries collaborate with each other in a facile manner. So it is time for the libraries to use the cloud base technology for libraries services to provide reliable and rapid services to their users. The library professional in this virtual era should also start making cloud based services as a reliable medium to disseminate the library services to their users with ease of use and to save the time of the users. Cloud based library services could bring the power of library cooperation to core library management.

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Improved Trivariate Spectral Collocation Method of Solution for Two-dimensional Nonlinear Initial-boundary Value Problems via Domain Decomposition

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Abstract. In this article, we propose an accurate and computationally efficient overlapping grid based multi-domain trivariate spectral collocation method for solving two-dimensional nonlinear initial-boundary value problems over large time intervals. In the current solution approach, the quasi-linearization method is used to simplify the nonlinear PDEs. The spatial domain is decomposed into a sequence of overlapping subintervals of equal length whereas the time domain is broken into equal non-overlapping subintervals. Trivariate Lagrange interpolating polynomials constructed using Chebyshev-Gauss-Lobatto (CGL) points is used to approximate solutions to the nonlinear PDEs. A purely spectral collocation-based discretization is employed on the two space variables and the time variable on each subinterval to yield a system of linear algebraic equations that is solved. The PDEs are solved simultaneously across all subintervals in space but independently on each subinterval in time with the continuity condition been applied to obtain initial conditions in subsequent time subintervals. The numerical scheme is tested on typical examples of two dimensional nonlinear parabolic PDEs reported in the literature as a single equation or system of equations. Numerical results confirm that the proposed solution approach is highly accurate and computationally efficient when applied to solve two-dimensional initial-boundary value problems defined on large time intervals and large spatial domains when compared with the standard method on a single domain. In addition, it is demonstrated that the overlapping grids technique preserve the stability of the numerical scheme when solving fluid mechanics problems for large Reynolds numbers. The new error bound theorems and proofs on trivariate polynomial interpolation that we present support findings from the numerical simulations.

Keywords: Trivariate Lagrange Interpolating Polynomials, Spectral Collocation, Two-dimensional Parabolic PDEs, Overlapping Grid, Non-overlapping Grids, CGL Points.

12 Introduction

Spectral collocation-based methods, since their existence, have gained popularity in the numerical approximation of the solution of partial differential equations owing to their superior accuracy when applied to solve problems with smooth solutions [1]. They are particularly desirable for approximating solutions of nonlinear PDEs defined on regular geometries and they require a few numbers of grid points to achieve

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results with stringent accuracy [2]. Despite the benefits of the spectral collocation methods, review of the literature indicates that previous application of purely spectral collocation methods has focused on the solutions of ordinary differential equations and or partial differential equations involving two independent variables [3]. There exists extensive literature in the studies by Zhao et al. [4] and Tadmor [5] where the spectral collocation methods have been applied successfully on these types of problems and highly accurate results achieved in a computationally efficient manner have been reported. In a few noticeable exceptions, for instance, in [6] where spectral collocation methods have been applied to obtain numerical solutions of two-dimensional time-dependent PDEs, such has been achieved through the application of spectral collocation discretization on the space variables and finite difference discretization on the time variable. It is well known that finite difference methods require many grid points to yield accurate results which can hardly match those obtained when spectral collocation methods are applied on PDEs defined on simple geometries particularly if the underlying solutions are smooth. As observed in [7], the accuracy of a single domain based spectral collocation method deteriorates when the method is applied to solve PDE defined over a large time interval even with a large number of grid points. As shown by Motsa et al. [8], the utility of the spectral collocation method can be improved by decomposing the large time domain into smaller non-overlapping subintervals and solving the differential equation independently at each of these subintervals in time. Further, as it will be shown later, decomposing the spatial domains into a sequence of overlapping subintervals improves accuracy when solving differential equations defined over large spatial domains and presents a stable numerical scheme when solving a differential equation for very large or small values of the parameters. Motivated by these facts, we propose an overlapping grid based multi-domain trivariate spectral collocation method solving nonlinear two-dimensional time-dependent PDEs defined on large rectangular domains over large time intervals.

Typical examples of two-dimensional nonlinear time-dependent PDEs considered in this study include the nonlinear PDEs given as single equations that describe the problem of unsteady two-dimensional heat and mass transfer, firstly, in quiescent media with chemical reaction [9], and secondly, with power-law temperature-dependent thermal conductivity [10]. The problems of heat and mass transfer phenomena are found throughout virtually all of the physical world and the industrial domain. For nonlinear PDEs described as systems of equations we consider a case of the coupled two-dimensional Burger's system [11] and the two-dimensional reaction-diffusion Brusselator system [12]. The Burger's equation is a fundamental PDE from fluid mechanics. Burger's equation occurs in various areas of applied mathematics, such as modeling of hydrodynamics turbulence, shock waves theory, and traffic flow problems. It also describes the sedimentation of particles in fluid suspensions under the effect of gravity, transport, and dispersion of pollutants in rives [13]. The second system of PDEs considered is the Brusselator system arising in the mathematical modeling of chemical systems such as enzymatic reactions, and in plasma and laser physics in multiple coupling between certain modes [14]. Brusselator model is also evident in the formation of the ozone layer through a triple collision of oxygen atoms. The problems considered here have exact solutions and have been reported in the literature to be very useful in testing newly developed numerical methods of solution for nonlinear partial differential equations arising in modeling of various aspects of the real world. We, therefore, consider them appropriate to demonstrate the effectiveness of the current method of solution.

Exact solutions of two-dimensional heat and mass transfer problem in quiescent media with chemical reaction were discussed by Polyanin et al. [9]. The problem has been solved numerically using an implicit finite-difference method by Chamkha in

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[15]. On the other hand, the problem of two-dimensional heat and mass transfer with power-law temperature-dependent thermal conductivity was examined by authors in [10] where they obtained a particular exact solution using the Adomian decomposition method and numerical methods of solution for this problem can be found in references given therein. Burger [11] pioneered investigation of the mathematical properties of Burger's equation. Analytical solution of unsteady two dimensional coupled Burger's equation was first given by Fletcher [16] using the Hopf-Cole transformation. In [17], the differential transformation method was applied to obtain the analytical solution of a coupled unsteady Burger's equation. Numerical solution of Burger's equation is a natural and first step towards developing methods for the computation of complex flows. Burger's equation has been used intensively to test new approaches in computational fluid dynamics by first implementing novel and new approaches to it, for instance, a numerical method based on local discontinuous Galerkin finite element was analyzed in [18] to solve two-dimensional Burger's equation. The local radial basis functions collocation method to approximate the numerical solution of the transient coupled Burgers' equation was examined in [19]. In recent the decades, Brusellor model has been extensively studied both numerically and analytically. Twizell et al. [20] developed a second-order finite difference method for the numerical solution of the initial-boundary value problems of the Brusselator model. Khan et al. [21] found exact solutions of the Brusselator reaction-diffusion model using the Exp-function method. Biazar and Ayati [22] obtained an approximate solution to the Brusselator system by applying the Adomian decomposition method.

In this paper, a purely spectral collocation method, namely, the overlapping grids multi-domain trivariate spectral collocation method is introduced and applied to solve two-dimensional initial-boundary value problems defined on over large space and time intervals. The solution process involves, first, the simplification of the PDE using the quasi-linearization method. The spatial domain is decomposed into a sequence of equal overlapping subintervals and the large time domain is decomposed into equal non-overlapping subintervals. The solution to the linearized PDE is assumed to be a trivariate Lagrange interpolating polynomials constructed on Chebyshev-Gauss-Lobatto points defined on each subinterval. The PDE is discretized in all space variables and time variable using spectral collocation method to yield a system of linear algebraic equations that are solved iteratively. The solution of the PDE is computed simultaneously across all subintervals in space and independently at each subinterval in time applying the continuity condition to obtain initial condition from second to last subintervals. The current numerical method is tested using typical examples of initial-boundary value problems reported in the literature. The accuracy of the numerical scheme is accessing by computing the absolute difference between the numerical results with the exact solutions which are presented and discussed in tabular and graphical form. Numerical results obtained using the current solution approach are compared against those obtained using the standard single domain based trivariate spectral collocation method. Findings from numerical simulations show that the current method yields highly accurate results in a computationally efficient manner when applied to problems defined on a large time interval, large spatial domains, and obtaining numerical approximations of solutions to the differential equation for large parameter values. To the best of our knowledge, the spectral collocation-based method with Chebyshev-Gauss-Lobatto points has not been applied on overlapping grids in two-dimensional space and non-overlapping grids in time simultaneously. The new theoretical results of error bound theorems support the finding of the numerical simulations.

The rest of this paper is organized as follows. In Section 2, we describe the overlapping grids based multi-domain trivariate spectral collocation method for approxi-

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mating the solution of two-dimensional nonlinear initial-boundary value problems described as single equations or systems of equations. In Section 3, the error bound theorems and proofs emanating from trivariate Lagrange interpolating polynomials constructed on Chebyshev-Gauss-Lobatto grid points emerge. In Section 4, we give four test examples where the numerical method is applied to demonstrate its applicability. Section 5 is devoted to results and discussion. In Section 6, we summarize the findings and point out the direction of future work.

13 The method of solution

In this section, we describe the algorithm for solving two-dimensional partial differential equations of initial-boundary value problems type. The present investigation focuses on the partial differential equations of the second order. For purposes of simplicity, this section is divided into two subsections. In the first subsection, we construct numerical algorithms for solving nonlinear PDEs that are expressible as a single equation and in the second subsection; the idea is extended to systems of nonlinear PDEs.

13.1 Method of solution for a single nonlinear PDE

In this subsection, the overlapping grids based multi-domain spectral collocation algorithm for solving two-dimensional partial differential equations of initial-boundary value problems type given as a single nonlinear equation is described. To illustrate the solution process, we consider a general second-order nonlinear PDE that takes the form;

$$\frac{\partial u}{\partial t} = F\left(\frac{\partial^2 u}{\partial x^2}, \frac{\partial^2 u}{\partial y^2}, \frac{\partial u}{\partial x}, \frac{\partial u}{\partial y}, u\right), \quad (x, y) \in (a, b) \times (c, d), \; t \in (0, \mathrm{T}], \tag{3}$$

where F is a nonlinear operator operating on the unknown function u and its first and second order spatial derivatives. Eq. (1) is solved subject to the boundary conditions

$$\alpha_1^{\mathrm{a}} \frac{\partial \mathrm{u}}{\partial \mathrm{x}}(\mathrm{a}, \mathrm{y}, \mathrm{t}) + \alpha_0^{\mathrm{a}} u(\mathrm{a}, \mathrm{y}, \mathrm{t}) = \mathrm{f_a}(\mathrm{y}, \mathrm{t}), \quad \alpha_1^{\mathrm{b}} \frac{\partial \mathrm{u}}{\partial \mathrm{x}}(\mathrm{b}, \mathrm{y}, \mathrm{t}) + \alpha_0^{\mathrm{b}} u(\mathrm{b}, \mathrm{y}, \mathrm{t}) = \mathrm{f_b}(\mathrm{y}, \mathrm{t}),$$

$$\beta_1^{\mathrm{c}} \frac{\partial \mathrm{u}}{\partial \mathrm{y}}(\mathrm{x}, \mathrm{c}, \mathrm{t}) + \beta_0^{\mathrm{c}} u(\mathrm{x}, \mathrm{c}, \mathrm{t}) = \mathrm{g_c}(\mathrm{x}, \mathrm{t}), \quad \beta_1^{\mathrm{d}} \frac{\partial \mathrm{u}}{\partial \mathrm{y}}(\mathrm{x}, \mathrm{d}, \mathrm{t}) + \beta_0^{\mathrm{d}} u(\mathrm{x}, \mathrm{d}, \mathrm{t}) = \mathrm{g_d}(\mathrm{x}, \mathrm{t}), \tag{4}$$

where α_1^a, α_0^a, α_1^b, α_0^b, β_1^c, β_0^c, β_1^d, β_0^d are known constants and $f_a(y,t)$, $f_b(y,t)$, $g_c(x,t)$, $g_d(x,t)$, are known functions. The initial condition for this problem is given as

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$$u(x, y, 0) = h(x, y),$$

(5)

The solution process involves the stages given in the subsections below;

2.1.1 The quasi-linearization method

The PDE Eq. (1) is first simplified using the quasi-linearization method (QLM) of Bellman and Kalaba [24]. The QLM is based on the Newton-Raphson method and is constructed from the linear terms of Taylor series expansion about an initial approximation to the solution. The QLM assumes that the difference between solutions at

two successive iterations, denoted by $u_{s+1} - u_s$ is very small. In particular, the QLM is comparable to the linear approximation of a function of several variables where the derivatives of a different order and the previous approximation to solution assumes the role of independent variables and the functional value at the reference point, respectively. Finer details about linear approximation of functions can be found in any elementary book on differential calculus. Applying the QLM on Eq. (1) we obtain

$$\delta_{4,s}\frac{\partial^2 u_{s+1}}{\partial x^2} + \delta_{3,s}\frac{\partial^2 u_{s+1}}{\partial y^2} + \delta_{2,s}\frac{\partial u_{s+1}}{\partial x} + \delta_{1,s}\frac{\partial u_{s+1}}{\partial y} + \delta_{0,s}u_{s+1} - \dot{u}_{s+1} = R_s,$$

(6)

where

$$\delta_{4,s} = \frac{\partial F}{\partial (u_{xx})_s},\quad \delta_{3,s} = \frac{\partial F}{\partial (u_{yy})_s},\quad \delta_{2,s} = \frac{\partial F}{\partial (u_x)_s},\quad \delta_{1,s} = \frac{\partial F}{\partial (u_y)_s},\quad \delta_{0,s} = \frac{\partial F}{\partial (u)_s},$$

$$R_s = \delta_{4,s}(u_{xx})_s + \delta_{3,s}(u_{yy})_s + \delta_{2,s}(u_x)_s + \delta_{1,s}(u_y)_s + \delta_{0,s}u_s - F_s,$$

(7)

The subscripts in u_{xx} and u_x denotes second and the first partial derivatives of u with respect to x. Similarly, the first and the second derivatives with respect to y are denoted u_y and u_{yy}, respectively. The dot in $\dot{u}$ denotes derivative with respect to t and s signifies the previous iteration.

2.1.2 Domain decomposition and discretization

If we let $t \in \Gamma$ where $\Gamma = [0, T]$. The domain of approximation in the time direction Γ is decomposed into equal p non-overlapping subintervals as;

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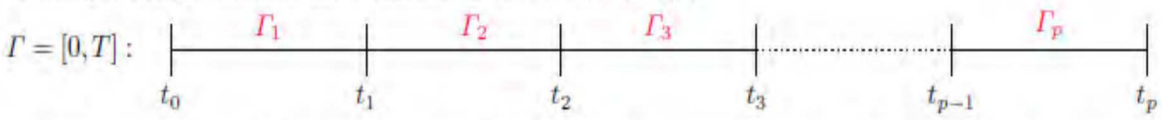
$$\Gamma_\tau = [t_{\tau-1}, t_\tau], \quad t_{\tau-1} < t_\tau, \quad t_0 = 0, \quad t_p = T, \quad \tau = 1,2,\dots,p.$$

(8)

The domain decomposition in the t variable is illustrated below;



The subdomain $t \in [t_{\tau-1}, t_\tau]$ in each of the τ^{th} subinterval is transformed into $\hat{t} \in [-1,1]$ using the linear map

$$\hat{t}(t) = \frac{2}{t_\tau - t_{\tau-1}}\left[t - \frac{1}{2}(t_\tau + t_{\tau-1})\right], \quad t \in [t_{\tau-1}, t_\tau], \quad \hat{t} \in [-1,1], \quad \tau = 1,2,\dots,p,$$

(9)

before the spectral collocation is applied. The domain of approximation in each time subinterval is further discretized into into $N_t + 1$ Chebyshev-Gauss-Lobatto nodes defined in [25] as

$$\{\hat{t}_k\}_{k=0}^{N_t} = \cos\left(\frac{k\pi}{N_t}\right).$$

(10)

The entire grid in the t variable can be represented as

$$\left\{0 = t_{N_t}^{(1)}, \dots, t_0^{(1)} = t_{N_t}^{(2)}, \dots, t_0^{(\tau-1)} = t_{N_t}^{(\tau)}, \dots, t_0^{(p)} = T, \quad 2 \le \tau \le p\right\}.$$

(11)

The superscripts and subscripts denote the subinterval and grid points indices, respectively. The spatial domain $x \in [a, b]$ is decomposed into q overlapping subintervals of equal length as

$$\Lambda_l = [x_{l-1}, \bar{x}_l], \quad x_{l-1} < x_l < \bar{x}_l, \quad x_0 = a, \quad \bar{x}_q = b, \quad l = 1,2,\dots,q,$$

(12)

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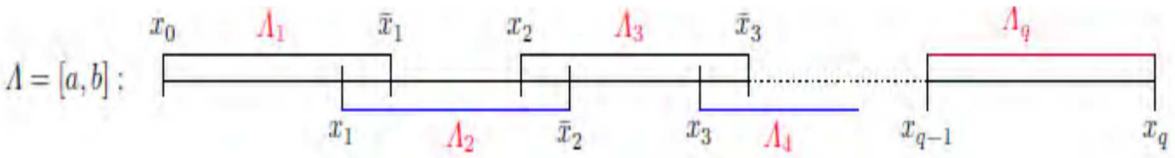
where $x_{l-1} < \bar{x}_l$ depicts the overlapping nature. Pictorially, this overlapping

domain decomposition in x can be represented as;



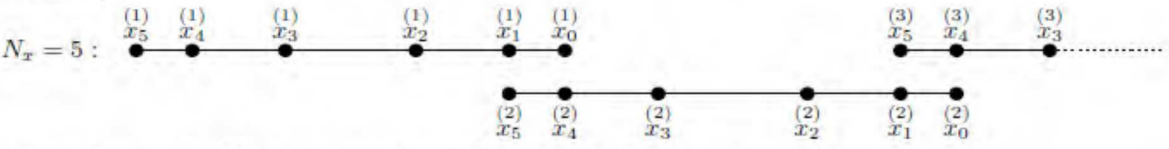
The computational domain $[x_{l-1}, \bar{x}_l]$ in the l^{th} subinterval is then transformed

into $\hat{x} \in [-1,1]$ where the standard Chebyshev differentiation matrix is defined

by applying the linear map

$$\hat{x}(x) = \frac{2}{\bar{x}_l - x_{l-1}}\left[x - \frac{1}{2}(\bar{x}_l + x_{l-1})\right], \quad x \in [x_{l-1}, \bar{x}_l], \quad \hat{x} \in [-1,1]. \tag{13}$$

Further, each subinterval is discretized into $N_x + 1$ Chebyshev Gauss Lobatto points. The subintervals in the decomposed domain overlap in such a manner that the last two points in the Λ_l subinterval overlap with the first two points in the Λ_{l+1} subinterval and they remain common. For illustrative purpose, the case $N_x = 5$ is considered;



In general, the set of grid points over the entire x domain can be represented as

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$$\left\{a = x_{N_x}^{(1)}, \dots, x_1^{(1)} = x_{N_x}^{(2)}, x_0^{(1)} = x_{N_x-1}^{(2)}, \dots, x_1^{(l-1)} = x_{N_x}^{(l)}, x_0^{(l-1)} = x_{N_x-1}^{(l)}, \dots, x_0^{(q)} = b, \quad 2 \le l \le q\right\}.$$

(14)

Similarly, the spatial domain in y variable $[c, d]$ is decomposed into m equal overlapping subintervals which are further discretized into $N_y + 1$ collocation points. The subdivision of the computational domain in y is illustrated by

$$\Omega_\zeta = [y_{\zeta-1}, \bar{y}_\zeta], \quad y_{\zeta-1} < y_\zeta < \bar{y}_\zeta, \quad y_0 = c, \quad \bar{y}_m = d, \quad \zeta = 1,2, \dots, m,$$

(15)

and the overlapping nature is analogous to that in the x variable. The computational domain $[y_{\zeta-1}, \bar{y}_\zeta]$ in the ζ^{th} subinterval is transformed into $\hat{y} \in [-1,1]$ by applying the linear transformation

$$\hat{y}(y) = \frac{2}{\bar{y}_\zeta - y_{\zeta-1}}\left[y - \frac{1}{2}(\bar{y}_\zeta + y_{\zeta-1})\right], \quad y \in [y_{\zeta-1}, \bar{y}_\zeta], \quad \hat{y} \in [-1,1],$$

(16)

before spectral collocation is applied. The grid points in the entire y domain can be represented as

$$\left\{c = y_{N_y}^{(1)}, \dots, y_1^{(1)} = y_{N_y}^{(2)}, y_0^{(1)} = y_{N_y-1}^{(2)}, \dots, y_1^{(\zeta-1)} = y_{N_y}^{(\zeta)}, y_0^{(\zeta-1)} = y_{N_y-1}^{(\zeta)}, \dots, y_0^{(m)} = d \quad 2 \le \zeta \le m\right\}$$

. (17)

We remark that the number of subintervals q in x need not to be equal to the number of subintervals m in y. The ordering of grid points as illustrated in Eq. (12) and Eq. (15) signifies that the spectral collocation is done from right to left of the subinterval. The grid points in the l^{th} subinterval in x and the ζ^{th} subinterval in y variable are defined in [25] by

$$\{\hat{x}_i\}_{i=0}^{N_x} = \cos\left(\frac{i\pi}{N_x}\right), \quad \text{and} \quad \{\hat{y}_j\}_{j=0}^{N_y} = \cos\left(\frac{j\pi}{N_y}\right).$$

(18)

To obtain explicit expression of the length of each subinterval $L = \bar{x}_l - x_l$ in x and $Z = \bar{y}_\zeta - y_\zeta$ in y in terms of the number of subintervals q and m, respectively, we solve

$$qL - L(q-1)\left(\frac{1}{2} - \frac{1}{2}\cos\left\{\frac{\pi}{N_x}\right\}\right) = b - a, \quad mZ - Z(m-1)\left(\frac{1}{2} - \frac{1}{2}\cos\left\{\frac{\pi}{N_y}\right\}\right) = d - c,$$

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(19)

to obtain

$$L = \frac{b-a}{q+(1-q)\left(\frac{1}{2}-\frac{1}{2}\cos\left\{\frac{\pi}{N_x}\right\}\right)}, \quad \text{and} \quad Z = \frac{d-c}{m+(1-m)\left(\frac{1}{2}-\frac{1}{2}\cos\left\{\frac{\pi}{N_y}\right\}\right)}.$$

(20)

Consequently, we obtain the following relations;

$$\bar{x}_i = x_i + L\left(\frac{1}{2}-\frac{1}{2}\cos\left\{\frac{\pi}{N_x}\right\}\right), \quad \bar{y}_\zeta = y_\zeta + Z\left(\frac{1}{2}-\frac{1}{2}\cos\left\{\frac{\pi}{N_y}\right\}\right).$$

(21)

Eq. (19) is used in defining the boundaries of the overlapping subintervals when performing discretization.

2.1.3 Spectral collocation

The overlapping grids multi-domain trivariate spectral collocation method is implemented on the linearized QLM scheme Eq. (4) as detailed below. For simplicity, the label $u^{(\tau)}$, $\tau = 1,2,\dots,p,$ will been used to distinguish solutions at different subintervals in time. We note that the application of the non-overlapping technique is limited to the time interval only. The PDE is solved independently at each subinterval in t, $\tau = 1,2,\dots,p,$ and therefore we must solve

$$\delta_{4,s}\frac{\partial^2 u_{s+1}^{(\tau)}}{\partial x^2} + \delta_{3,s}\frac{\partial^2 u_{s+1}^{(\tau)}}{\partial y^2} + \delta_{2,s}\frac{\partial u_{s+1}^{(\tau)}}{\partial x} + \delta_{1,s}\frac{\partial u_{s+1}^{(\tau)}}{\partial y} + \delta_{0,s}u^{(\tau)}{}_{s+1} - \frac{\partial u_{s+1}^{(\tau)}}{\partial t} = R_s,$$

(22)

$$(x,y) \in (a,b)\times(c,d),\ t \in (t_{\tau-1},t_\tau],$$

subject to the boundary conditions

$$\alpha_1^a\frac{\partial u_{s+1}^{(\tau)}}{\partial x}(a,y,t) + \alpha_0^a u_{s+1}^{(\tau)}(a,y,t) = f_a(y,t),\ \alpha_1^b\frac{\partial u_{s+1}^{(\tau)}}{\partial x}(b,y,t) + \alpha_0^b u_{s+1}^{(\tau)}(b,y,t) = f_b(y,t),$$

$$\beta_1^c\frac{\partial u_{s+1}^{(\tau)}}{\partial y}(x,c,t) + \beta_0^c u_{s+1}^{(\tau)}(x,c,t) = g_c(x,t),\ \beta_1^d\frac{\partial u_{s+1}^{(\tau)}}{\partial y}(x,d,t) + \beta_0^d u_{s+1}^{(\tau)}(x,d,t) = g_d(x,t),$$

(23)

and the initial condition

$$u^{(1)}(x,y,0) = h(,x,y), \quad u^{(\tau)}(x,y,t_{\tau-1}) = u^{(\tau-1)}(x,y,t_{\tau-1}),\ \tau = 2,3,\dots,p,$$
$$(x,y) \in [a,b]\times[c,d].$$

(24)

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In the solution process, the approximate solution of the linearized QLM scheme Eq. (4) at each subinterval in time is assumed to be the trivariate Lagrange interpolating polynomial that takes the form;

$$u^{(\tau)}(x,y,t) \approx U^{(\tau)}(x,y,t) = \sum_{p=0}^{N_x}\sum_{q=0}^{N_y}\sum_{r=0}^{N_t} U^{(\tau)}(x_p,y_q,t_r)L_p(x)L_q(y)L_r(t)$$

(25)

The spatial differentiation matrix in x is approximated at the collocation nodes $(\hat{x}_i,\hat{y}_j,\hat{t}_k)$, for $j = 0,1,\dots,N_y$, and $k = 0,1,\dots,N_t$ in the l^{th} subinterval as follows;

$$\frac{\partial u^{(\tau)}}{\partial x}(\hat{x}_i,\hat{y}_j,\hat{t}_k) \approx \sum_{p=0}^{N_x}\sum_{q=0}^{N_y}\sum_{r=0}^{N_t} U^{(\tau)}(x_p,y_q,t_r)L'_p(\hat{x}_i)L_q(\hat{y}_j)L_r(\hat{t}_k) = \sum_{p=0}^{N_x} U^{(\tau)}(x_p,y_j,t_k)\,L'_p(\hat{x}_i) = \boldsymbol{D}^i\boldsymbol{U}_k^j = \left(\frac{2}{L}\right)\widehat{\boldsymbol{D}}^i\boldsymbol{U}_k^j$$

,

(26)

where $\widehat{\boldsymbol{D}}^l = \left(\frac{L}{2}\right)\boldsymbol{D}^i$ is the standard first order Chebyshev differentiation matrix of size $(N_x+1)\times(N_x+1)$ defined in [25]. The higher order differentiation matrices are obtained using matrix multiplication. The vector $\boldsymbol{U}_k^j$ is defined as

$$\boldsymbol{U}_k^j = \left[u(x_0,y_j,t_k),u(x_1,y_j,t_k),\dots,u(x_{N_x},y_j,t_k)\right]^T,\quad j = 0,1,\dots,N_y,\quad k = 0,1,\dots,N_t,$$

(27)

where T denotes matrix transpose. Similarly, the spatial differentiation matrix in y is approximated at the collocation points nodes $(\hat{x}_i,\hat{y}_j,\hat{t}_k)$, for $i = 0,1,\dots,N_x$, and $k = 0,1,\dots,N_t$ in the ζ-th subinterval as

$$\frac{\partial u^{(\tau)}}{\partial y}(\hat{x}_i,\hat{y}_j,\hat{t}_k) \approx \sum_{q=0}^{N_y} U^{(\tau)}(x_i,y_q,t_k)\,L'_q(\hat{y}_j) = \sum_{q=0}^{N_y}\bar{D}_{j,q}^{\zeta}\boldsymbol{U}_k^q = \sum_{q=0}^{N_y}\left(\frac{2}{z}\right)\widehat{\bar{D}}_{j,q}^{\zeta}\boldsymbol{U}_k^q,$$

(28)

where $\widehat{\bar{D}}_{j,q}^{\zeta} = \left(\frac{z}{2}\right)\bar{D}_{j,q}^{\zeta}, j,q = 0,1,2,\dots,N_y,$ are entries of a standard first order Chebyshev differentiation matrix of size $(N_y+1)\times(N_y+1)$. Higher order differentiation matrix with respect to y can be obtained using matrix multiplication. Finally, the differentiation matrix in t at the collocation points $(\hat{x}_i,\hat{y}_j,\hat{t}_k)$, for $i = 0,1,\dots,N_x$, and $j = 0,1,\dots,N_y$ in the τ-th subinterval is approximated as;

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$$\frac{\partial u^{(\tau)}}{\partial t}\left(\hat{x}_i,\hat{y}_j,\hat{t}_k\right) \approx \sum_{r=0}^{N_t}\sum_{q=0}^{N_y} U^{(\tau)}\left(x_i,y_j,t_r\right) L'_r(\hat{t}_k) = \sum_{r=0}^{N_t}\sum_{q=0}^{N_y} \bar{\bar{D}}_{k,r}\boldsymbol{U}_r^q = \sum_{r=0}^{N_t}\sum_{q=0}^{N_y}\left(\frac{2}{t_\tau - t_{\tau-1}}\right)\hat{\bar{\bar{D}}}_{k,r}\boldsymbol{U}_r^q,$$

(29)

$$\tau = 1,2,\ldots,p,$$

where $\hat{\bar{\bar{D}}}_{k,r} = \left(\frac{t_\tau - t_{\tau-1}}{2}\right)\bar{\bar{D}}_{k,r},\ \ k,r = 0,1,2,\ldots,N_t,$ are entries of a standard first order Chebyshev differentiation matrix of size $(N_t+1)\times(N_t+1)$. We remark that the bar in $\bar{D}$ at Eq. (26) and double bar in $\bar{\bar{D}}$ at Eq. (27) distinguishes the differentiation matrix in y and t, respectively, from that in x. We note that in generating the sequence of vectors $\boldsymbol{U}_k^j,\ j = 0,1,2,\ldots,N_y,\ k = 0,1,2,\ldots,N_t,$ the superscript j is varied of each subscript k. Such a pattern will be useful when arranging the system of linear algebraic equations to assemble coefficient matrices.

The solution in spatial directions is computed simultaneously across all subintervals and the multi-domain approach only noticeable when assembling differentiation matrices. A key step towards the solution involve the assembling the differentiation matrices in both space variables. To achieve this, we take x variable as an example and since the last two points in the l^{th} subinterval and the first two points in the $(l+1)^{th}$ subinterval overlap and remains common, we discard the rows corresponding to the recurrent grid points and assemble the Chebyshev differentiation matrix $\mathbf{D}$ (without the superscript l) for the overlapping grids multi-domain approach in x as

$$\boldsymbol{D} = \begin{bmatrix}
D^q_{0,0} & \cdots & D^q_{0,N_x-1} & D^q_{0,N_x} & & & & & \\
D^q_{1,0} & \cdots & D^q_{1,N_x-1} & D^q_{1,N_x} & & & & & \\
\ddots & \ddots & \ddots & \ddots & & & & & \\
D^q_{N_x-1,0} & \cdots & D^q_{N_x-1,N_x-1} & D^q_{N_x-1,N_x} & & & & & \\
 & & D^2_{1,0} & D^2_{1,1} & \cdots & D^2_{1,N_x-1} & D^2_{1,N_x} & & \\
 & & \ddots & \ddots & \ddots & \ddots & \ddots & & \\
 & & D^2_{N_x-1,0} & D^2_{N_x-1,1} & \cdots & D^2_{N_x-1,N_x-1} & D^2_{N_x-1,N_x} & & \\
 & & & & & D^1_{1,0} & D^1_{1,1} & \cdots & \\
 & & & & & \ddots & \ddots & \ddots & \\
 & & & & & D^1_{N_x-1,0} & D^1_{N_x-1,1} & \cdots & \\
 & & & & & D^1_{N_x,0} & D^1_{N_x,1} & \cdots &
\end{bmatrix}$$

(30)

Here the empty entries of matrix $\mathbf{D}$ are zeros and $\boldsymbol{D}^l$ represents Chebyshev differentiation matrix in l^{th} subinterval in space variable x. The size of matrix $\mathbf{D}$ is

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$(\delta+1)\times(\delta+1)$, where $\delta = N_x + (N_x-1)\times(q-1)$. The differentiation matrix in y is assembled using $\bar{\boldsymbol{D}}^{\zeta}$ in a similar manner to obtain a matrix $\bar{\boldsymbol{D}}$ of size $(\sigma+1)\times(\sigma+1)$, where $\sigma = N_y + (N_y-1)\times(m-1)$. The second order differentiation matrices with respect to x and y, $\boldsymbol{D}^2$ and $\bar{\boldsymbol{D}}^2$, respectively, can be obtained using matrix multiplication. Notation wise, the bar in $\bar{\boldsymbol{D}}$ has been used to distinguish the assembled differentiation matrices in y from those in x.

2.1.4 Assembling linear system of algebraic equations

Using Eq. (24), Eq. (26) and Eq. (27) in the QLM scheme Eq. (20), we obtain a $(N_t+1)(\sigma+1)(\delta+1)$ system of linear algebraic equations given by;

$$\left[\delta_{4,s}\boldsymbol{D}^2+\delta_{2,s}\boldsymbol{D}+\delta_{0,s}\mathbf{I}\right]\bar{\boldsymbol{U}}_k^j+\sum_{q=0}^{\sigma}\left[\delta_{3,s}\bar{D}_{j,q}^2+\delta_{1,s}\bar{D}_{j,q}\right]\bar{\boldsymbol{U}}_k^q-\sum_{r=0}^{N_t}\sum_{q=0}^{\sigma}\bar{\bar{D}}_{k,r}\bar{\boldsymbol{U}}_r^q=\boldsymbol{R}_k^j,\ \tau=1,\dots,p, \tag{31}$$

For $j=0,1,2,\dots,\sigma,\ k=0,1,2,\dots,N_t$ and $\mathbf{I}$ is an identity matrix of size $(\delta+1)\times(\delta+1)$. The vector $\bar{\boldsymbol{U}}_k^j$ of size $(\delta+1)$ represents the values of the unknown function $u(x,y,t)$ evaluated at the $(\delta+1)$ grid points in entire x domain Eq. (12) and the j-th and the k-th grid points in y and t, respectively. The bar in $\bar{\boldsymbol{U}}_k^j$ distinguishes it from vector $\boldsymbol{U}_k^j$ of size (N_x+1) defined at Eq. (25). The initial condition when evaluated at the collocation points yield
$u^{(1)}(x_i,y_j,0)=u^{(1)}(x_i,y_j,t_{N_t})=h(x_i,y_j)=\bar{\boldsymbol{U}}_{N_t}^j,\ i=0,1,2,\dots,\delta,\ j=0,1,2,\dots,\sigma,$

$$u^{(\tau)}(x_i,y_j,t_{\tau-1})=u^{(\tau-1)}(x_i,y_j,t_{\tau-1}),\ \tau=2,3,\dots,p. \tag{32}$$

Using the initial condition Eq. (30), we can reduce Eq. (29) to

$$\left[\delta_{4,s}\boldsymbol{D}^2+\delta_{2,s}\boldsymbol{D}+\delta_{0,s}\mathbf{I}\right]\bar{\boldsymbol{U}}_k^j+\sum_{q=0}^{\sigma}\left[\delta_{3,s}\bar{D}_{j,q}^2+\delta_{1,s}\bar{D}_{j,q}\right]\bar{\boldsymbol{U}}_k^q-\sum_{r=0}^{N_t-1}\sum_{q=0}^{\sigma}\bar{\bar{\boldsymbol{D}}}_{k,r}\bar{\boldsymbol{U}}_r^q=\bar{\boldsymbol{R}}_k^j,\ \tau=1,\dots,p, \tag{33}$$

where $j=0,1,2,\dots,\sigma,\ k=0,1,2,\dots,N_t-1$, and

$$\bar{\boldsymbol{R}}_k^j=\boldsymbol{R}_k^j+\sum_{q=0}^{\sigma}\bar{\bar{\boldsymbol{D}}}_{k,N_t}\bar{\boldsymbol{U}}_{N_t}^q,\ k=0,1,2,\dots,N_t-1. \tag{34}$$

The linear system of equations in Eq. (31) can be expanded into $N_t(\sigma+1)(\delta+1)\times N_t(\sigma+1)(\delta+1)$ matrix system given by;

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$$\begin{bmatrix} \boldsymbol{A}_{0,0} & \boldsymbol{A}_{0,1} & \boldsymbol{A}_{0,2} & \cdots & \boldsymbol{A}_{0,N_t-1} \\ \boldsymbol{A}_{1,0} & \boldsymbol{A}_{1,1} & \boldsymbol{A}_{1,2} & \cdots & \boldsymbol{A}_{1,N_t-1} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ \boldsymbol{A}_{N_t-1,0} & \boldsymbol{A}_{N_t-1,1} & \boldsymbol{A}_{N_t-1,2} & \cdots & \boldsymbol{A}_{N_t-1,N_t-1} \end{bmatrix} \begin{bmatrix} \bar{\boldsymbol{U}}_0^j \\ \bar{\boldsymbol{U}}_1^j \\ \vdots \\ \bar{\boldsymbol{U}}_{N_t-1}^j \end{bmatrix} = \begin{bmatrix} \bar{\boldsymbol{R}}_0^j \\ \bar{\boldsymbol{R}}_1^j \\ \vdots \\ \bar{\boldsymbol{R}}_{N_t-1}^j \end{bmatrix}, \quad \tau = 1,2,3,\dots,p.$$

(35)

The matrix system Eq. (33) can be written compactly for $\tau = 1,2,3,\dots,p$, as

$$[\boldsymbol{A}]\left[\boldsymbol{U}^{(\tau)}\right] = \left[\boldsymbol{R}^{(\tau)}\right],$$

(36)

where

$$\boldsymbol{A}_{k,k} = \boldsymbol{B} - \bar{\bar{D}}_{k,k}\mathbf{I}_{xy}, \quad \boldsymbol{A}_{k,r} = -\bar{\bar{D}}_{k,r}\mathbf{I}_{xy}, \quad k \neq r, \; k,r = 0,1,2,,\dots,N_t - 1,$$

$$\boldsymbol{B}_{i,i} = \boldsymbol{\delta}_{4,s}\boldsymbol{D}^2 + \boldsymbol{\delta}_{2,s}\boldsymbol{D} + \boldsymbol{\delta}_{0,s}\mathbf{I}_x + \boldsymbol{\delta}_{3,s}\bar{D}_{i,i}^2\mathbf{I}_x + \boldsymbol{\delta}_{1,s}\bar{\boldsymbol{D}}_{i,i}\mathbf{I}_x,$$

(37)

$$\boldsymbol{B}_{i,j} = \boldsymbol{\delta}_{3,s}\bar{D}_{i,j}^2\mathbf{I}_x + \boldsymbol{\delta}_{1,s}\bar{\boldsymbol{D}}_{i,j}\mathbf{I}_x, \quad i \neq j, \quad i,j = 0,1,2,\dots,\sigma,$$

$$\boldsymbol{U}^{(\tau)} = \left[u^{(\tau)}(x_0,y_0,t_0),\dots,u^{(\tau)}(x_\delta,y_0,t_0),u^{(\tau)}(x_0,y_1,t_0),\dots,u^{(\tau)}(x_\delta,y_\sigma,t_0),\dots,u^{(\tau)}(x_\delta,y_\sigma\right.$$

and $\boldsymbol{R}^{(\tau)}$ is the right hand side corresponding to the unknown vector $\boldsymbol{U}^{(\tau)}$. The quantities $\mathbf{I}_{xy}$ and $\mathbf{I}_x$ are identity matrices of size $(\sigma+1)(\delta+1)\times(\sigma+1)(\delta+1)$ and $(\delta+1)\times(\delta+1)$, respectively. The boundary conditions Eq. (21) are evaluated at the collocation nodes as;

$$\alpha_1^a\sum_{p=0}^{\delta}D_{\delta,p}u^{(\tau)}(x_p,\mathrm{y}_j,\mathrm{t}_k) + \alpha_0^a u^{(\tau)}(x_\delta,\mathrm{y}_j,\mathrm{t}_k) = \mathrm{f_a}(\mathrm{y}_j,\mathrm{t}_k),$$

$$\alpha_1^b\sum_{p=0}^{\delta}D_{0,p}u^{(\tau)}(x_p,\mathrm{y}_j,\mathrm{t}_k) + \alpha_0^b u^{(\tau)}(x_0,\mathrm{y}_j,\mathrm{t}_k) = \mathrm{f_b}(\mathrm{y}_j,\mathrm{t}_k), \quad j = 0,1,2,\dots,,\sigma,$$
$$k = 0,1,2,\dots,N_t,$$

(38)

and

$$\beta_1^c\sum_{q=0}^{\sigma}\bar{D}_{\sigma,q}u^{(\tau)}(x_i,y_q,t_k) + \beta_0^c u^{(\tau)}(x_i,y_\sigma,t_k) = \mathrm{g_c}(\mathrm{x}_i,\mathrm{t}_k),$$

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$$\beta_1^d \sum_{q=0}^{\sigma} \bar{D}_{0,q}\, u^{(\tau)}(x_i, y_q, t_k) + \beta_0^d u^{(\tau)}(x_i, y_0, t_k) = g_d(x_i, t_k),\ \ i = 0,1,2,\dots,\delta,\ \ k = 0,1,2,\dots,N_t.$$

(39)

The boundary conditions are imposed on the main diagonal sub-blocks of matrices in Eq. (33) to yield a new consistent system of linear algebraic equations. The required solution of this system is obtained through an iterative process starting with an appropriate initial approximation to the solution.

13.2 Method of solution for systems of nonlinear PDEs

In this subsection, we extend the algorithm described in the previous subsection to solution of systems of nonlinear PDEs. To demonstrate the construction of the algorithm, we consider a system of two nonlinear PDEs that is expressible in the form;

$$\frac{\partial u}{\partial t} = F_1\left(\frac{\partial^2 u}{\partial x^2}, \frac{\partial^2 v}{\partial x^2}, \frac{\partial^2 u}{\partial y^2}, \frac{\partial^2 v}{\partial y^2}, \frac{\partial u}{\partial x}, \frac{\partial v}{\partial x}, \frac{\partial u}{\partial y}, \frac{\partial v}{\partial y}, u, v\right),$$

$$\frac{\partial v}{\partial t} = F_2\left(\frac{\partial^2 u}{\partial x^2}, \frac{\partial^2 v}{\partial x^2}, \frac{\partial^2 u}{\partial y^2}, \frac{\partial^2 v}{\partial y^2}, \frac{\partial u}{\partial x}, \frac{\partial v}{\partial x}, \frac{\partial u}{\partial y}, \frac{\partial v}{\partial y}, u, v\right).$$

(40)

where F_1 and F_2 are nonlinear operators acting on the unknown functions u and v and their derivatives with respect to x and y as illustrated. The system Eq. (38) is solved subject to boundary conditions

$$\alpha_1^a \frac{\partial u}{\partial x}(a,y,t) + \alpha_0^a u(a,y,t) = f_a(y,t),\ \ \alpha_1^b \frac{\partial u}{\partial x}(b,y,t) + \alpha_0^b u(b,y,t) = f_b(y,t),$$

$$\beta_1^c \frac{\partial u}{\partial y}(x,c,t) + \beta_0^c u(x,c,t) = g_c(x,t),\ \ \beta_1^d \frac{\partial u}{\partial y}(x,d,t) + \beta_0^d u(x,d,t) = g_d(x,t),$$

(41)

and

$$\alpha_1^{a^*} \frac{\partial v}{\partial x}(a,y,t) + \alpha_0^{a^*} v(a,y,t) = f_{a^*}(y,t),\ \ \alpha_1^{b^*} \frac{\partial v}{\partial x}(b,y,t) + \alpha_0^{b^*} v(b,y,t) = f_{b^*}(y,t),$$

$$\beta_1^{c^*} \frac{\partial v}{\partial y}(x,c,t) + \beta_0^{c^*} v(x,c,t) = g_{c^*}(x,t),\ \ \beta_1^{d^*} \frac{\partial v}{\partial y}(x,d,t) + \beta_0^{d^*} v(x,d,t) = g_{d^*}(x,t).$$

(42)

The star * in Eq. (40) distinguishes the boundary conditions in v from those of u. The initial conditions for this problem are

$$u(x,y,0) = h_1(x,y), \qquad v(x,y,0) = h_2(x,y).$$

(43)

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Applying the QLM, Eq. (38) can be expressed as the linearized coupled system

$$\delta_{4,s}^{1}\frac{\partial^2 u_{s+1}}{\partial x^2}+\delta_{3,s}^{1}\frac{\partial^2 u_{s+1}}{\partial y^2}+\delta_{2,s}^{1}\frac{\partial u_{s+1}}{\partial x}+\delta_{1,s}^{1}\frac{\partial u_{s+1}}{\partial y}+\delta_{0,s}^{1}u_{s+1}$$

$$-\dot{u}_{s+1}+\sigma_{4,s}^{1}\frac{\partial^2 v_{s+1}}{\partial x^2}+\sigma_{3,s}^{1}\frac{\partial^2 v_{s+1}}{\partial y^2}+\sigma_{2,s}^{1}\frac{\partial v_{s+1}}{\partial x}+\sigma_{1,s}^{1}\frac{\partial v_{s+1}}{\partial y}+\sigma_{0,s}^{1}v_{s+1}=R_{1,s},$$

(44)

$$\delta_{4,s}^{2}\frac{\partial^2 u_{s+1}}{\partial x^2}+\delta_{3,s}^{2}\frac{\partial^2 u_{s+1}}{\partial y^2}+\delta_{2,s}^{2}\frac{\partial u_{s+1}}{\partial x}+\delta_{1,s}^{2}\frac{\partial u_{s+1}}{\partial y}+\delta_{0,s}^{2}u_{s+1}$$

$$+\sigma_{4,s}^{2}\frac{\partial^2 v_{s+1}}{\partial x^2}+\sigma_{3,s}^{2}\frac{\partial^2 v_{s+1}}{\partial y^2}+\sigma_{2,s}^{2}\frac{\partial v_{s+1}}{\partial x}+\sigma_{1,s}^{2}\frac{\partial v_{s+1}}{\partial y}+\sigma_{0,s}^{2}v_{s+1}-\dot{v}_{s+1}=R_{2,s},$$

(45)

where

$$\delta_{4,s}^{\nu}=\frac{\partial F_{\nu}}{\partial(u_{xx})_s},\quad \delta_{3,s}^{\nu}=\frac{\partial F_{\nu}}{\partial(u_{yy})_s},\ \delta_{2,s}^{\nu}=\frac{\partial F_{\nu}}{\partial(u_x)_s},\quad \delta_{1,s}^{\nu}=\frac{\partial F_{\nu}}{\partial(u_y)_s},\quad \delta_{0,s}^{\nu}=\frac{\partial F_{\nu}}{\partial(u)_s},$$

$$\sigma_{4,s}^{\nu}=\frac{\partial F_{\nu}}{\partial(v_{xx})_s},\quad \sigma_{3,s}^{\nu}=\frac{\partial F_{\nu}}{\partial(v_{yy})_s},\ \sigma_{2,s}^{\nu}=\frac{\partial F_{\nu}}{\partial(v_x)_s},\quad \sigma_{1,s}^{\nu}=\frac{\partial F_{\nu}}{\partial(v_y)_s},\quad \sigma_{0,s}^{\nu}=\frac{\partial F_{\nu}}{\partial(v)_s},\quad \nu=1,2,$$

(46)

$$R_{\nu,s}=\delta_{4,s}^{\nu}(u_{xx})_s+\delta_{3,s}^{\nu}(u_{yy})_s+\delta_{2,s}^{\nu}(u_x)_s+\delta_{2,s}^{\nu}(u_x)_s+\delta_{1,s}^{\nu}(u_y)_s+\delta_{0,s}^{\nu}u_s+$$

$$\sigma_{4,s}^{\nu}(v_{xx})_s+\sigma_{3,s}^{\nu}(v_{yy})_s+\sigma_{2,s}^{\nu}(v_x)_s+\sigma_{2,s}^{\nu}(v_x)_s+\sigma_{1,s}^{\nu}(v_y)_s+\sigma_{0,s}^{\nu}v_s-F_{\nu,s},\quad ,\quad \nu=1,2.$$

(47)

For each subinterval in time, we must solve

$$\delta_{4,s}^{1}\frac{\partial^2 u_{s+1}^{(\tau)}}{\partial x^2}+\delta_{3,s}^{1}\frac{\partial^2 u_{s+1}^{(\tau)}}{\partial y^2}+\delta_{2,s}^{1}\frac{\partial u_{s+1}^{(\tau)}}{\partial x}+\delta_{1,s}^{1}\frac{\partial u_{s+1}^{(\tau)}}{\partial y}+\delta_{0,s}^{1}u_{s+1}^{(\tau)}$$

$$-\frac{\partial u_{s+1}^{(\tau)}}{\partial t}+\sigma_{4,s}^{1}\frac{\partial^2 v_{s+1}^{(\tau)}}{\partial x^2}+\sigma_{3,s}^{1}\frac{\partial^2 v_{s+1}^{(\tau)}}{\partial y^2}+\sigma_{2,s}^{1}\frac{\partial v_{s+1}^{(\tau)}}{\partial x}+\sigma_{1,s}^{1}\frac{\partial v_{s+1}^{(\tau)}}{\partial y}+\sigma_{0,s}^{1}v_{s+1}^{(\tau)}=R_{1,s},$$

(48)

$$\delta_{4,s}^{2}\frac{\partial^2 u_{s+1}^{(\tau)}}{\partial x^2}+\delta_{3,s}^{2}\frac{\partial^2 u_{s+1}^{(\tau)}}{\partial y^2}+\delta_{2,s}^{2}\frac{\partial u_{s+1}^{(\tau)}}{\partial x}+\delta_{1,s}^{2}\frac{\partial u_{s+1}^{(\tau)}}{\partial y}+\delta_{0,s}^{2}u_{s+1}^{(\tau)}$$

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$$+\sigma_{4,s}^2\frac{\partial^2 v_{s+1}^{(\tau)}}{\partial x^2}+\sigma_{3,s}^2\frac{\partial^2 v_{s+1}^{(\tau)}}{\partial y^2}+\sigma_{2,s}^2\frac{\partial v_{s+1}^{(\tau)}}{\partial x}+\sigma_{1,s}^2\frac{\partial v_{s+1}^{(\tau)}}{\partial y}+\sigma_{0,s}^2 v_{s+1}^{(\tau)}-\frac{\partial v_{s+1}^{(\tau)}}{\partial t}=R_{2,s},$$

(49)

subject to the corresponding boundary conditions. Here the initial conditions are evaluated at collocation points as;

$$u^{(1)}(x_i,y_j,0)=u^{(1)}(x_i,y_j,t_{N_t})=h_1(x_i,y_j)=\bar{U}_{N_t}^{j},\quad v^{(1)}(x_i,y_j,0)=v^{(1)}(x_i,y_j,t_{N_t})=h_2(x_i,y_j)=\bar{V}_{N_t}^{j},$$

$$u^{(\tau)}(x_i,y_j,t_{\tau-1})=u^{(\tau-1)}(x_i,y_j,t_{\tau-1}),\quad v^{(\tau)}(x_i,y_j,t_{\tau-1})=v^{(\tau-1)}(x_i,y_j,t_{\tau-1}),\ \tau=2,3,\dots,p.$$

(50)

Applying spectral collocation method to the linearized QLM scheme Eqs. (46)-(47) and taking account of the effect of initial condition we obtain a system of $2N_t(\sigma+1)(\delta+1)$ linear algebraic equations for each subinterval $\tau=1,2,\dots,p,$ in t given by

$$[\boldsymbol{\delta}_{4,s}^1\boldsymbol{D}^2+\boldsymbol{\delta}_{2,s}^1\boldsymbol{D}+\boldsymbol{\delta}_{0,s}^1\mathbf{I}]\bar{\boldsymbol{U}}_k^j+\sum_{q=0}^{\sigma}[\boldsymbol{\delta}_{3,s}^1\bar{D}_{j,q}^2+\boldsymbol{\delta}_{1,s}^1\bar{D}_{j,q}]\,\bar{\boldsymbol{U}}_k^q$$

$$-\sum_{r=0}^{N_{t-1}}\sum_{q=0}^{\sigma}\bar{\bar{D}}_{k,r}\bar{\boldsymbol{U}}_r^q+[\boldsymbol{\sigma}_{4,s}^1\boldsymbol{D}^2+\boldsymbol{\sigma}_{2,s}^1\boldsymbol{D}+\boldsymbol{\sigma}_{0,s}^1\mathbf{I}]\bar{\boldsymbol{V}}_k^j+\sum_{q=0}^{\sigma}[\boldsymbol{\sigma}_{3,s}^1\bar{D}_{j,q}^2+\boldsymbol{\sigma}_{1,s}^1\bar{D}_{j,q}]\,\bar{\boldsymbol{V}}_k^q=\bar{\boldsymbol{R}}_{1,k}^j,$$

(51)

$$[\boldsymbol{\delta}_{4,s}^2\boldsymbol{D}^2+\boldsymbol{\delta}_{2,s}^2\boldsymbol{D}+\boldsymbol{\delta}_{0,s}^2\mathbf{I}]\bar{\boldsymbol{U}}_k^j+\sum_{q=0}^{\sigma}[\boldsymbol{\delta}_{3,s}^2\bar{D}_{j,q}^2+\boldsymbol{\delta}_{1,s}^2\bar{D}_{j,q}]\,\bar{\boldsymbol{U}}_k^q$$

$$+[\boldsymbol{\sigma}_{4,s}^2\boldsymbol{D}^2+\boldsymbol{\sigma}_{2,s}^2\boldsymbol{D}+\boldsymbol{\sigma}_{0,s}^2\mathbf{I}]\bar{\boldsymbol{V}}_k^j+\sum_{q=0}^{\sigma}[\boldsymbol{\sigma}_{3,s}^2\bar{D}_{j,q}^2+\boldsymbol{\sigma}_{1,s}^2\bar{D}_{j,q}]\,\bar{\boldsymbol{V}}_k^q-\sum_{r=0}^{N_{t-1}}\sum_{q=0}^{\sigma}\bar{\bar{D}}_{k,r}\bar{\boldsymbol{V}}_r^q=\bar{\boldsymbol{R}}_{2,k}^j,$$

(52)

Eqs. (49)-(50) can be expressed into $2N_t(\sigma+1)(\delta+1)\times 2N_t(\sigma+1)(\delta+1)$ matrix system given by

$$\begin{bmatrix}\boldsymbol{A}_{1,1} & \boldsymbol{A}_{1,2}\\ \boldsymbol{A}_{2,1} & \boldsymbol{A}_{2,2}\end{bmatrix}\begin{bmatrix}\boldsymbol{U}^{(\tau)}\\ \boldsymbol{V}^{(\tau)}\end{bmatrix}=\begin{bmatrix}\boldsymbol{R}_1^{(\tau)}\\ \boldsymbol{R}_2^{(\tau)}\end{bmatrix},$$

(53)

where

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$$\boldsymbol{R}_1^{(\tau)} = R_{1,s} + \sum_{q=0}^{\sigma} \bar{\bar{D}}_{k,N_t} \bar{\boldsymbol{U}}_{N_t}^{q}, \quad \boldsymbol{R}_2^{(\tau)} = R_{2,s} + \sum_{q=0}^{\sigma} \bar{\bar{D}}_{k,N_t} \bar{\boldsymbol{V}}_{N_t}^{q}, \quad k = 0,1,2,\ldots,N_t - 1.$$

(54)

The vector $\boldsymbol{V}^{(\tau)}$ is defined in similar manner to vector $\boldsymbol{U}^{(\tau)}$ given in Eq. (35). The right hand side vectors $\boldsymbol{R}_1^{(\tau)}$ and $\boldsymbol{R}_2^{(\tau)}$ correspond to vectors $\boldsymbol{U}^{(\tau)}$ and $\boldsymbol{V}^{(\tau)}$, respectively. The boundary conditions Eq. (39) and Eq. (40) are evaluated at the collocation points in a manner similar to that illustrated at Eq. (36) and Eq. (37). We remark that if the initial conditions $u(x, y, 0)$ and $v(x, y, 0)$ are not available, the system of differential equations is first solved for $t = 0$ to approximate the initial conditions. In summary, we assert that the algorithms described so far can be adjusted easily and applied to PDEs of higher orders (> 2) and on problems modeled by larger systems of nonlinear PDEs. An extension to numerical schemes of solutions of two-dimensional time-dependent PDEs exhibiting slightly different forms of nonlinearity can be achieved in a straightforward manner.

14 Error bounds theorems in a trivariate polynomial interpolation

In this section, we present new error bound theorems that govern polynomial interpolation error in a trivariate Lagrange interpolating polynomial constructed using Chebyshev Gauss-Lobatto nodes. Fundamental ingredients of this subject related to the construction of proofs of the theorems include; first, the understanding that CGL nodes are the relative extremes of the N_x-th degree Chebyshev polynomial of the first kind $T_{N_x}(\hat{x}) = \cos[N_x \arccos(\hat{x})]$, $\hat{x} \in [-1,1]$, secondly, the general properties of Chebyshev polynomials, and thirdly, the understanding of the mean value theorem in calculus. Although to the best of our knowledge, there does not exist a well-known family of polynomials whose roots are the CGL nodes, it is easy to discern that the interior CGL nodes are roots of $T'_{N_x}(\hat{x}) = 0$. This fact leads to the discovery of a complete set of the CGL nodes as the roots of the $(N_x + 1)$-th degree polynomial given by;

$$L_{N_x+1}(\hat{x}) = (1 - \hat{x}^2) T'_{N_x}(\hat{x}).$$

(55)

Below, we give the theorem that benchmarks formulation of the error bound theorems on trivariate polynomial interpolation;

Theorem 1. *[27] Let* $u(x, y, t) \in C^{N_x+N_y+N_t+3}([a, b] \times [c, d] \times [0, T])$ *be sufficiently smooth such that at least the* $(N_x + 1)$*-th partial derivative with respect to* x*,* $(N_y + 1)$*-th partial derivative with respect to* y*,* $(N_t + 1)$*-th partial derivative with respect to* t*, and the* $(N_x + N_y + N_t + 3)$*-th mixed partial derivative with respect to* x*,* y*, and* t *exists and are all continuous, then there exists values* $\xi_x, \xi'_x \in (a, b)$*,* $\xi_y, \xi'_y \in (c, d)$ *,and* $\xi_t, \xi'_t \in (0, T)$*, such that*

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$$u(x,y,t) - U(x,y,t) = \frac{\partial^{N_x+1}u(\xi_x,y,t)}{\partial x^{N_x+1}(N_x+1)!}\prod_{i=0}^{N_x}(x-x_i) + \frac{\partial^{N_y+1}u(x,\xi_y,t)}{\partial y^{N_y+1}(N_y+1)!}\prod_{j=0}^{N_y}(y-y_j) + \frac{\partial^{N_t+1}u(x,y,\xi_t)}{\partial t^{N_t+1}(N_t+1)!}\prod_{k=0}^{N_t}(t-t_k)$$

$$- \frac{\partial^{N_x+N_y+N_t+3}u(\xi'_x,\xi'_y,\xi'_t)}{\partial x^{N_x+1}\partial y^{N_y+1}\partial t^{N_t+1}(N_x+1)!(N_y+1)!(N_t+1)!}\prod_{i=0}^{N_x}(x-x_i)\prod_{j=0}^{N_y}(y-y_j)\prod_{k=0}^{N_t}(t-t_k)$$

(56)

where $U(x,y,t)$ is a trivariate interpolating polynomial of $u(x,y,t)$ at $\{x_i\}_{i=0}^{N_x}$ grid points in x-variable, $\{y_j\}_{j=0}^{N_y}$ grid points in y-variable, and $\{t_k\}_{k=0}^{N_t}$ grid points in t-variable.

The remainder formula Eq. (54) is based on the mean value theorem and is derived recursively from the corresponding univariate error formula given in [28] for a sufficiently smooth function $u(x,y,t)$. Taking the absolute value of Eq. (54) we obtain

$$|u(x,y,t) - U(x,y,t)| \leq \max_{(x,y,t)\in\Omega}\left|\frac{\partial^{N_x+1}u(\xi_x,y,t)}{\partial x^{N_x+1}}\right|\frac{\left|\prod_{i=0}^{N_x}(x-x_i)\right|}{(N_x+1)!}$$

$$+\max_{(x,y,t)\in\Omega}\left|\frac{\partial^{N_y+1}u(x,\xi_y,t)}{\partial y^{N_y+1}}\right|\frac{\left|\prod_{j=0}^{N_y}(y-y_j)\right|}{(N_y+1)!}$$

$$+\max_{(x,y,t)\in\Omega}\left|\frac{\partial^{N_t+1}u(x,y,\xi_t)}{\partial t^{N_t+1}}\right|\frac{\left|\prod_{k=0}^{N_t}(t-t_k)\right|}{(N_t+1)!}$$

$$+\max_{(x,y,t)\in\Omega}\left|\frac{\partial^{N_x+N_y+N_t+3}u(\xi'_x,\xi'_y,\xi'_t)}{\partial x^{N_x+1}\partial y^{N_y+1}\partial t^{N_t+1}}\right|\frac{\left|\prod_{i=0}^{N_x}(x-x_i)\right|\left|\prod_{j=0}^{N_y}(y-y_j)\right|\left|\prod_{k=0}^{N_t}(t-t_k)\right|}{(N_x+1)!(N_y+1)!(N_t+1)!}$$

(57)

where $\Omega = [a,b]\times[c,d]\times[0,T]$. Since the function $u(x,y,t)$ is assumed to be smooth on the interval of approximation, it follows that its derivatives are bounded and thus $\exists$ constants C_1, C_2, C_3 and C_4, such that

$$\max_{(x,y,t)\in\Omega}\left|\frac{\partial^{N_x+1}u(x,y,t)}{\partial x^{N_x+1}}\right| \leq C_1, \qquad \max_{(x,y,t)\in\Omega}\left|\frac{\partial^{N_y+1}u(x,y,t)}{\partial y^{N_y+1}}\right| \leq C_2,$$

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$$\max_{(x,y,t)\in\Omega}\left|\frac{\partial^{N_t+1}u(x,y,t)}{\partial t^{N_t+1}}\right| \le C_3, \quad \max_{(x,y,t)\in\Omega}\left|\frac{\partial^{N_x+N_y+N_t+3}u(x,y,t)}{\partial x^{N_x+1}\partial y^{N_y+1}\partial t^{N_t+1}}\right| \le C_4.$$

(58)

The error bound for trivariate polynomial interpolation using Chebyshev Gauss-Lobatto nodes on a single domain is governed by the theorem below;

Theorem 2 (The error bound in a single domain). *The resulting error bound when CGL grid points* $\{x_i\}_{i=0}^{N_x} \in [a,b]$, *in* x*-variable,* $\{y_j\}_{j=0}^{N_y} \in [c,d]$ *in* y*-variable, and* $\{t_k\}_{k=0}^{N_t} \in [0,T]$, *in* t*-variable are used in trivariate polynomial interpolation is given by*

$$E(x,y,t) \le C_1\frac{8\left(\frac{b-a}{4}\right)^{N_x+1}}{(N_x+1)!} + C_2\frac{8\left(\frac{d-c}{4}\right)^{N_y+1}}{(N_y+1)!} + C_3\frac{8\left(\frac{T}{4}\right)^{N_t+1}}{(N_t+1)!} + C_4\frac{8^3\left(\frac{b-a}{4}\right)^{N_x+1}\left(\frac{d-c}{4}\right)^{N_y+1}\left(\frac{T}{4}\right)^{N_t+1}}{(N_x+1)!(N_y+1)!(N_t+1)!}$$

(59)

Proof. First, using the relation stated in [29] we express Eq. (53) as

$$L_{N_x+1}(\hat{x}) = (1-\hat{x}^2)T'_{N_x}(\hat{x}) = -N_x\hat{x}T_{N_x}(\hat{x}) + N_xT_{N_x-1}(\hat{x}).$$

(60)

Using the triangle inequality and noting that $|T_{N_x}(\hat{x})| \le 1, \ \forall\ \hat{x} \in [-1,1]$, we have

$$|L_{N_x+1}(\hat{x})| = |-N_x\hat{x}T_{N_x}(\hat{x}) + N_xT_{N_x-1}(\hat{x})| \le |-N_x\hat{x}T_{N_x}(\hat{x})| + |N_xT_{N_x-1}(\hat{x})| \le 2N_x.$$

(61)

The leading coefficient of $L_{N_x+1}(\hat{x})$ is $2^{N_x-1}N_x$, where the components 2^{N_x-1} and N_x comes from the leading coefficient of $T_{N_x}(\hat{x})$ and the application of N_x-th rule of differentiation on $T_{N_x}(\hat{x})$, respectively. The product factor in the first term of the error bound expression given at Eq. (55) can therefore be taken as the factorized form of monic polynomial $\frac{L_{N_x+1}(x)}{2^{N_x-1}N_x}$. We write,

$$\prod_{i=0}^{N_x}(\hat{x}-\hat{x}_i) = \frac{L_{N_x+1}(\hat{x})}{2^{N_x-1}N_x}, \quad \hat{x} \in [-1,1].$$

(62)

Using Eq. (59), it is easy to establish that the monic polynomial Eq. (60) is bounded by

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$$|\prod_{i=0}^{N_x}(\hat{x}-\hat{x}_i)| = \left|\frac{L_{N_x+1}(\hat{x})}{2^{N_x-1}N_x}\right| \leq \frac{2N_x}{2^{N_x-1}N_x} = \frac{4}{2^{N_x}}.$$

(63)

Considering a general interval $x \in [a,b]$, we can show that the first product factor in Eq. (55) is bounded by

$$\max_{a\leq x\leq b}\left|\prod_{i=0}^{N_x}(x-x_i)\right| = \max_{-1\leq \hat{x}\leq 1}\left|\prod_{i=0}^{N_x}\frac{(b-a)}{2}(\hat{x}-\hat{x}_i)\right| = \left(\frac{b-a}{2}\right)^{N_x+1}\max_{-1\leq \hat{x}\leq 1}\left|\prod_{i=0}^{N_x}(\hat{x}-\hat{x}_i)\right|$$

$$= \left(\frac{b-a}{2}\right)^{N_x+1}\max_{-1\leq \hat{x}\leq 1}\left|\frac{L_{N_x+1}(\hat{x})}{2^{N_x-1}N_x}\right| \leq \frac{4\left(\frac{b-a}{2}\right)^{N_x+1}}{2^{N_x}} = 8\left(\frac{b-a}{4}\right)^{N_x+1}.$$

(64)

Similarly, we conclude that the second and the third product factor are bounded, respectively, by;

$$\max_{c\leq y\leq d}\left|\prod_{j=0}^{N_y}(y-y_j)\right| = \left(\frac{d-c}{2}\right)^{N_y+1}\max_{-1\leq \hat{y}\leq 1}\left|\frac{L_{N_y+1}(\hat{y})}{2^{N_y-1}N_y}\right| \leq \frac{4\left(\frac{d-c}{2}\right)^{N_y+1}}{2^{N_y}} = 8\left(\frac{d-c}{4}\right)^{N_y+1},$$

(65)

and

$$\max_{0\leq t\leq T}\left|\prod_{k=0}^{N_t}(t-t_k)\right| = \left(\frac{T}{2}\right)^{N_t+1}\max_{-1\leq \hat{t}\leq 1}\left|\frac{L_{N_t+1}(\hat{t})}{2^{N_t-1}N_t}\right| \leq \frac{4\left(\frac{T}{2}\right)^{N_t+1}}{2^{N_t}} = 8\left(\frac{T}{4}\right)^{N_t+1}.$$

(66)

Using Eqs. (62)-(64), and Eq. (56) in Eq. (55) the proof is completed.

Theorem 3 (The error bound in a decomposed domain). *The resulting error bound when CGL grid points* $\{x_i\}_{i=0}^{N_x} \in [x_{l-1},\bar{x}_l],\ l = 1,2,\dots,q,$ *for the decomposed domain in* x*-variable and* $\{y_j\}_{j=0}^{N_y} \in [y_{\zeta-1},\bar{y}_\zeta],\ \zeta = 1,2,\dots,m,$ *for the decomposed domain in* y*-variable, and* $\{t_k\}_{k=0}^{N_t} \in [t_{\tau-1},t_\tau],\ \tau = 1,2,\dots,p,$ *for the decomposed domain in* t*-variable are used in trivariate polynomial interpolation is given by*

$$E(x,y,t) \leq C_1\frac{8\left(\frac{L}{4}\right)^{N_x+1}}{(N_x+1)!} + C_2\frac{8\left(\frac{Z}{4}\right)^{N_y+1}}{(N_y+1)!} + C_3\frac{8\left(\frac{T}{4}\right)^{N_t+1}}{(N_t+1)!}\left(\frac{1}{p}\right)^{N_t+1} +$$
$$C_4\frac{8^3\left(\frac{L}{4}\right)^{N_x+1}\left(\frac{Z}{4}\right)^{N_y+1}\left(\frac{T}{4}\right)^{N_t+1}}{(N_x+1)!(N_y+1)!(N_t+1)!}\left(\frac{1}{p}\right)^{N_t+1}.$$

(67)

Proof. First, we consider the t variable. In the entire domain $[0,T]$, we have that

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$$\left|\prod_{k=0}^{N_t}(t-t_k)\right| \leq 8\left(\frac{T}{4}\right)^{N_t+1},\ t \in [0,T].$$

(68)

The implication is that in the decomposed domain and at each subinterval, we must have

$$\left|\prod_{k=0}^{N_t}(t-t_k)\right| \leq 8\left(\frac{T}{4p}\right)^{N_t+1} = 8\left(\frac{T}{4}\right)^{N_t+1}\left(\frac{1}{p}\right)^{N_t+1},\ t \in [t_{\tau-1},t_\tau],\ \tau = 1,2,\ldots,p.$$

(69)

For smooth u, there exists $\xi_\tau \in (t_{\tau-1},t_\tau),\ \tau = 1,2,\ldots,p,$ for which the values of (N_t+1)-st partial derivatives of u with respect to t in each subinterval is the absolute extrema. This enables us to break the third term $C_3\frac{8\left(\frac{T}{4}\right)^{N_t+1}}{(N_t+1)!}$ that appears in the error bound expression at Eq. (57) into different components that are necessarily not equal in the decomposed domain as

$$\left\{C_3^{(\tau)}\frac{8\left(\frac{T}{4}\right)^{N_t+1}}{(N_t+1)!}\left(\frac{1}{p}\right)^{N_t+1}\right\}_{\tau=1}^{p},$$

(70)

where

$$\max_{(x,y,t)\in\Omega}\left|\frac{\partial^{N_t+1}u(x,y,t)}{\partial t^{N_t+1}}\right| = \left|\frac{\partial^{N_t+1}u(x,y,\xi_\tau)}{\partial t^{N_t+1}}\right| \leq C_3^{(\tau)},\ t \in [t_{\tau-1},t_\tau].$$

We define

$$\|\hat{C}_3\|_\infty = \max\left\{C_3^{(1)},C_3^{(2)},\ldots,C_3^{(p)}\right\},$$

(71)

to denote the maximum absolute value of (N_t+1)-st partial derivatives of u with respect to t in $[0,T]$. Clearly, $\|\hat{C}_3\|_\infty = C_3$, where C_3 is identical to the one given at Eq. (57). To expand the error bound over the entire t domain, we shall take the largest possible error across all subintervals in t which is

$$C_3\frac{8\left(\frac{T}{4}\right)^{N_t+1}}{(N_t+1)!}\left(\frac{1}{p}\right)^{N_t+1}.$$

(72)

Similar reasoning can be applied to show that the first and the second component in error bound Eq. (57) in the decomposed x and y domain translates to

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$C_1 \frac{g\left(\frac{L}{4}\right)^{N_x+1}}{(N_x+1)!}$, and $C_2 \frac{g\left(\frac{Z}{4}\right)^{N_y+1}}{(N_y+1)!}$, respectively.

(73)

Consequently, the forth component in Eq. (57) becomes

$$C_4 \frac{g^3\left(\frac{L}{4}\right)^{N_x+1}\left(\frac{Z}{4}\right)^{N_y+1}\left(\frac{T}{4}\right)^{N_t+1}}{(N_x+1)!(N_y+1)!(N_t+1)!}\left(\frac{1}{p}\right)^{N_t+1},$$

(74)

in the decomposed domain. Using Eqs. (70)-(72) in Eq.(57) completes the proof.

Comparing Eq. (57) and Eq. (64) we note that the error in trivariate polynomial interpolation is smaller when interpolation is conducted on multiple domains than on a single domain. Further, we remark that CGL nodes are preferable candidates of interpolation when using spectral collocation methods to solve boundary value problems because they are convenient in constructing differentiation matrices as they contain the boundary nodes which are advantageous when treating the boundary conditions of the problem.

15 Numerical experiment

In this section, we apply the method described in the previous section to a selected class of two-dimensional nonlinear initial-boundary value problems. The accuracy and efficiency of the proposed method are demonstrated by comparing the numerical results against the exact solution.

Example 1. Consider the problem of two-dimensional heat and mass transfer in quiescent media with chemical reaction given in its general form by

$$\frac{\partial u}{\partial t} = a\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) + f(u),$$

(75)

where a is a real constant. We analyze a special case of this problem when $a = 1$ and $f(u) = -4u^3 - 2u^2$ and solve the problem subject to the boundary conditions

$$u(2,y,t) = (2+y+2t)^{-1},\ u(5,y,t) = (5+y+2t)^{-1},\ 2 \le y \le 5,\ t > 0,$$

$$u(x,2,t) = (2+x+2t)^{-1},\ u(x,5,t) = (5+x+2t)^{-1},\ 2 \le x \le 5,\ t > 0,$$

(76)

The initial condition for this problem is given by

$$u(x,y,0) = (x+y)^{-1},\ 2 \le x \le 5,\quad 2 \le y \le 5.$$

(77)

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The exact solution is given in [9] as

$$u(x, y, t) = (x + y + 2t)^{-1}.$$

(78)

Example 2. We consider the two-dimensional heat and mass transfer equation with power-law temperature-dependent thermal conductivity [10]

$$\frac{\partial u}{\partial t} = a\left[\frac{\partial}{\partial x}\left(u^n \frac{\partial u}{\partial x}\right)\right] + b\left[\frac{\partial}{\partial y}\left(u^m \frac{\partial u}{\partial y}\right)\right] + \beta u,$$

(79)

where m, n can be an integer or fraction and $a, b,$ and β are some parameters. For simplicity, we consider a special case of Eq. (77) when $a = 1,\ b = 1,\ m = n = 1,$ and $\beta = 0$ in which Eq. (77) reduces to Boussinesq equation

$$\frac{\partial u}{\partial t} = \left[\frac{\partial}{\partial x}\left(u \frac{\partial u}{\partial x}\right)\right] + \left[\frac{\partial}{\partial y}\left(u \frac{\partial u}{\partial y}\right)\right].$$

(80)

The Boussinesq equation arises in nonlinear heat conduction and the theory of unsteady flow through porous media with a free surface. Eq. (78) is solved subject to boundary conditions

$$u(0, y, t) = y + 2t, \quad u(5, y, t) = 5 + y + 2t, \quad 0 \le y \le 4, \quad t > 0,$$

$$u(x, 0, t) = x + 2t, \quad u(x, 4, t) = 4 + x + 2t, \quad 0 \le x \le 5, \quad t > 0,$$

(81)

The initial condition for this problem is given by

$$u(x, y, 0) = x + y.$$

(82)

The exact solution is given by authors in [9] as

$$u(x, y, t) = x + y + 2t.$$

(83)

Example 3. We consider the system two-dimensional Burgers' equations given by

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \frac{1}{Re}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right),$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = \frac{1}{Re}\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right),$$

(84)

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where $u(x,y,t)$ and $v(x,y,t)$ are velocity components to be determined and Re is the Reynolds number. Eq. (82) is subject to boundary conditions

$$u(0,y,t)=\frac{3}{4}-\frac{1}{4\left[1+e^{\left(\frac{Re(4y-t)}{32}\right)}\right]},\quad u(5,y,t)=\frac{3}{4}-\frac{1}{4\left[1+e^{\left(\frac{Re(4y-20-t)}{32}\right)}\right]},$$

$$u(x,0,t)=\frac{3}{4}-\frac{1}{4\left[1+e^{\left(\frac{Re(-4x-t)}{32}\right)}\right]},\quad u(5,y,t)=\frac{3}{4}-\frac{1}{4\left[1+e^{\left(\frac{Re(20-4x-t)}{32}\right)}\right]},$$

(85)

$$v(0,y,t)=\frac{3}{4}+\frac{1}{4\left[1+e^{\left(\frac{Re(4y-t)}{32}\right)}\right]},\quad v(5,y,t)=\frac{3}{4}+\frac{1}{4\left[1+e^{\left(\frac{Re(4y-20-t)}{32}\right)}\right]},$$

$$v(x,0,t)=\frac{3}{4}+\frac{1}{4\left[1+e^{\left(\frac{Re(-4x-t)}{32}\right)}\right]},\quad v(5,y,t)=\frac{3}{4}+\frac{1}{4\left[1+e^{\left(\frac{Re(20-4x-t)}{32}\right)}\right]}.$$

(86)

The initial conditions are

$$u(x,y,0)=\frac{3}{4}-\frac{1}{4\left[1+e^{\left(\frac{Re(y-x)}{8}\right)}\right]},\qquad v(x,y,0)=\frac{3}{4}+\frac{1}{4\left[1+e^{\left(\frac{Re(y-x)}{8}\right)}\right]}.$$

(87)

The exact solutions for this problem are given in [30] as

$$u(x,y,t)=\frac{3}{4}-\frac{1}{4\left[1+e^{\left(\frac{Re(4y-4x-t)}{32}\right)}\right]},\qquad v(x,y,t)=\frac{3}{4}+\frac{1}{4\left[1+e^{\left(\frac{Re(4y-4x-t)}{32}\right)}\right]}.$$

(88)

Example 4. We consider the two-dimensional Brusselator system given by

$$\frac{\partial u}{\partial t}=B+u^2v-(A+1)u+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right),$$

$$\frac{\partial v}{\partial t}=Au-u^2v+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right),$$

(89)

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where $u(x,y,t)$ and $v(x,y,t)$ represent dimensionless concentration of two reactants, A and B are constant concentrations of the two reactants, and μ is the diffusion coefficient. The exact solutions for this problem are given in [31] for $A = 1,\ B = 0,$ and $\mu = \frac{1}{4}$ as

$$u(x,y,t) = e^{-x-y-t/2}, \qquad v(x,y,t) = e^{x+y+t/2}. \tag{90}$$

Eq. (87) is solved subject to boundary conditions

$$u(0,y,t) = e^{-y-\frac{t}{2}},\ u(2,y,t) = e^{-2-y-\frac{t}{2}},\ u(x,0,t) = e^{-x-\frac{t}{2}},\quad u(x,2,t) = e^{-2-x-\frac{t}{2}}, \tag{91}$$

$$v(0,y,t) = e^{y+\frac{t}{2}},\ v(2,y,t) = e^{2+y+\frac{t}{2}},\ v(x,0,t) = e^{x+\frac{t}{2}},\quad v(x,2,t) = e^{2+x+\frac{t}{2}}. \tag{92}$$

The initial conditions for this problem are

$$u(x,y,t) = e^{-x-y}, \qquad v(x,y,t) = e^{x+y}. \tag{93}$$

16 Results and discussion

In this section, results obtained after solving selected initial-boundary value problems using the overlapping grids based multi-domain spectral collocation method are presented and discussed in tabular and graphical forms. The results demonstrate various aspects of the proposed numerical method of solution. For comparison purposes, the modified solution approach is compared against the standard spectral collocation method on a single domain to reveal the benefits of in-cooperating both overlapping and non-overlapping grids techniques in the solution algorithm. The selected test examples possess exact solutions and therefore, we access the accuracy of the method by displaying the absolute error norms obtained the 5 iterations upon which the iterative numerical scheme is discerned to have converged. The error norms are computed as

$$E_5 = |u - U|_\infty, \tag{94}$$

where u and U are vectors representing the exact solution and approximate solution evaluated at selected collocation points. We examine the dependence of accuracy on the length of time interval, length of spatial domain and size of the parameters present in the given differential equation.

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Results obtained when Eq. (73) is solved are displayed in Table 1. The single domain approach is invoked using $N_x = 20,\ N_y = 20$ grid points in the spatial domains and $N_t = 10$ grid points per unit interval in the time domain in such a manner that when $T = 1,\ N_t = 10,$ when $T = 2,\ N_t = 20$ and so on until $N_t = 50$ is used for $T = 5$. In the multi-domain domain approach, the spatial domains are broken into two overlapping subintervals with 10 grid points in each subinterval, $N_x = 10,\ N_y = 10,\ q = 2,\ m = 2$ in all five cases of time interval considered. The domain decomposition on the time interval is achieved as follows, $N_t = 10$ is used per unit time which implies that when $T = 1$ only one interval in time is considered with $N_t = 10$, but when $T = 2$, two non-overlapping subintervals are used with $N_t = 10$ grid points in each and so on such that 5 non-overlapping subintervals are used with $N_t = 10$ grid points each when $T = 5$. Comparison of results in the second and the third column suggests that in-cooperating the domain decomposition technique for large time intervals yields highly accurate results as opposed to increasing the number of grid points on a single interval. The entries in the first row show that even for smaller time intervals, decomposing the large spatial domain into overlapping subintervals improves the accuracy of the numerical approximation. The CPU time displayed in this table is the cumulative time required to run the algorithm over the different time levels, $T = 1$ to $T = 5$. Shorter computation time is taken to yield results in the multi-domain approach as compared to the single domain approach. The condition number displayed is that of the coefficient matrix of the system of linear algebraic equations when $T = 5$. Deterioration of accuracy with large time intervals can be explained by large condition number of the coefficient matrix in the single domain approach with many grid points. Shorter computational time is attributed to the small-sized matrices in the multi-domain approach that are easy to invert.

Results obtained when Eq. (78) is solved are displayed in Table 2. The grid points distribution is similar to those used to generate results in the previous table. From Table 2, we observe that although the error norm is slightly larger in the single domain approach than in the multi-domain case, it remains relatively steady as the length of the computational domain in time increase. A close scrutiny of the exact solution of Eq. (78) reveals that its higher ordered derivatives are bounded within the interval of approximation. For problems whose higher ordered derivatives are bounded, the accuracy ought not to deteriorate with an increase in the number of grid points. This observation agrees with error bound theorems given in the previous section. However, since, in many practical applications, there is no prior knowledge of the exact solution of the differential equation and in view of the computational time constraint, the multi-domain approach beats the single domain approach as long as the domain of approximation is large. The CPU time and condition numbers show a trend similar to that of the previous table.

Results obtained when Eq. (82) is solved are displayed in Table 3, Figure 1 and Figure 2. In Table 3, the single domain approach is invoked using $N_x = 40,\ N_y = 40$ grid points in the spatial domains and $N_t = 50$ grid points over the entire time domain of length $T = 10$. In the multi-domain approach, $q = m = 4$ overlapping

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subintervals are used in space directions with $N_x = N_y = 10$ grid points and $p = 5$ non-overlapping subintervals with $N_t = 10$ are used in time direction. We observe that as the values of Reynolds (Re) number increase, single domain approach records higher drop in accuracy as compared to the multi-domain approach. It is worth mentioning that the factor $\frac{1}{Re}$ is the coefficient of higher ordered space derivatives in Eq. (82) and so for large values of Re, this coefficient is small. The consequence of multiplying the differentiation matrices by this small value is a reduction in precision of the entries of the coefficient matrix derived from the resulting system of linear algebraic equations. Numerical computations with small valued matrix entries have pronounced round-off errors which deteriorate the accuracy of numerical approximations. In-cooperating overlapping grids technique in spatial domain introduces scaling in the coefficient matrix which in turn counters the effect of large values of Re. In Figure 1, the spatial domain is not decomposed and values of Reynolds number is kept small at $Re = 5$. Figure 1 emphasizes the need of non-overlapping grids technique when solving problems over large time intervals and it shows the graph of error norms plotted against the length of the time interval. We examine the variation of error norms by considering a single domain approach and a multi-domain approach in which the large time domain has been broken into 5 and 10 subintervals. The total number of grid points over the entire domain is kept constant with $N_t = 10$ per unit time and the algorithm is run using $T = 4,\ T = 8,\ T = 12,\ T = 16,\ T = 20,$ time intervals. It can be observed that for small time intervals, single domain approach gives the best accuracy for a fixed number of grid points across all the three cases considered. Breaking a small time interval at the expense of increasing the number of grid points is equivalent to reducing the degree of the interpolating polynomial approximating the solution of the differential equation leading to poor approximations. Having examined the usefulness of non-overlapping grids technique in the case of large time intervals, in Figure 2 we maintain the time interval large at $T = 20$ and subdivide it into 5 subintervals then investigate the effect of varying the Reynolds number values on the accuracy of numerical approximations. We observe that for the large Reynolds (Re) numbers and large time intervals, using both overlapping subintervals in space and non-overlapping subintervals in time give the best accuracy.

Results obtained when Eq. (87) is solved are displayed in Table 4, Figure 3, and Figure 4. Results given in Table 4 are closely explained by theoretical results of the error bound theorems. We notice that unlike in the previous Examples 1-3, in which higher ordered derivatives of the solution are bounded, the solution of Eq. (87) is unbounded within the domain of approximation. Consequently, increasing the number of grid points result to large interpolation errors which are propagated into the numerical solution of the differential equation. For large time domain, the single approach gives less accurate results and there is a noticeable improvement in accuracy when multiple domain approaches are adopted for large time intervals. In Figure 3, error norms resulting from the use of $N_t = 20$ and $N_t = 10$ grid points over a single time interval of length $T = 5$ units are compared. We notice that when the interval is large, using many grid points does not really improve accuracy. This phenomenon is caused by the unboundedness nature of higher ordered derivatives of the solution of Eq. (87). In Figure 4, we re-examine decomposition of large time domain and compare solution of single domain approach with the multiple domain approaches while

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maintaining the number of grid points over the entire time interval constant. Consequently, as supported by error bound theorems, the use of a large number of grid points on a single domain records less accurate results for problems with unbounded higher ordered derivatives. In fact, beyond a certain threshold of the length of time interval, the numerical scheme becomes unstable. A domain decomposition approach improves the accuracy of numerical approximations and poses a stable numerical algorithm.

Table 10. Absolute error norms values for spectral approximation of Example 1 using different lengths of

time intervals $[0,T]$: $N_x = 10,\ N_y = 10,\ q = 2,\ m = 2,\ N_t = 10$ per unit length in time.

T	Single Domain	Multiple Domains
1.0	2.26291e-12	2.97384e-13
2.0	2.95380e-12	4.15001e-13
3.0	7.35126e-11	2.37643e-13
4.0	6.01130e-10	1.85810e-13
5.0	2.75105e-09	1.52454e-13
CPU time (sec)	15.259924	1.717759
Cond Number	4.7356e+05	7.9950e+03

Table 2. Absolute error norms values for spectral approximation of Example 2 using different lengths of

time intervals $[0,T]$: $N_x = 10,\ N_y = 10,\ q = 2,\ m = 2,\ N_t = 10$ per unit length in time.

T	Single Domain	Multiple Domains
1.0	2.29941e-11	1.71063e-12
2.0	2.19984e-11	2.13518e-12
3.0	2.30047e-11	3.24896e-12
4.0	5.26619e-11	6.46949e-12
5.0	3.48477e-11	5.11946e-12
CPU time (sec)	6.507918	0.636237
Cond Number	7.3179e+04	1.8094e+03

Table 3. Absolute error norm values obtained when Example 3 is solved for different values of Reynolds

number (Re): $N_x = 10,\ N_y = 10,\ q = 4,\ m = 4,\ [0,T] = [0,10],\ N_t = 10,\ p = 5.$

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	Single Domain		Multiple Domains	
Re	Error Norm in u	Error Norm in v	Error Norm in u	Error Norm in v
1.0	4.09006e-13	5.62328e-13	2.37022e-12	4.03122e-12
5.0	4.26503e-12	4.26625e-12	2.46692e-12	3.52773e-12
10.0	9.17247e-09	9.17326e-09	3.56237e-12	6.11633e-12
15.0	4.22525e-08	4.22845e-08	3.00593e-11	4.43479e-11
20.0	4.23489e-07	4.32432e-07	2.69562e-10	3.20433e-10

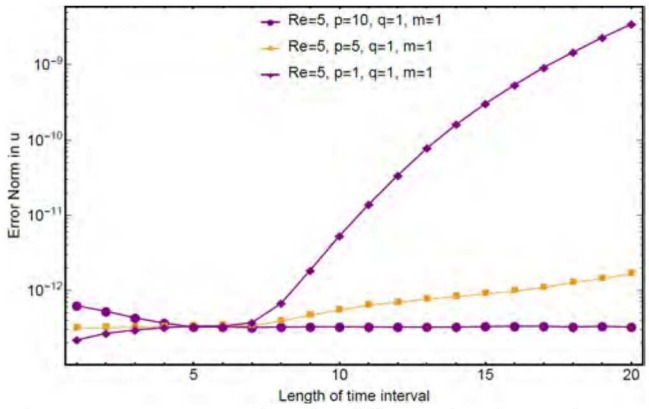

Figure 10. Error norms in u for different time intervals [0,T] for 2D coupled Burger's system

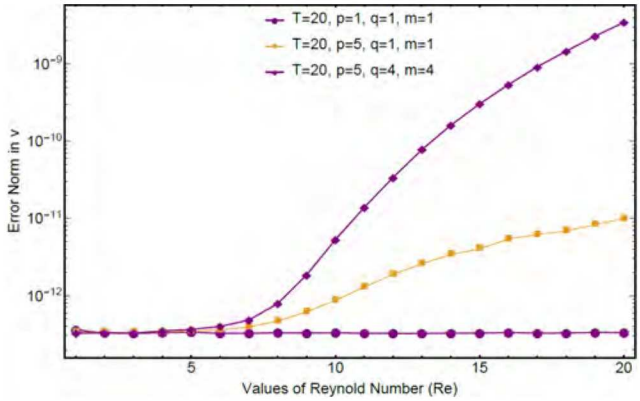

Figure 11. Error norms in v for different values of Reynolds number for 2D coupled Burger's system

Table 4. Absolute error norm values for different time intervals obtained when Example 4 is solved:

$N_x = 10,\ N_y = 10,\ q = 4,\ m = 4,\ [0,T] = [0,10],\ N_t = 10,\ p = 5.$

	Single Domain		Multiple Domains	
T	Error Norm in u	Error Norm in v	Error Norm in u	Error Norm in v
1.0	1.89722e-13	2.13396e-13	9.53246e-14	1.10242e-13
2.0	1.10363e-12	1.19616e-12	7.75372e-13	8.65135e-13

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3.0	2.23119e-09	2.33731e-09	2.80567e-12	3.01118e-12
4.0	4.35874e-01	3.38041e-01	2.22283e-11	2.31627e-11
5.0	4.71456e+02	5.69322e+02	4.13003e-09	7.22800e-09
CPU time (sec)	17.345153		1.826348	
Cond Number	3.6427e+07		2.9215e+03	

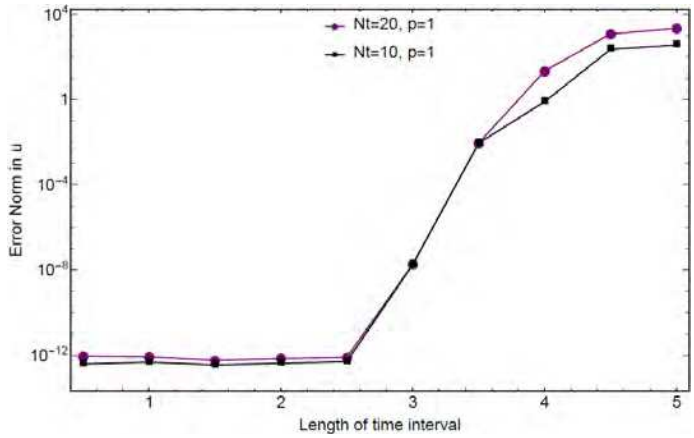

Figure 12. Error norms in u for different time intervals [0,T] for 2D coupled Brusselator system

(Varying grid points)

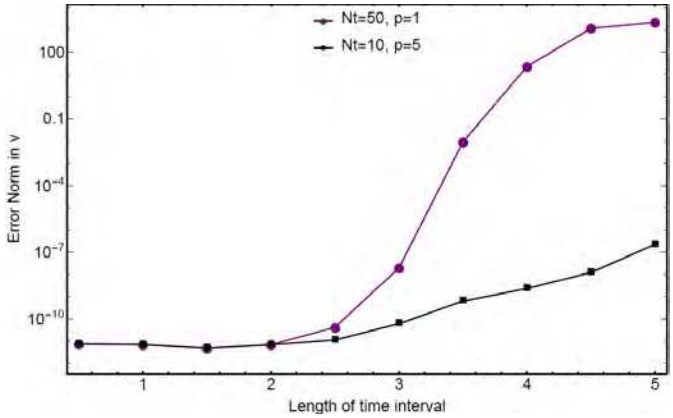

Figure 13. Error norms in v for different time intervals [0,T] for 2D coupled Brusselator system (fixed grid points)

17 Conclusion

In this work, a modified numerical method namely, the overlapping grids based multi-domain trivariate spectral collocation method for solving nonlinear two-dimensional initial-boundary value problems is proposed. The method has been described and successively applied on typical examples of two-dimensional initial-boundary value problems reported in the literature as a single nonlinear equation or systems of nonlinear equations. From the numerical simulations, we arrive at the following conclusions; the standard single domain based trivariate spectral collocation method is only accurate when applied to solve nonlinear two-dimensional initial-boundary value problems defined on a small time interval. When the time interval is large, many grid points are required to achieve results with stringent accuracy

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and this is only applicable if the solutions' higher ordered derivatives are bounded within the computational domain. For solutions with unbounded higher ordered derivatives, the application of the standard single domain based trivariate spectral collocation method is limited to problems defined on a small time interval as a large number of grid points would be computationally expense and won't guarantee the accuracy of the numerical approximations. For fluid flow problems demonstrated in this case by the two-dimensional Burger's system, values of the governing flow parameters ought to be small to obtain accurate results with the single domain approach. The main challenge in deciding whether to use the standard trivariate spectral collocation method is that in many practical problems the exact solutions are not known at the onset of the application of the method, therefore, the standard single domain trivariate spectral collocation method has many shortcomings. The modified overlapping grids based multi-domain spectral collocation method is reliable as it gives highly accurate results over short CPU time. Accuracy wise, the superiority of the current method of solution can be attributed to the purely spectral collocation discretization performed in all variables coupled with the small condition numbers of the coefficient matrices in the multi-domain approach. The short CPU time required to generate results is linked to the small-sized coefficient matrix in the multi-domain approach that is easy to invert. Owing to the remarkable benefits, the current method of solution is a suitable alternative method for solving two-dimensional nonlinear initial-boundary value problems defined on large regular spatial domains over a large time interval. In addition, the overlapping grids technique is a useful tool when solving differential equations with large parameter values and those defined over large spatial domains. Future work will entail an extension of the current numerical method to problems defined on circular domains.

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Declaration of interest:

There is no conflict of interest regarding publication of this paper.

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MHD Free Convection Flow of Chemically Reacting Casson Fluid from Vertical Surface in Porous Media Considering Ohmic Dissipation

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Abstract. An efficient multi-domain bivariate spectral method is presented and applied to solve a two-dimensional steady MHD free convection flow, heat and mass transfer over a vertical surface embedded in a non-Darcy saturated porous medium. This study focuses on the combined effects of chemical reaction, hall and ion-slip including ohmic dissipation. The flow problem is reduced to coupled system of nonlinear partial differential equations using dimensionless variables and then solved using overlapping multi-domain bivariate spectral quasilinearisation method (OMD-BSQLM). Previously, the multi-domain technique have been applied to either space or time variable but not both. The new approach applies the Chebyshev spectral collocation method that uses bivariate Lagrange Interpolation Polynomials as bases functions to discretize the iterative scheme to form matrix equations that are solved over a sequence of overlapping sub-intervals in space and non-overlapping sub-intervals in time. Overlapping grid helps to improve the accuracy of spectral collocation methods through making the coefficient matrix less dense. Numerical analysis of the error and convergence properties of the method are discussed. The method is found to be convergent and gives very accurate results with very few grid points. The behaviour of the fluid properties, skin friction coefficients, heat and mass transfer rates have been discussed for variations in the governing parameters.

Keywords: Multi-domain, Overlapping grid, Bivariate spectral quasilinearisation method, Casson fluid, Non-Darcy model, Forchheimer parameter, Chemical reaction, Hall currents, Ionslip currents.

19 Introduction

The study of Magnetohydrodynamic (MHD) flows, heat and mass transfer in porous and non-porous media have stimulated extensive attention due to its significant applications like the MHD power generator and Hall accelerator. In addition, this type of flow finds applications in many engineering problems such as MHD generators, plasma studies and geothermal energy extractions. Free convection in electrically conducting fluids through an external magnetic field has been a subject of considerable research interest of a large number of scholars for a long time due to its diverse applications in the fields such as nuclear reactors and liquid metals among others. There are many transport processes that are governed by the combined action of buoyancy forces due to both thermal and mass diffusion in the presence of the chemical reaction effect. These processes are observed in nuclear reactor safety and combustion systems, solar collectors, as well as metallurgical and chemical engineering. Gribben [1] presented the boundary layer flow over a semi-infinite plate with an aligned magnetic field in the presence of pressure gradient. He obtained solutions for large and small magnetic Prandtl number using the method of matched asymptotic expansion. Soundalgekar et al. [2] analyzed the problem of free convection effects on Stokes problem for a vertical plate under the action of transversely applied magnetic field with mass transfer. Raptis et al. [3] analyzed hydromagnetic free convection flow through a porous medium between two parallel plates. Kinyanjui et al. [4] presented simultaneous heat and mass transfer in unsteady free convection flow

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with radiation absorption past an impulsively started infinite vertical porous plate subjected to a strong magnetic field. Postelnicu [5] studied simultaneous heat and mass transfer by natural convection from a vertical plate embedded in electrically conducting fluid saturated porous medium, using Darcy-Boussinesq model including Soret, and Dufour effects.

Hall and ion-slip effect plays vital role in many geophysical and astrophysical applications besides several engineering problems. Srinivasacharya and Shiferaw [6, 7] presented the significance of Hall and Ion-slip effects in non-Newtonian fluids. Joule heating and viscous dissipation effects are oriented to be significant for massive variations of gravitational force, operating at high rotational speeds and strong magnetic field. Takhar and Soundalgekar [8] studied the effects of viscous dissipation and Joule heating on the MHD free convection flow past a vertical plate. Palani and Kim [9] studied effects of Joule heating and viscous dissipation on MHD flow past a semi-infinite inclined plate with variable surface temperature. Abo-Eldahab and El Aziz [10] presented the effects of Hall and ion-slip currents on MHD free convective heat generating flow past a semi-finite vertical plate. Abo-Eldahab and El Aziz [11] also studied the effects of viscous dissipation and Joule heating on MHD-free convection from a vertical plate with power-law variation in surface temperature in the presence of Hall and ion-slip currents.

There are many transport processes that are governed by the combined action of buoyancy forces due to both thermal and mass diffusion in the presence of the chemical reaction effect. These processes are observed in nuclear reactor safety and combustion systems, solar collectors, as well as metallurgical and chemical engineering. Hall current and ion-slip effect including chemical reaction effect were examined by several researchers. Salem and Abd El-Aziz [12] examined the effect of hall currents and chemical reaction on hydromagnetic flow of a stretching vertical surface with internal heat generation/ absorption. Motsa and Shateyi [13] studied the effects of chemical reaction, Hall, ion-slip currents, and variable thermal diffusivity on the magneto-micropolar fluid flow, heat, and mass transfer with suction through a porous medium using successive linearization method together with the Chebyshev collocation method. Elgazery [14] analyzed numerically the problem of magneto-micropolar fluid flow, heat and mass transfer with suction and blowing through a porous medium under the effects of chemical reaction, Hall, ion-slip currents, variable viscosity and variable thermal diffusivity.

None of the above mentioned studies simultaneously studied the effects of Hall and ion-slip, ohmic dissipation and chemical reaction, on boundary layer free convection MHD flow over a vertical surface through a porous medium. In this study we consider the effects of chemical reaction, Hall and ion slip currents on MHD free convection flow of chemically reacting Casson fluid from vertical surface in porous media. The transformed system of equations modelling the problem is solved using overlapping multi-domain bivariate spectral quasilinearisation method (OMD-BSQLM). The challenge of finding more accurate and computationally efficient numerical methods for solving strongly nonlinear boundary value problems still persists. Spectral collocation based methods have been found to be more accurate than traditional methods like finite difference methods. In the present study we describe the development of OMD-BSQLM which is slightly accurate than non-overlapping multi-domain bivariate spectral quasilinearisation method (MD-BSQLM) [15]. The MD-BSQLM has been successfully implemented in solving systems of non-similar Boundary layer PDEs [16-18]. Previously, the multi-domain approach in spectral methods (e.g. MD-BSQLM) have been applied to either space or time but not both. However, the accuracy of spectral methods can be improved by applying the multi-domain technique in both space and time. The proposed method uses multi-domain technique, Chebyshev-Gauss-Lobatto grid points [19, 20], quasilinearisation method [21] together with spectral collocation method on approximate

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functions defined as bivariate Lagrange interpolation polynomials. The multi-domain approach uses the noble idea of dividing the time interval into non-overlapping sub-intervals and the space interval into overlapping sub-intervals. The quasilinearisation method helps to linearise the nonlinear differential equations. The spectral collocation method is applied independently both in space and time variables of the linearized equations. The linear differential equations are then solved at each sub-interval. Since the method combines bivariate spectral quasilinearisation method (BSQLM), non-overlapping and overlapping multi-domain technique, for reference purposes we shall refer to the method as overlapping multi-domain bivariate spectral quasilinearisation method (OMD-BSQLM). Since OMD-BSQLM has not been used before to solve systems of non-similar Boundary layer PDEs, validation of this method for fluid flows, heat and mass transfer problems is required. This study presents the first opportunity to evaluate the accuracy and robustness of the OMD-BSQLM in solving systems of nonlinear PDEs arising in fluid dynamics.

20 Mathematical formulation of the problem

Consider MHD natural convection flow of electrically conducting Casson fluid adjacent to a non-isothermal vertical surface in (x, y, z) coordinate system embedded in

a non-Darcy saturated porous medium. The magnetic field act only in the y-direction

with component ‚B-0„. Initially both the fluid and the surface are maintained at the

same temperature and concentration. Instantaneously, they are raised to a tempera-

ture ‚T-∞„ ‚T-w„ and concentration ‚C-∞„ ‚C-w„ then after the ambient temperature

and concentration remain unchanged. Under the above assumptions along with the assumptions of Boussinesq and boundary layer approximations, the basic equations of Casson fluid governing the steady free convection boundary layer flow under the influence of transversely applied magnetic field and implementing Darcy-Forchheimer model in saturated porous medium can be written as:

$$‚∂u-∂x„+‚∂u-∂y„=0, \quad (0)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\left[1+\frac{1}{\beta}\right]\frac{\partial^2 u}{\partial y^2}+g^*[\beta_T(T-T_\infty)+\beta_c(C-C_\infty)]-\nu\frac{u}{k^*}-b\frac{u^2}{k^*}-\frac{\sigma {B_0}^2}{\rho({\alpha_e}^2+{\beta_e}^2)}(\alpha_e u+\beta_e w) \quad (0)$$

,

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$$u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}=\nu\left[1+\frac{1}{\beta}\right]\frac{\partial^2 w}{\partial y^2}-\nu\frac{w}{k^*}-b\frac{w^2}{k^*}+\frac{\sigma {B_0}^2}{\rho(\alpha_e{}^2+\beta_e{}^2)}(\beta_e u-\alpha_e w), \quad (0)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=k\frac{\partial^2 T}{\partial y^2}+\frac{\nu}{C_p}\left[\left(\frac{\partial u}{\partial y}\right)^2+\left(\frac{\partial w}{\partial y}\right)^2\right]+\frac{\sigma {B_0}^2}{\rho C_p(\alpha_e{}^2+\beta_e{}^2)}(u^2+w^2), \quad (0)$$

u,∂C-∂x.+v,∂C-∂y.=,D-m.„∂-2.C-,∂y-2..-,K-1.(C-,C-∞.), (0)

where *u, v* and *w* are velocity components in the *x, y, z*- directions, ρ is the fluid density, ,g-*. is the acceleration due to gravity, *k* is the permeability of the porous medium, σ is electrical conductivity of the fluid, ,k-*.is the permeability of the porous medium, β is Casson fluid parameter, ,β-T. is the coefficient of thermal expansion, ,β-c. is the coefficient of solutal expansion, ,B-0. is the magnetic field intensity, k is thermal conductivity, ν is kinematic viscosity of the fluid, ,C-p. is the specific heat, ,D-m. is the mass diffusivity, ,K-1. is the chemical reaction parameter and ,α-e.=1+ ,β-i.„β-e. , where ,β-i. is the ion-slip parameter, ,β-e.=,ω-e.„t-e. is the hall current, ,ω-e. is the electron frequency and ,t-e. is the electron collision time.

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The boundary conditions are given by

$$u = v = w = 0, T = T_w, C = C_w, \qquad \text{at } y = 0, \tag{0}$$

u=0, w = 0, T = ,T-∞., C= ,C-∞, . as y→∞, (0)

To introduce the governing equations (1)-(5) into a dimensionless form, we introduce a stream function Ψ defined by u=,∂Ψ-∂y. and v= -$\frac{\partial \Psi}{\partial x}$, thus satisfying the mass conservation equation (1). Furtheremore, the following dimensionless variables are introduced into equations (1)-(5):

ζ=„x-1/2.-,L-1/2.., η = ,cy -,x-1/4.., w = 4ν,c-2.,x-,1-2..G,ζ,η., Ψ=4νc,x-,3-4..f,ζ,η., Da= „k-*.-,L-2..,

θ,ζ,η. =,T-,T-∞.-,T-w.-,T-∞.., ϕ,ζ,η.= ,C-,C-∞.-,C-w.-,C-∞.., K= „K-1.,L-1/2.-ν,c-2..,

M= ,σ„B-0.-2.,L-1/2.-2ρν.,

$$c = \left\{\frac{g^* \beta (T_w - T_\infty)}{4\nu^2}\right\}^{1/4}, Ec = \frac{4\, L^{1/2}}{C_p (T_w - T_\infty)}, \qquad Gr_x = \frac{g^* \beta_T (T_w - T_\infty) x^3}{\nu^2},$$

P,r-= ,μ,C-p.-k.., Fs= ,b-L., Sc= ,ν-,D-m.., (0)

where L denotes characteristics length, M is magnetic parameter, ζ is dimensionless tangential coordinate, η is the dimensionless normal coordinate, Ec is Eckert (viscous heating) number, K is chemical reaction parameter, Da is Darcy number, Fs is

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Forchheimer (inertial) parameter, f is dimensionless stream function, θ is dimen-

sionless temperature, ϕ is dimensionless concentration and ,Gr-x. is local Grashof

number.

Substituting equation (8) onto equations (1)-(5), we obtain the following non-dimensional equations:

,1+,1-β..,f-'''.+3f,f-''.-2„f-'.-2.+,θ+δϕ.-,2-Da „Gr-x.-,1-2...,ζ-

4.,f-'.-,4Fs-Da.,ζ-2.„f-'.-2.

(0)

-,2M-„α-e.-2.+„β-e.-2..ζ„α-e.,f-'.+,β-e.G.=2ζ„f-'. ,∂,f-'.-

∂ζ.-,f-''.„∂f-∂ζ..,

$$\left(1+\frac{1}{\beta}\right)G''+3fG'-2Gf'-\frac{2}{Da\ Gr_x^{\frac{1}{2}}}\zeta^4G-\frac{4Fs}{Da}\zeta^2G^2$$

+,2M-„α-e.-2.+„β-e.-2..ζ„β-e.,f-'.- ,α-e.G.=2ζ„f-'. ,∂G-

(0)

∂ζ.-,G-'.„∂f-∂ζ..,

,1-Pr.,θ-''.+3f,θ-'.+4,ζ-4.Ec„„f-''.-2.+„G-'.-2..+ (0)

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$$\frac{2MEc}{\alpha_e{}^2+\beta_e{}^2}\zeta^3[f'^2+G^2]=2\,\zeta\left(f'\,\frac{\partial\theta}{\partial\zeta}-\theta'\frac{\partial f}{\partial\zeta}\right),$$

$$,1-Sc.,\phi-''.+3f,\phi-'.-\zeta K\phi=2\,\zeta,,f-'.\,,\partial\phi-\partial\zeta.-,\phi-'.,\partial f-\partial\zeta..,\qquad(0)$$

The corresponding transformed non-dimensional boundary conditions are

$$f,\zeta,0.=0,\ ,f-'.,\zeta,0.=0,\ G,\zeta,0.=0,\ \theta,\zeta,0.=\phi,\zeta,0.=1,\ \text{at}\ \eta=0,\qquad(0)$$

$$,f-'.\to0,\ G\to0,\ \theta\to0,\ \phi\to0,\ \text{as}\ \eta\to\infty,\qquad(0)$$

The non-dimensional skin frictions, the Nusselt and Sherwood numbers are respectively given by

$$,C-fx.=,1+,1-\beta..,f-''.,\zeta,0.,\quad,C-fz.=,1+,1-\beta..G',\zeta,0.,$$

$$,Nu-x.=-,1-,-2..,,Gr-x.-,1-4..,\theta-'.,\zeta,0.,\quad Sh_x=-\frac{1}{\sqrt{2}}Gr_x^{\frac{1}{4}}\phi'(\zeta,0),\qquad(0)$$

21 Method of solution

In this section, we give a brief description of the OMD-BSQLM for solving the system of governing equations (9)-(12). The method applies the Chebyshev spectral collocation method that uses bivariate Lagrange Interpolation Polynomials as bases functions to discretize the iterative scheme to form matrix equations that are solved over a sequence of non-overlapping sub-intervals in time and overlapping sub-intervals in space. In order to apply the OMD-BSQLM, the time interval $\zeta\in[0,,\zeta-F.]$ is decomposed into q non-overlapping sub-intervals defined as

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$$,J-\varepsilon.=,,\zeta-\varepsilon-1.,,\zeta-\varepsilon..,\quad \varepsilon=1,2,3,...,q, \tag{0}$$

For the semi-finite space domain [0,∞], a truncated grid [0,,η-∞.] is used. We choose a finite value of ,η-∞. that is large enough such that the flow properties at ,η-∞. resemble those at ∞. The truncated space interval [0,,η-∞.] is decomposed into *p* overlapping sub-intervals of length L, denoted by

$$,I-\mu.=[,,\eta-0.-\mu.,,,\eta-,N-\eta..-\mu.],\quad \mu=1,2,3,\ldots,p, \tag{0}$$

where each ,I-μ. interval is further discretized into ,N-η.+1 collocation points. Without loss of generality, we consider that each subinterval has the same length

$$L=,,\eta-\infty.-p+,1-2.(1-p)(1-,\cos-,\pi-,N-\eta...)., \tag{0}$$

for the overlap to be possible and the same number of collocation points (,N-η.+1) is used in each subinterval. In the domain decomposition scheme, we use overlap-

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ping subintervals ,I-μ., where the first two points of the interval ,I-μ+1. coincide

with the last two points of the interval ,I-μ., that is „η-0.-1.=0,

$$\eta_{N_\eta}{}^{p} = \eta_\infty, \eta_{N_\eta-1}{}^{\mu} = \eta_0{}^{\mu+1},\ \eta_{N_\eta}{}^{\mu} = \eta_1{}^{\mu+1}.$$

Applying quasilinearisation method in each sub-interval to the system of nonlinear partial differential equations (9)-(12) gives the following system of linear partial differential equations to be solved iteratively:

,α-1,3,r-(1,μ,ε).„∂-3.,f-r+1-(μ,ε).-∂,η-3..+,α-1,2,r-(1,μ,ε).„∂-2.,f-

r+1-(μ,ε).-∂,η-2..+,α-1,1,r-(1,μ,ε).,∂,f-r+1-(μ,ε).-∂η.+ (0)

$$\alpha_{1,0,r}^{(1,\mu,\varepsilon)} f_{r+1}^{(\mu,\varepsilon)} + \alpha_{2,0,r}^{(1,\mu,\varepsilon)} G_{r+1}^{(\mu,\varepsilon)} + \alpha_{3,0,r}^{(1,\mu,\varepsilon)} \theta_{r+1}^{(\mu,\varepsilon)} + \alpha_{4,0,r}^{(1,\mu,\varepsilon)} \phi_{r+1}^{(\mu,\varepsilon)} + \gamma_{1,r}^{(1,\mu,\varepsilon)} \frac{\partial}{\partial\zeta}\left(\frac{\partial f_{r+1}^{(\mu,}}{\partial\eta}\right.$$

$$\beta_{1,r}^{(1,\mu,\varepsilon)} \frac{\partial f_{r+1}^{(\mu,\varepsilon)}}{\partial\zeta} = R_{1,r}^{(\mu,\varepsilon)},$$

$$\alpha_{2,2,r}^{(2,\mu,\varepsilon)} \frac{\partial^2 G_{r+1}^{(\mu,\varepsilon)}}{\partial\eta^2} + \alpha_{2,1,r}^{(2,\mu,\varepsilon)} \frac{\partial G_{r+1}^{(\mu,\varepsilon)}}{\partial\eta} + \alpha_{2,0,r}^{(2,\mu,\varepsilon)} G_{r+1}^{(\mu,\varepsilon)} + \alpha_{1,1,r}^{(2,\mu,\varepsilon)} \frac{\partial f_{r+1}^{(\mu,\varepsilon)}}{\partial\eta} \qquad (0)$$

+,α-1,0,r-(2,μ,ε).,f-r+1-(μ,ε). + ,β-2,r-(2,μ,ε).,∂,G-r+1-(μ,ε).-

∂ζ. +,β-1,r-(2,μ,ε).,∂,f-r+1-(μ,ε).-∂ζ.=,R-2,r-(μ,ε).,

$$\alpha_{3,2,r}^{(3,\mu,\varepsilon)} \frac{\partial^2 \theta_{r+1}^{(\mu,\varepsilon)}}{\partial\eta^2} + \alpha_{3,1,r}^{(3,\mu,\varepsilon)} \frac{\partial \theta_{r+1}^{(\mu,\varepsilon)}}{\partial\eta} + \alpha_{3,0,r}^{(3,\mu,\varepsilon)} \theta_{r+1}^{(\mu,\varepsilon)} + \alpha_{1,2,r}^{(3,\mu,\varepsilon)} \frac{\partial^2 f_{r+1}^{(\mu,\varepsilon)}}{\partial\eta^2} \qquad (0)$$

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$$+\alpha_{1,1,r}^{(3,\mu,\varepsilon)}\frac{\partial f_{r+1}^{(\mu,\varepsilon)}}{\partial\eta}$$ +,α-1,0,r-(3,μ,ε).,f-r+1-(μ,ε). + ,β-3,r-(3,μ,ε).,∂,θ-r+1-(μ,ε).-∂ζ.

+,β-1,r-(3,μ,ε).,∂,f-r+1-(μ,ε).-∂ζ.=,R-3,r-(μ,ε).,

$$\alpha_{4,2,r}^{(4,\mu,\varepsilon)}\frac{\partial^2\phi_{r+1}^{(\mu,\varepsilon)}}{\partial\eta^2}+\alpha_{4,1,r}^{(4,\mu,\varepsilon)}\frac{\partial\phi_{r+1}^{(\mu,\varepsilon)}}{\partial\eta}+\alpha_{4,0,r}^{(4,\mu,\varepsilon)}\phi_{r+1}^{(\mu,\varepsilon)}+\alpha_{1,1,r}^{(4,\mu,\varepsilon)}\frac{\partial f_{r+1}^{(\mu,\varepsilon)}}{\partial\eta} \qquad (0)$$

+,α-1,0,r-(4,μ,ε).,f-r+1-(μ,ε). + ,β-4,r-(4,μ,ε).,∂,ϕ-r+1-(μ,ε).-

∂ζ. +,β-1,r-(4,μ,ε).,∂,f-r+1-(μ,ε).-∂ζ.=,R-4,r-(μ,ε).,

where the variable coefficient are given by

,α-1,3,r-,1,μ,ε..=1+,1-β., ,α-1,2,r-,1,μ,ε..= 3,f-r-,μ,ε..+ 2ζ,∂,f-r-,μ,ε..-∂ζ., ,α-

1,0,r-,1,μ,ε..=3,,∂-2.,f-r-,μ,ε..-∂,η-2..,

$$\alpha_{1,3,r}^{(1,\mu,\varepsilon)}=-4\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\eta}-\frac{2\zeta^4}{DaGr_x^{\frac{1}{2}}}-\frac{8Fs\zeta^2}{Da}\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\eta}-\frac{2M\zeta\alpha_e}{\alpha_e^2+\beta_e^2}-2\zeta\frac{\partial}{\partial\zeta}\left(\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\eta}\right).$$

,α-2,0,r-,1,μ,ε..=-,2Mζ,β-e.-,α-e-2.+,β-e-2.., ,α-3,0,r-,1,μ,ε..=1, , ,α-4,0,r-,1,μ,ε..=δ, ,α-

2,2,r-,2,μ,ε..=1+,1-β. ,

$$\alpha_{2,0,r}^{(2,\mu,\varepsilon)}=-2\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\eta}-\frac{2\zeta^4}{DaGr_x^{\frac{1}{2}}}-\frac{8Fs\zeta^2}{Da}G_r^{(\mu,\varepsilon)}-\frac{2M\zeta\alpha_e}{\alpha_e^2+\beta_e^2},$$

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$$\alpha_{2,1,r}^{(2,\mu,\varepsilon)} = 3f_r^{(\mu,\varepsilon)} + 2\zeta\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\zeta}, \qquad \alpha_{1,1,r}^{(2,\mu,\varepsilon)} = -2\,G_r^{(\mu,\varepsilon)} + \frac{2M\zeta\beta_e}{\alpha_e^2+\beta_e^2} - 2\zeta\frac{\partial G_r^{(\mu,\varepsilon)}}{\partial\zeta},$$

$$\alpha_{1,0,r}^{(2,\mu,\varepsilon)} = 3\frac{\partial G_r^{(\mu,\varepsilon)}}{\partial\eta}, \alpha_{3,2,r}^{(3,\mu,\varepsilon)} = \frac{1}{Pr}, \alpha_{3,1,r}^{(3,\mu,\varepsilon)} = 3f_r^{(\mu,\varepsilon)} + 2\zeta\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\zeta}, \alpha_{2,1,r}^{(3,\mu,\varepsilon)} = 4\zeta^4 Ec\frac{\partial G_r^{(\mu,\varepsilon)}}{\partial\eta},$$

$$\alpha_{2,0,r}^{(3,\mu,\varepsilon)} = \frac{4MEc\zeta^3}{\alpha_e^2+\beta_e^2}\,G_r^{(\mu,\varepsilon)}, \alpha_{1,2,r}^{(3,\mu,\varepsilon)} = 4\zeta^4 Ec\frac{\partial^2 f_r^{(\mu,\varepsilon)}}{\partial\eta^2}, \alpha_{1,0,r}^{(3,\mu,\varepsilon)} = 3\frac{\partial\theta_r^{(\mu,\varepsilon)}}{\partial\eta},$$

$$\alpha_{1,1,r}^{(3,\mu,\varepsilon)} = \frac{4MEc\zeta^3}{\alpha_e^2+\beta_e^2}\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\eta} - 2\zeta\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\zeta}, \alpha_{4,2,r}^{(4,\mu,\varepsilon)} = \frac{1}{Sc}, \alpha_{4,1,r}^{(4,\mu,\varepsilon)} = 3f_r^{(\mu,\varepsilon)} + 2\zeta\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\zeta},$$

$$\alpha_{4,0,r}^{(4,\mu,\varepsilon)} = -\zeta\,K, \alpha_{1,1,r}^{(4,\mu,\varepsilon)} = -2\zeta\frac{\partial\phi_r^{(\mu,\varepsilon)}}{\partial\zeta}, \alpha_{1,0,r}^{(4,\mu,\varepsilon)} = 3\frac{\partial\phi_r^{(\mu,\varepsilon)}}{\partial\eta}, \gamma_{1,r}^{(1,\mu,\varepsilon)} = -2\zeta\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\eta},$$

$$\beta_{1,r}^{(1,\mu,\varepsilon)} = 2\zeta\frac{\partial^2 f_r^{(\mu,\varepsilon)}}{\partial\eta^2}, \beta_{2,r}^{(2,\mu,\varepsilon)} = -2\zeta\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\eta}, \beta_{1,r}^{(2,\mu,\varepsilon)} = 2\zeta\frac{\partial G_r^{(\mu,\varepsilon)}}{\partial\eta}, \beta_{3,r}^{(3,\mu,\varepsilon)} = -2\zeta\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\eta},$$

$$\beta_{1,r}^{(3,\mu,\varepsilon)} = 2\zeta\frac{\partial\theta_r^{(\mu,\varepsilon)}}{\partial\eta}, \beta_{4,r}^{(4,\mu,\varepsilon)} = -2\zeta\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\eta}, \beta_{1,r}^{(4,\mu,\varepsilon)} = 2\zeta\frac{\partial\phi_r^{(\mu,\varepsilon)}}{\partial\eta}, \qquad R_{1,r}^{(\mu,\varepsilon)} =$$

3,f-r-,μ,ε.,,,∂-2.,f-r-,μ,ε..-∂,η-2..-,2+,4 Fs ,ζ-2.-Da.,,,,∂,f-r-,μ,ε..-∂η..-2.-2ζ,∂,f-r-,μ,ε..-∂η.,∂-

$$\partial\zeta.,,,\partial,\text{f-r-},\mu,\varepsilon..-\partial\eta..+2\zeta\,\frac{\partial^2 f_r^{(\mu,\varepsilon)}}{\partial\eta^2}\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\zeta},$$

$$R_{2,r}^{(\mu,\varepsilon)} = 3f_r^{(\mu,\varepsilon)}\frac{\partial G_r^{(\mu,\varepsilon)}}{\partial\eta} - 2G_r^{(\mu,\varepsilon)}\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\eta} - \frac{4\,Fs\zeta^2}{Da}\left(G_r^{(\mu,\varepsilon)}\right)^2 - 2\zeta\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\eta}\frac{\partial G_r^{(\mu,\varepsilon)}}{\partial\zeta}$$

$$+\zeta\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\eta}\frac{\partial G_r^{(\mu,\varepsilon)}}{\partial\zeta}, R_{3,r}^{(\mu,\varepsilon)} = 4\zeta^4 Ec\left(\frac{\partial^2 f_r^{(\mu,\varepsilon)}}{\partial\eta^2}\right)^2 + 3f_r^{(\mu,\varepsilon)}\frac{\partial\theta_r^{(\mu,\varepsilon)}}{\partial\eta} + 4\zeta^4 Ec\left(\frac{\partial G_r^{(\mu,\varepsilon)}}{\partial\eta}\right)^2$$

$$+\frac{4MEc\zeta^3}{\alpha_e^2+\beta_e^2}\left(\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\eta}\right)^2 + \frac{4MEc\zeta^3}{\alpha_e^2+\beta_e^2}\left(G_r^{(\mu,\varepsilon)}\right)^2 - 2\zeta\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\eta}\frac{\partial\theta_r^{(\mu,\varepsilon)}}{\partial\zeta} + 2\zeta\frac{\partial\theta_r^{(\mu,\varepsilon)}}{\partial\eta}\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\zeta},$$

$$R_{4,r}^{(\mu,\varepsilon)} = 3f_r^{(\mu,\varepsilon)}\frac{\partial\phi_r^{(\mu,\varepsilon)}}{\partial\eta} - 2\zeta\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\eta}\frac{\partial\phi_r^{(\mu,\varepsilon)}}{\partial\zeta} + \frac{\partial\phi_r^{(\mu,\varepsilon)}}{\partial\eta}\frac{\partial f_r^{(\mu,\varepsilon)}}{\partial\zeta}.$$

The boundary conditions take the form

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,f-r+1-,μ,ε..,ζ,0.=,G-r+1-,μ,ε..,ζ,0. =0, ,∂,f-r+1-,μ,ε..-∂η.,ζ,0.=0,

$$\theta_{r+1}^{(\mu,\varepsilon)}(\zeta,0) = \phi_{r+1}^{(\mu,\varepsilon)}(\zeta,0) = 1$$

$$,\partial,f\text{-}r+1\text{-},\mu,\varepsilon..\text{-}\partial\eta.,\zeta,\infty.=0 \ , ,G\text{-}r+1\text{-},\mu,\varepsilon..,\zeta,\infty. = \tag{0}$$

$$\theta_{r+1}^{(\mu,\varepsilon)}(\zeta,\infty) = \phi_{r+1}^{(\mu,\varepsilon)}(\zeta,\infty) = 0$$

The constants r and $r + 1$ denote previous and current iterations, respectively. The system of lineaer partial differential equations (19)-(22) is discretized using the spectral collocation method in both η and ζ directions. Before applying the spectral method on the sub-intervals, the time interval ζ∈[,ζ-ε.,,ζ-ε-1.] and space interval η∈[,η-0-ε.,,η-,N-η.-ε.] are respectively transformed into τ∈[-1,1] and z∈[-1,1], using the linear transformation

$$,\zeta\text{-}j\text{-}\varepsilon.=,1\text{-}2.,,\zeta\text{-}\varepsilon.\text{-},\zeta\text{-}\varepsilon\text{-}1..,\tau\text{-}j.+,1\text{-}2.,,\zeta\text{-}\varepsilon.+,\zeta\text{-}\varepsilon\text{-}1..,\ ,\tau\text{-} \tag{0}$$

$$j.=,\cos\text{-},,\pi j\text{-},N\text{-}\zeta....,$$

$$,\eta\text{-}i\text{-}\mu.=,L\text{-}2.,,z\text{-}i.+1.,\ z_j = \cos\left(\frac{\pi j}{N_\eta}\right), \tag{0}$$

We assume that at each subinterval, the required solution say f(η,ζ) can be approximated by bivariate Lagrange interpolation polynomial of the form

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,f-,μ,ε..,η,ζ.≈,i=0-,N-η.-,j=0-,N-ζ.-,f-,μ,ε..,, z-j., ,τ-j...,L-i.,z.,L-j.,τ... (0)

where μ=1,2,3,...,p and ε=1,2,3,...,q. The bivariate interpolation polynomial interpolates ,f-,μ,ε..(z,τ) at selected points (,z-i.,,τ-j.) in both *z* and τ directions, for i=0,1,2,3,...,,N-η. and j=0,1,2,3,...,,N-ζ.. The function $\mathcal{L}_i(z)$ and $\mathcal{L}_j(\tau)$ are well known characteristic Lagrange cardinal polynomial based on the Chebyshev Gauss-Lobatto points [19,20]. The required solution for G,η,ζ., θ(η,ζ) and ϕ (η,ζ) can be approximated in a similar manner. We then substitute equation (26) and the other bivariate Lagrange interpolation polynomials into equation (19)-(22). The required solution procedure requires that the derivatives of $\mathcal{L}_i(z)$ and $\mathcal{L}_j(\tau)$ with respect to *z* and τ, respectively be evaluated at the Chebyshev-Gauss Lobatto grid points. The derivatives of ,f-,μ,ε..(η,ζ) with respect to η and ζ at the Chebyshev-Gauss Lobatto points ,,z-k.,,τ-k.. , are computed as

$$\frac{\partial f^{(\mu,\varepsilon)}}{\partial \eta}\Big|_{\text{-(,z-k.,,τ-i.).}} = \sum_{\omega=0}^{N_\eta}\sum_{j=0}^{N_\zeta} f^{(\mu,\varepsilon)}(z_\omega,\tau_j)\frac{d\mathcal{L}_i(z_k)}{dz}\mathcal{L}_j(\tau_i),$$

$$= \sum_{\omega=0}^{N_\eta} D_{k,\omega}^{(\mu)} f^{(\mu,\varepsilon)}(z_\omega,\tau_i) = \left[\boldsymbol{D}^{(\mu)}\right]\mathbf{F}_i^{(\mu,\varepsilon)} \quad (0)$$

$$\frac{\partial f^{(\mu,\varepsilon)}}{\partial \zeta}\Big|_{\text{-(,z-k.,,τ-i.).}} = \sum_{\omega=0}^{N_\eta}\sum_{j=0}^{N_\zeta} f^{(\mu,\varepsilon)}(z_\omega,\tau_j)\mathcal{L}_\omega(z_k)\frac{d\mathcal{L}_j(\tau_i)}{d\tau},$$

$$=,j=0-,N-ζ.-,d-i,j..,f-,μ,ε..,,z-k.,,τ-j..=,j=0-,N-ζ.-,d-i,j..\mathbf{F}_j^{(\mu,\varepsilon)} \quad (0)$$

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where ,d-i,j.=,d,L-j.„τ-i..-dτ. is the ,i-th. and j^{th} entry of the standard first derivative Chebyshev-Gauss-Lobatto based differentiation matrix $\boldsymbol{d} = [d_{i,j}]$,for i,j=0,1,2,3,...,,N-ζ., of size (,N-ζ.+1)×(,N-ζ.+1) , ,D-k,ω-,μ..=,2-,η-,N-η.-μ.-,η-0-μ..,D-k,ω. with ,D-k,ω.=,d,L-ω.„z-k..-dz. being the ,k-th. and ,ω-th. entries of the standard first derivative Chebyshev-Gauss-Lobatto differentiation matrix of size ,M+1.×(M+1) ,where M=,N-η.+(,N-η.-1)(p-1) is the total number of collocation points over a single domain ,-1,1.. In general, to find the ,n-th. order derivative with respect to η, we have

$$,-.,,\partial-\eta.,f-,\mu,\varepsilon..-\partial,\eta-\eta..\Big|_{,}(z-k.,,\tau-i.)=,\omega=0-,N-\eta.-.,,,D-k,\omega-,\mu....-\eta.,,f-,\mu,\varepsilon.,,,z-\omega.,,\tau-i..= \tag{0}$$

$$,,,D-(\mu)..-\eta.,F-i-(\mu,\varepsilon).,$$

The vector $\mathbf{F}_i^{(\mu,\varepsilon)}$ is defined as

$$\mathbf{F}_i^{(\mu,\varepsilon)} = \left[f^{(\mu,\varepsilon)}\left(z_0^{(\mu)},\tau_i^{(\mu)}\right), f^{(\mu,\varepsilon)}\left(z_1^{(\mu)},\tau_i^{(\mu)}\right), f^{(\mu,\varepsilon)}\left(z_2^{(\mu)},\tau_i^{(\mu)}\right), \ldots, f^{(\mu,\varepsilon)}\left(z_{N_\eta}^{(\mu)},\tau_i^{(\mu)}\right)\right]^T,$$

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where T denotes the matrix transpose. The derivatives d and $[\boldsymbol{D}^{(\mu)}]^n$ are scaled by multiplying by the factors Λ=,2-,ζ-ε.-,ζ-ε-1.. and Ω=„„2-,η-,N-η.-μ.-,η-0-μ...-n.=„„2-L..-n., respectively. The space and time derivatives of G, θ and ϕ at each sub-interval can be transformed to discrete matrix form in a similar manner. Applying spectral collocation method by evaluating equations (19)-(22) at the collocation points and making use of the derivative matrices as well as incorporating the initial conditions which corresponds to ,ζ-,N-ζ..=-1 gives,

,A-1,1-,μ,ε.. ,F-i,r+1-,μ,ε.. +,A-1,2-,μ,ε.. ,G-i,r+1-,μ,ε..+,A-1,3-,μ,ε.. ,Θ-

(0)

i,r+1-,μ,ε..+,A-1,4-,μ,ε.. ,ϕ-i,r+1-,μ,ε..

$$+ \gamma_{1,r}^{(1,\mu,\varepsilon)} \sum_{j=0}^{N_\zeta - 1} d_{i,j} \boldsymbol{D}^{(\mu)} \mathbf{F}_j^{(\mu,\varepsilon)} + \beta_{1,r}^{(1,\mu,\varepsilon)} \sum_{j=0}^{N_\zeta - 1} d_{i,j} \mathbf{F}_j^{(\mu,\varepsilon)} = \mathbf{K}_{1,i}^{(\mu,\varepsilon)},$$

,A-2,1-,μ,ε.. ,F-i,r+1-,μ,ε.. +,A-2,2-,μ,ε.. ,G-i,r+1-,μ,ε..+,A-2,3-,μ,ε.. ,Θ-

(0)

i,r+1-,μ,ε..+,A-2,4-,μ,ε.. ,ϕ-i,r+1-,μ,ε..

$$+ \beta_{1,r}^{(2,\mu,\varepsilon)} \sum_{j=0}^{N_\zeta - 1} d_{i,j} \mathbf{F}_j^{(\mu,\varepsilon)} + \beta_{2,r}^{(2,\mu,\varepsilon)} \sum_{j=0}^{N_\zeta - 1} d_{i,j} \boldsymbol{G}_j^{(\mu,\varepsilon)} = \mathbf{K}_{2,i}^{(\mu,\varepsilon)},$$

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,A-3,1-,μ,ε.. ,F-i,r+1-,μ,ε.. +,A-3,2-,μ,ε.. ,G-i,r+1-,μ,ε..+,A-3,3-,μ,ε.. ,Θ-

(0)

i,r+1-,μ,ε..+,A-3,4-,μ,ε.. ,Φ-i,r+1-,μ,ε..

$$+\beta_{1,r}^{(3,\mu,\varepsilon)}\sum_{j=0}^{N_\zeta-1} d_{i,j}\mathbf{F}_j^{(\mu,\varepsilon)}+\beta_{3,r}^{(3,\mu,\varepsilon)}\sum_{j=0}^{N_\zeta-1} d_{i,j}\boldsymbol{\Theta}_j^{(\mu,\varepsilon)}=\mathbf{K}_{3,i}^{(\mu,\varepsilon)},$$

,A-4,1-,μ,ε.. ,F-i,r+1-,μ,ε.. +,A-4,2-,μ,ε.. ,G-i,r+1-,μ,ε..+,A-4,3-,μ,ε.. ,Θ-

(0)

i,r+1-,μ,ε..+,A-4,4-,μ,ε.. ,Φ-i,r+1-,μ,ε..

$$+\beta_{1,r}^{(4,\mu,\varepsilon)}\sum_{j=0}^{N_\zeta-1} d_{i,j}\mathbf{F}_j^{(\mu,\varepsilon)}+\beta_{4,r}^{(4,\mu,\varepsilon)}\sum_{j=0}^{N_\zeta-1} d_{i,j}\boldsymbol{\Phi}_j^{(\mu,\varepsilon)}=\mathbf{K}_{4,i}^{(\mu,\varepsilon)},$$

where ,A-1,1-,μ,ε..=, α -1,3,r-,1,μ,ε...,D-,μ..-3.+,α -1,2,r-,1,μ,ε...,D-,μ..-2.+,α

-1,1,r-,1,μ,ε.. ,D-,μ..+,α -1,0,r-,1,μ,ε..,

,A-1,2-,μ,ε..=,α -2,0,r-,1,μ,ε.., ,A-1,3-,μ,ε..=,α -3,0,r-,1,μ,ε..,A-1,4-,μ,ε..=,α -4,0,r-,1,μ,ε.., ,A-

2,1-,μ,ε..= ,α -1,1,r-,2,μ,ε.. ,D-,μ..+, α -1,0,r-,2,μ,ε..,

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$$A_{2,3}^{(\mu,\varepsilon)} = A_{2,4}^{(\mu,\varepsilon)} = 0, A_{2,2}^{(\mu,\varepsilon)} = ,\alpha\ \text{-2,2,r-,1,}\mu,\varepsilon\text{..,,,}\mathbf{D}\text{-,}\mu\text{..-2.}^{+},\alpha\ \text{-2,1,r-,2,}\mu,\varepsilon\text{..}$$

$$D^{(\mu)} + \alpha_{2,0,r}^{(2,\mu,\varepsilon)}$$

$$A_{3,1}^{(\mu,\varepsilon)} = ,\alpha\ \text{-1,2,r-,3,}\mu,\varepsilon\text{..,,,}\mathbf{D}\text{-,}\mu\text{..-2.}^{+},\alpha\ \text{-1,1,r-,3,}\mu,\varepsilon\text{..}\ D^{(\mu)} + \alpha_{1,0,r}^{(3,\mu,\varepsilon)}, A_{3,4}^{(\mu,\varepsilon)} = 0,$$

$$A_{3,2}^{(\mu,\varepsilon)} = ,\alpha\ \text{-2,1,r-,3,}\mu,\varepsilon\text{..}\ D^{(\mu)} + \alpha_{2,0,r}^{(3,\mu,\varepsilon)}, A_{3,3}^{(\mu,\varepsilon)} = ,\alpha\ \text{-3,1,r-,3,}\mu,\varepsilon\text{..}\ D^{(\mu)} + \alpha_{3,0,r}^{(3,\mu,\varepsilon)},$$

$$A_{4,1}^{(\mu,\varepsilon)} = ,\alpha\ \text{-1,1,r-,4,}\mu,\varepsilon\text{..}\ D^{(\mu)} + \alpha_{1,0,r}^{(4,\mu,\varepsilon)}, A_{3,1}^{(\mu,\varepsilon)} = A_{3,1}^{(\mu,\varepsilon)} = 0,$$

$$A_{4,4}^{(\mu,\varepsilon)} = ,\alpha\ \text{-4,2,r-,4,}\mu,\varepsilon\text{..,,,}\mathbf{D}\text{-,}\mu\text{..-2.}^{+},\alpha\ \text{-4,1,r-,4,}\mu,\varepsilon\text{..}\ D^{(\mu)} + \alpha_{4,0,r}^{(4,\mu,\varepsilon)}$$

$$,\text{K-1,i-,}\mu,\varepsilon\text{..} = ,\text{R-1,i-,}\mu,\varepsilon\text{..-,}\gamma\text{-1,r-(1,}\mu,\varepsilon),\text{d-i,,N-}\zeta\text{..}\ D^{(\mu)}\mathbf{F}_{N_\zeta}^{(\mu,\varepsilon)} - \beta_{1,r}^{(1,\mu,\varepsilon)}\mathrm{d}_{i,N_\zeta}\mathbf{F}_{N_\zeta}^{(\mu,\varepsilon)}.$$

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$$,K-2,i-,\mu,\varepsilon..= ,R-2,i-,\mu,\varepsilon..-,\beta-1,r-(2,\mu,\varepsilon)„d-i„N-\zeta..\mathbf{F}_{N_\zeta}^{(\mu,\varepsilon)} - \beta_{2,r}^{(2,\mu,\varepsilon)}\mathbf{d}_{i,N_\zeta}\mathbf{G}_{N_\zeta}^{(\mu,\varepsilon)}$$

$$,K-3,i-,\mu,\varepsilon..= ,R-3,i-,\mu,\varepsilon..-,\beta-1,r-(3,\mu,\varepsilon)„d-i„N-\zeta..\mathbf{F}_{N_\zeta}^{(\mu,\varepsilon)} - \beta_{3,r}^{(3,\mu,\varepsilon)}\mathrm{d}_{i,N_\zeta}\boldsymbol{\Theta}_{N_\zeta}^{(\mu,\varepsilon)}$$

$$,K-4,i-,\mu,\varepsilon..= ,R-4,i-,\mu,\varepsilon..-,\beta-1,r-(4,\mu,\varepsilon)„d-i„N-\zeta..\mathbf{F}_{N_\zeta}^{(\mu,\varepsilon)} - \beta_{4,r}^{(4,\mu,\varepsilon)}\mathrm{d}_{i,N_\zeta}\boldsymbol{\Phi}_{N_\zeta}^{(\mu,\varepsilon)}$$

for i=0,1,2,3,...„N-ζ.-1. The vectors $\mathbf{F}_{i,r+1}^{(\mu,\varepsilon)}, \mathbf{G}_{i,r+1}^{(\mu,\varepsilon)}, \boldsymbol{\theta}_{i,r+1}^{(\mu,\varepsilon)}$ and $\boldsymbol{\Phi}_{i,r+1}^{(\mu,\varepsilon)}$ denote the vectors f,G,θand ϕ approximated at the collocation points. Equations (30)-(33) can be converted into a matrix system of size ,N-ζ.„M+1.×,N-ζ.(M+1). Starting from suitable initial guesses, the approximated solutions for f,η,ζ., G,η,ζ., θ(η,ζ) and ϕ (η,ζ) are obtained by iteratively solving the matrix equations.

22 Results and Discussion

In this section we present numerical results of the governing partial differential equations (9)-(12) obtained using the OMD-BSQLM. The set of results display convergence rates and accuracy of the iterative scheme together with the effect of the various flow parameters on the fluid properties, the skin friction, heat and mass transfer coefficients. The number of collocation points was 30 in space and 5 in time if not stated. The choice of these collocation points gave consistent results which did not change to a significant level when the values were increased. The value of ,η-∞. used was 15. The convergence of the proposed method was assessed by considering the norm of the difference in the values of the approximate solution of the un-

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known function between two successive iterations. Thus we define the following solution error

,E-f.=„max-0≤k≤,N-ζ..-.,||,F-r+1,k-,μ,ε..-,F-r,k-,μ,ε..||-∞., ,E-G.=„max-0≤k≤,N-

ζ..-.,||,G-r+1,k-,μ,ε..-,G-r,k-,μ,ε..||-∞.,

$$,E-\theta.=„\max\text{-}0\leq k\leq,N-\zeta..-.,||,\Theta-r+1,k-,\mu,\varepsilon..-,\Theta-r,k-,\mu,\varepsilon..||-\infty., \tag{0}$$

$$E_{\varphi}=\max_{0\leq k\leq N_{\zeta}}\ \|\Phi_{r+1,k}^{(\mu,\varepsilon)}-\Phi_{r,k}^{(\mu,\varepsilon)}\|_{\infty},$$

For the QLM scheme to converge, the norms defined in equations (34) are expected to decrease with increasing number of iterations. Fig. 1 (a) shows that the solution errors decrease as the number of iteration increases. This is an indication that the method converges and full convergence is reached at the point when the convergence plot begins to plateau off. The Figure shows that full convergence is achieved

after about six iterations with a solution error of less than ,10--14.. The accuracy of

the proposed OMD-BSQLM can also be estimated by considering the residual errors of the unknown functions after a specified number of iterations. We substitute the approximate solutions into equations (9)-(12) and determine the infinity norm of the residual error. These norms are given by

,||Res(f)||-∞.=||,1+,1-β..,f-'''.+3f,f-''.-2,,f-'.-2.+,θ+δϕ.-,2-Da „Gr-x.-,1-2...,ζ-

4.,f-'.-,4Fs-Da.,ζ-2.,,f-'.-2.

$$,-,2M-,,\alpha-e.-2.+„\beta-e.-2..\zeta,,\alpha-e.„f-'.+,\beta-e.G.-2\zeta„f-'.\ ,\partial,f-'.-\partial\zeta.-,f-''.„\partial f-\partial\zeta..||-\infty. \tag{0}$$

$$\|Res\,(G)\|_{\infty}=\|\left(1+\frac{1}{\beta}\right)G''+3fG'-2Gf'-\frac{2}{Da\ Gr_{x}^{\frac{1}{2}}}\zeta^{4}G-\frac{4Fs}{Da}\zeta^{2}G^{2}$$

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,+,2M-„α-e.-2.+„β-e.-2..ζ„β-e.„f-'.- ,α-e.G.-2ζ„f-'. ,∂G-∂ζ.-,G-'.„∂f-∂ζ..‖-∞. (0)

$$\|Res(\theta)\|_{\infty} = \|$$,1-Pr.„θ-''.+3f,θ-'.+4,ζ-4.Ec„„f-''.-2.+„G-'.-2..+ $\frac{2MEc}{\alpha_e^2+\beta_e^2}\zeta^3[f'^2 + G^2]$

,-2 ζ„f-'. ,∂θ-∂ζ.-,θ-'.„∂f-∂ζ..‖-∞., (0)

$$\|Res(\phi)\|_{\infty} = \|$$,1-Sc.,ϕ-''.+3f,ϕ-'.-ζKϕ-2 ζ„f-'. ,∂ϕ-∂ζ.-,ϕ-'.„∂f-∂ζ..‖ ∞, (0)

Fig.1 (b) shows the variation of the residual errors against iterations for different values of non-similar parameter ζ. It can be seen that the residual error decreases with increasing number of iterations. The figure displays convergence with a residual error less than ,10--14. which is obtained after three iterations. To verify the validity and accuracy of the proposed method, we have compared our numerical results for the values of the temperature gradient $-\theta'(0)$ with those reported by Pop and Watanabe [22], Takhar et al. [23], and Abo-Eldahab and El Aziz [11] for various values of Prandtl number Pr for the special case. We have considered $\beta\to\infty$, Fs→0 causing the inertial effects to disappear, Da→∞, causing the regime permeability to become infinite and porous fibers to vanish in the limit, Ec→0 causing both viscous heating and Joule electric current heating terms to vanish in the energy

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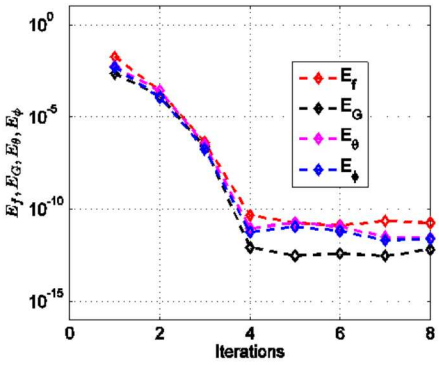
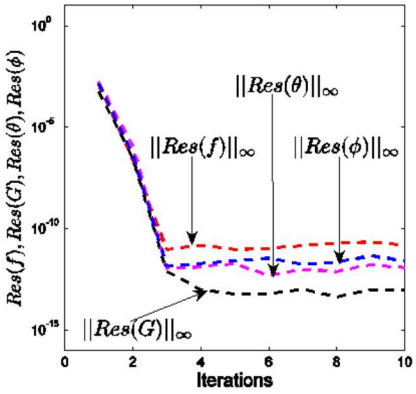
equation and M→0 resulting to Hall current and ion slip effects disappearing in the momentum equations.



(a)



(b)

Fig. 1 (a) Convergence graphs and (b) residual error graphs at ζ=4

Table 1 gives the comparison, where the present results are found to be in good agreement with previously published results. Efficient non-overlapping MD-BSQLM has also been used as a benchmarking tool to test the accuracy, and hence the reliability of the OMD-BSQLM results. We have used this method since our proposed method is an improvement of MD-BSQLM. Table 2 shows skin friction, heat and mass transfer coefficients for different values of Casson fluid, Hall, ion-slip and chemical reaction parameter computed using MD-BSQLM and OMD-BSQLM. To obtain comparable results, we have used 100 and 30 collocation points in space for OMD-BSQLM and MD-BSQLM, respectively. The number of collocation points in time were 5 in both methods. Only three iterations were needed in the OMD-BSQLM, while five iterations were required in the MD-BSQLM to produce comparable results. Space and time intervals were each decomposed into only 5 sub-intervals for OMD-BSQLM, while for the MD-BSQLM, the time interval was decomposed to 40 subinterval to achieve comparable results. Table 3 presents numerical results for skin friction, heat and mass transfer rates along with a variation in Forch-

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heimer parameter and transverse coordinate ,ζ.. Table 2 and 3 suggest that OMD-

BSQLM gives accurate results using small number of sub-intervals, minimal number of grid points and iterations for values of ζ smaller and larger than 1.

Table 1: Comparison of -θ'(0,0) for various values of Pr when M=,β-e.=K=δ=,β-

i.=Sc=Ec=Fs,=ζ=0, ,Gr-x.→∞, Da→∞, β→∞

Pr	Takkher et al. [23]	Pop and Watanabe[22]	Abo-Eldahab and El Aziz [11]	Present results
0.9	0.5465	-	0.546501	0.5465363
0.733	0.5079	-	0.507872	0.5079077
0.72	-	0.504620	0.504599	0.5046342
0.5	0.4412	-	0.441191	0.4411669

In order to gain an insight into the physics of the problem, graphical representation of the numerical results are presented in Fig. 2 - 5, depicting the influence of various governing parameters on the fluid properties. Fig. 2 displays typical profiles for the

velocity components f'(η,ζ) and G(η,ζ), temperature θ(η,ζ)and concentration ϕ(η,ζ)

for various values of chemical reaction parameter *K*. It is seen from Fig. 2 (a)-(c) that the primary velocity and secondary velocity decrease with an increase of chemical reaction, whereas the temperature is enhanced with increase of chemical reaction. The primary and secondary velocity increase, while the temperature decreases for values of $K < 0$. However, the opposite trend is obtained for values of $K > 0$: Table 2 indicates that the local skin friction in the *x*- and *z*- directions as well as the rate of heat transfer decrease with increasing K. Fig.2 (d) shows that the effect of chemical reaction within the boundary layer is very significant in concentration field. The chemical reaction reduces the dimensionless concentration, thus increasing its concentration gradient and its flux. From Fig.2 (d), we observe that the concentration accelerates during generative reaction ($K < 0$) and decelerates in destructive reaction ($K > 0$). Table 2 shows that the rate of mass transfer increases with increasing chemical reaction parameter. This is caused by a large reduction in the concentration boundary layer thickness.

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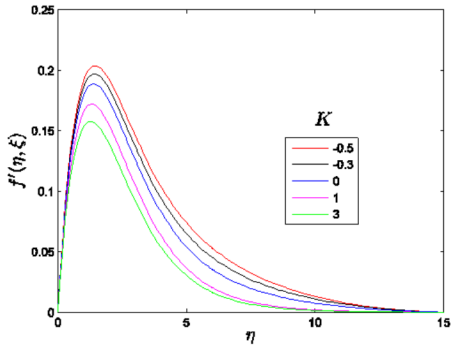

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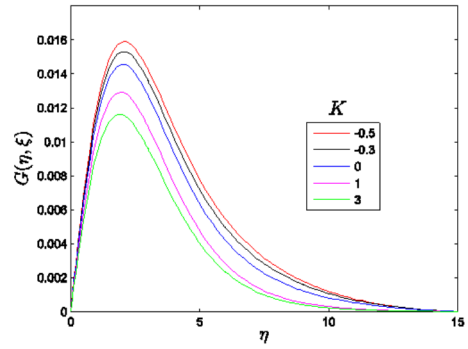

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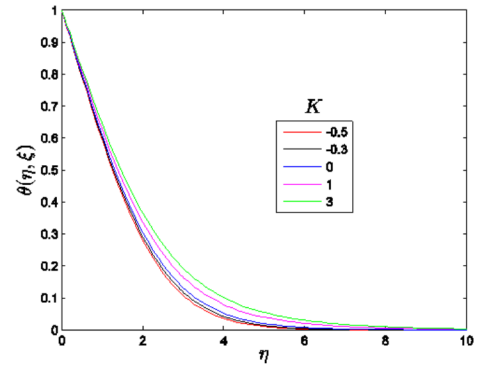

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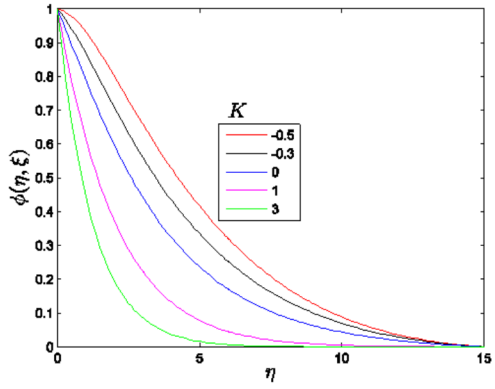

(d)

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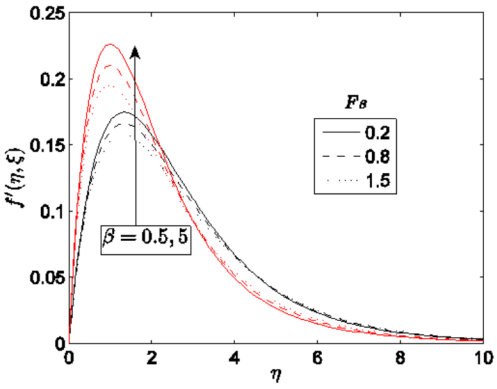
Fig.2 Effect of K on (a) primary velocity, (b) secondary velocity, (c) temperature and (d) concentration

Fig. 3 elucidate the effects of the Casson fluid parameter β and Forchheimer parameter Fs on the velocity, temperature and concentration profiles. The velocity is found to increase with increasing values of β close to the boundary. Due to an increase in the Casson parameter, the yield stress decreases and consequently the velocity boundary layer thickness increases. Further away from the boundary, the velocity components and thickness of the momentum boundary layers decrease with increasing values of β. This is because increasing values of β dilute the strength of yield stress of the Casson fluid which enhances the value of plastic dynamic viscosity of fluid that produces a drag force in the fluid and as a result velocity of the fluid falls. It is observed from Fig.3 (c) that the variation of the dimensionless temperature decrease with the Casson fluid parameter inside the thermal boundary layer. The variation of the dimensionless concentration is almost independent of the Casson fluid parameter as depicted in Fig. 3 (d). However, the small effect shows that concentration decreases with the Casson fluid parameter.

Table 2 reflects that as the value of Casson parameter increases, the rate of heat and mass transfer increases while the skin friction in x- and z- directions decreases. We also observe from Fig.3 that both temperature and concentration distributions increase with increasing Forchheimer parameter Fs, while the velocity components decrease. This is because the drag of the porous medium is increased when the inertia is included. The velocity profiles is observed to decelerate closer to the boundary, transverse to the plate surface. This is because inertial quadratic drag has stronger effect closer to the wall. The Forchheimer drag force is a second order retarding force simulated in the momentum conservation equation. Increasing inertial values causes a strong increase in Forchheimer drag which decelerates the flow and in turn reduces velocities. Increasing Fs is observed in Table 3 to decrease skin friction coefficient, heat transfer rate and mass transfer rate. However, for the transverse coordinate ζ greater than 1 the opposite trend is seen for the heat and mass transfer rate.



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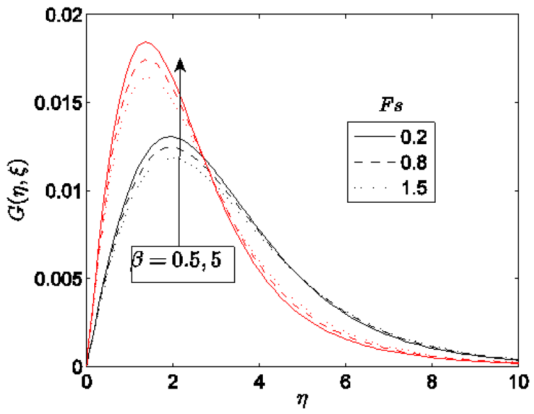

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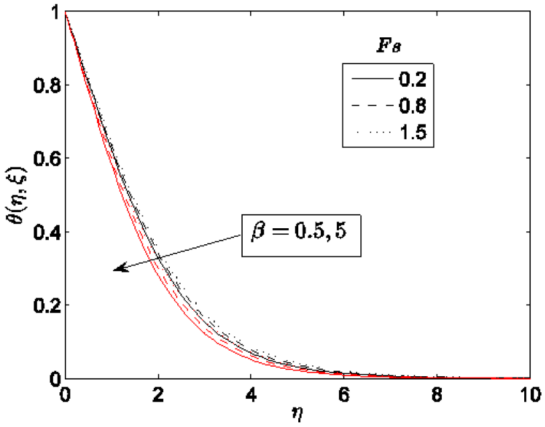

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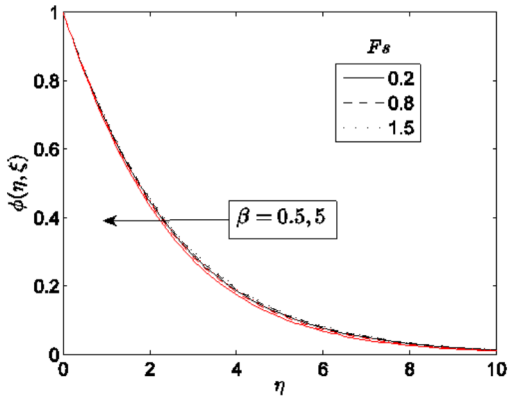

(d)

Fig.3 Effect of β and Fs on (a) primary velocity , (b) secondary velocity, (c) temperature and (d) concentration

The effect of Hall current ,β-e. on velocity components, temperature and concentration is presented in Fig. 4. We note that the primary velocity increases with rise in

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,β-e. as shown in Fig.4 (a). This is due to the fact that large values of Hall current accelerates the primary flow. It is observed that the primary velocity steeply rises up to maximum peaks some distance from the plate surface as the Hall parameter increases. Momentum supplied to accelerate the primary flow is consumed in the secondary flow and this is observable in a strong deceleration in secondary velocity, as seen in Fig. 4 (b). With increasing values of ,β-e. , the peak secondary velocity is displaced closer to the plate surface. The secondary velocity G(η,ζ) is observed to increase with increasing values of Hall parameter when ,β-e. < 1, but decreases as the Hall parameter increases when ,β-e. > 1. We can conclude that the maximum value of the secondary velocity first increases and then decreases as ,β-e. continuously increases.

These findings concur with that observed by Motsa and Shateyi [13]. The dimensionless temperature decreases with increasing values of ,β-e.. This is attributed to the inverse square effect occurring in the Joule heating term in equation (11). This term couples the primary and secondary velocity fields to the energy level. The thermal boundary layer is cooled and thickness is decreased with increasing values of Hall parameter. Similarly to temperature profiles, the concentration profiles is also observed to approach their classical values when the Hall parameter become large as seen in Fig.4 (d). The dimensionless concentration decreases with increasing values of ,β-e.. From Table 2, we observe that the heat transfer rate, mass transfer rate as

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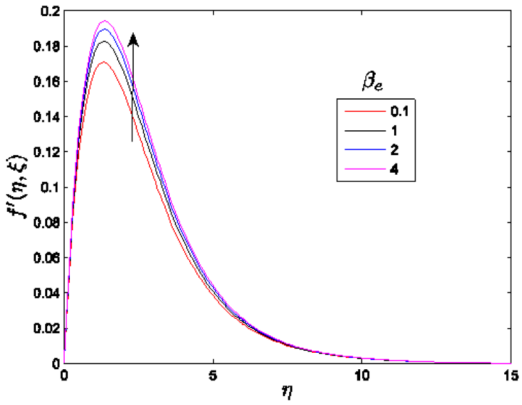
well as the local skin friction in the x- direction increase as the Hall parameter ,β-e. increases. However, the local skin friction in z- direction increases when ,β-e. increases to 1 and decreases for values of ,β-e. greater than 1.



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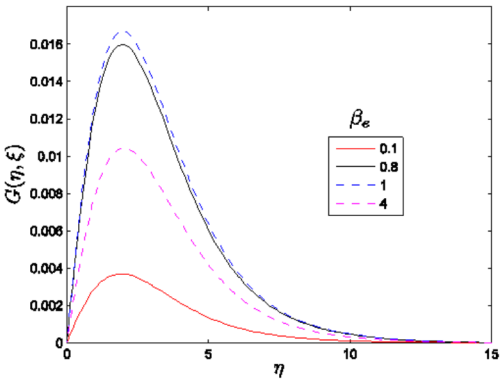

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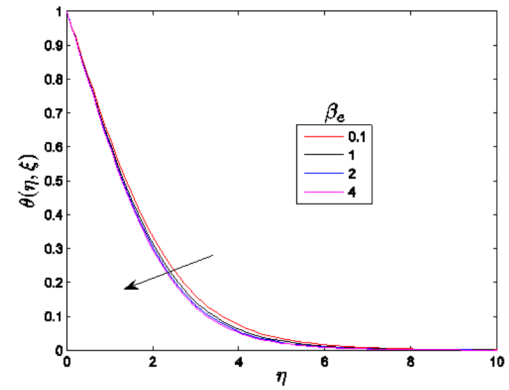

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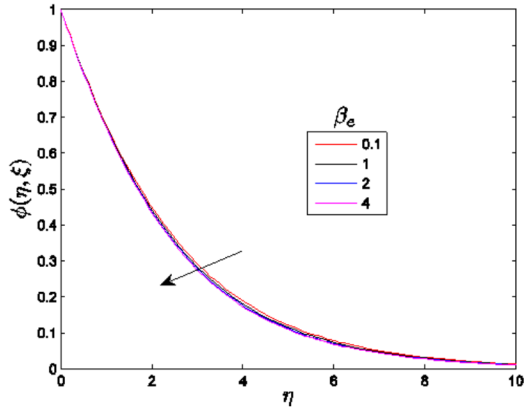

(c)

Fig. 4 Effect of β_e on (a) primary velocity, (b) secondary velocity, (c) temperature and (d) concentration

Fig.5 shows the effects of the ion slip parameter ,β-i. on the velocities, temperature and concentration distributions. The primary velocity is enhanced when ,β-i. increases, whereas the secondary velocity, temperature and concentration decrease with an increase in ,β-i. . The ion slip is observed to have a significant effect on the induced flow in the *z*-direction than in the *x*-direction. Ion slip arises in the parame-

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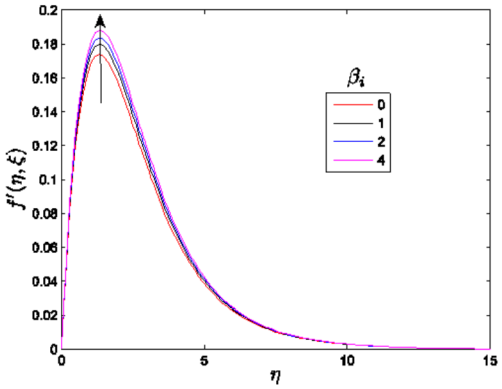
ter ,α-e.=1+,β-e.,β-i. , which causes a heating effect as the ions slip in the magnetic

field and a reduction in the secondary flow. Only primary velocity is positively influenced by ion slip effect and this become advantageous in MHD energy generator systems. Table 2 shows that Nusselt number Sherwood number and dimensionless

wall shear stress in the *x*-direction increase with increasing ion-slip parameter ,β-i.,

while the dimensionless wall shear stress in the z- direction decrease with increasing ion-slip parameter.



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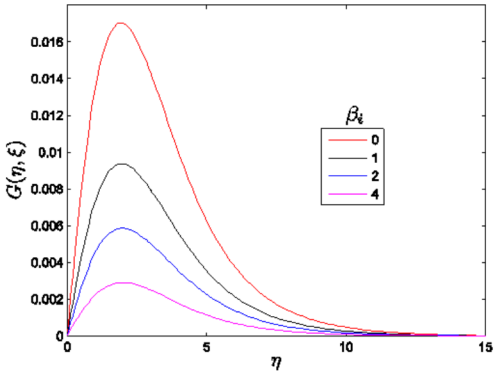

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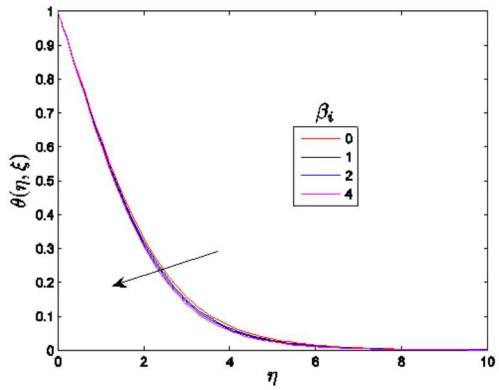

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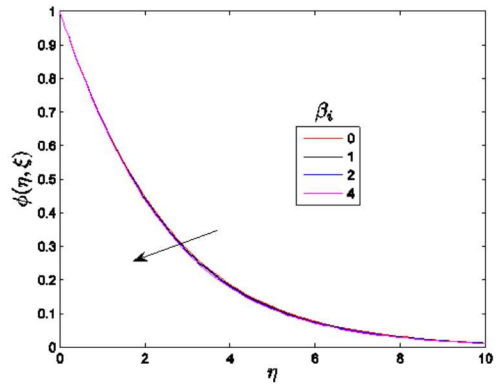

(d)

Fig. 5 Effect of β_i on (a) primary velocity, (b) secondary velocity, (c) temperature and (d) concentration

Table 2: Comparison of the OMD-BSQLM and MD-BSQLM results for ,C-fx.„C-fz.„Nu-x. and ,Sh-x. for different values of β,„β-e.„β-i. and *K* when ζ=1, δ=M=0.5, ,Gr-x.=1,P,r-=0.72, Sc=0.22, Da=1, Fs=0.1. and Ec=0.1

				OMD-BSQLM			
							Iter.
β	,	,	K	,C-fx.	,C-fz.	,Nu-x.	,Sh-x.

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β β-

- i.

e.

1	0.5	0.4	0.5	0.912791	0.035588	0.283864	0.258098	3
2	0.5	0.4	0.5	0.818913	0.033149	0.292315	0.260426	3
3	0.5	0.4	0.5	0.782806	0.032145	0.295431	0.261375	3
4	0.5	0.4	0.5	0.763579	0.031595	0.297044	0.261894	3
0.5	0.1	0.4	0.5	1.038777	0.011099	0.265573	0.253359	3
0.5	0.8	0.4	0.5	1.073971	0.046779	0.273560	0.255926	3
0.5	1	0.4	0.5	1.081989	0.048542	0.275347	0.256549	3
0.5	2	0.4	0.5	1.106263	0.043468	0.280712	0.258534	3
0.5	0.5	0	0.5	1.049869	0.050825	0.267867	0.254075	3
0.5	0.5	1	0.5	1.070961	0.027471	0.273083	0.255753	3
0.5	0.5	2	0.5	1.084417	0.017000	0.276183	0.256833	3
0.5	0.5	3	0.5	1.093477	0.011502	0.278199	0.257568	3
0.5	0.5	0.4	-0.3	1.109866	0.042371	0.283718	0.073086	3
0.5	0.5	0.4	-0.1	1.094599	0.041343	0.279741	0.125995	3
0.5	0.5	0.4	0	1.087725	0.040876	0.277922	0.150315	3
0.5	0.5	0.4	3	0.990321	0.034469	0.252369	0.574061	3
					MD-BSQLM			
1	0.5	0.4	0.4	0.912791	0.035588	0.283864	0.258098	5
2	0.5	0.4	0.4	0.818913	0.033149	0.292315	0.260426	5
3	0.5	0.4	0.4	0.782806	0.032145	0.295431	0.261375	5
4	0.5	0.4	0.4	0.763579	0.031595	0.297044	0.261894	5
0.5	0.1	0.4	0.4	1.038777	0.011099	0.265573	0.253359	5
0.5	0.8	0.4	0.4	1.073971	0.046779	0.273560	0.255926	5

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0.5	1	0.4	0.4	1.081989	0.048542	0.275347	0.256549	5
0.5	2	0.4	0.4	1.106263	0.043468	0.280712	0.258534	5
0.5	0.5	0	0.4	1.049869	0.050825	0.267867	0.254075	5
0.5	0.5	1	0.4	1.070961	0.027471	0.273083	0.255753	5
0.5	0.5	2	0.4	1.084417	0.017000	0.276183	0.256833	5
0.5	0.5	3	0.4	1.093477	0.011502	0.278199	0.257568	5
0.5	0.5	0.4	-0.3	1.109866	0.042371	0.283718	0.073086	5
0.5	0.5	0.4	-0.1	1.094599	0.041343	0.279741	0.125995	5
0.5	0.5	0.4	0	1.087725	0.040876	0.277922	0.150315	5
0.5	0.5	0.4	3	0.990321	0.034469	0.252369	0.574061	5

Table 3: Values of ‚C-fx.„Nu-x. and ‚Sh-x. for various values of *Fs* and ζ when

M=β=‚β-e.=K=δ=0.5, ‚β-i.=0.4, ‚Gr-x.=1,P‚r-=0.72, Sc=0.22, Ec=0,1, Da=1.

	Fs=0.6			Fs=1.5		
ζ	‚C-fx.	‚Nu-x.	‚Sh-x.	‚C-fx.	‚Nu-x.	‚Sh-x.
0.2	1.385397	0.344956	0.214875	1.380553	0.344029	0.214293
0.4	1.337362	0.335726	0.229068	1.320607	0.332386	0.227130
0.6	1.268813	0.321250	0.240602	1.238581	0.314892	0.237253
0.8	1.168599	0.298115	0.248369	1.130333	0.289460	0.244461
1	1.035226	0.264442	0.252776	0.999220	0.255487	0.249934
2	0.421009	0.070009	0.321620	0.418828	0.070302	0.322057
3	0.197336	0.018454	0.403717	0.197219	0.018793	0.403729

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4	0.112412	0.028115	0.468276	0.112400	0.028190	0.468276

23 Conclusion

In this paper, we have presented and applied OMD-BSQLM to solve two-dimensional steady MHD free convection flow, heat and mass transfer over a vertical surface embedded in a non-Darcy saturated porous medium. Numerical simulations were carried out successfully, showing convergence behaviour and accuracy of the iterative scheme. The method was found to be convergent and give very accurate results after a few number of iterations using very few grid points. The numerical results were presented to show effects of various physical parameters on the fluid properties and flow characteristics. Computations have been validated against non-overlapping MD-BSQLM and previously published work, where results were found to be consistent. Increasing Hall parameter and ion slip were found to weakly accelerate the primary flow and strongly decelerate the secondary flow. The chemical reacting rate was noted to reduce the velocity components and concentration while enhances the temperature profiles. Increasing Forchheimer number decelerates both primary and secondary flow while enhancing temperature and concentration. The dimensionless wall shear stress in the *x*- direction and the local Nusselt number are enhanced by increasing Hall current and ion slip values, but reduced by rising chemical reaction. The combined effect of Hall current, ion-slip and chemical reaction was to enhance mass transfer rate, while decreasing the wall shear stress in the *z*-direction. However, the dimensionless wall shear stress in the *z*- direction increases when the Hall current increases to 1 and decreases when the Hall current is greater than 1. The Casson fluid enhances the rate of heat and mass transfer, while reducing the skin friction in both *x*- and *z*- directions. The presence of inertia effects reduces all the flow characteristics.

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A Survey of Soft Computing Techniques for Software Testing

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Abstract:
Software testing is an important phase of software development life cycle. It is the process of examining the software with the aim of finding error and establishing that the software programs meet the required quality. Software testing takes up to 60% of the process of software development. This study focused on carrying out a qualitative review of the existing soft computing techniques used for software testing with emphasis on their strengths and weaknesses and also identify the relevance of user story vis-à-vis user involvement as basis for developing user centric software testing model. A systematic literature review (SLR) was carried out using customized search strings derived from our research. We identified 875 articles based on our search term and upon removal of duplicates, 527 were left. Reviewing paper titles and abstracts we had 95 left and out of which 69 articles were removed because they did not meet the inclusion criteria and we had 26 articles available for review after qualitative analysis. Our results suggest that soft computing techniques are adopted in software testing models but none of these model make use of user story as basis for testing neither were end users actively involved in the model development.

Keywords: Computational Techniques, Soft Computing, Software Testing, User Story, Survey

1. INTRODUCTION

The ultimate goal of software developers is to deliver good quality software product to their end users; thus proper evaluation of the software product using appropriate software testing model is a key towards achieving this goal. Software testing is the process of examining the software with the aim of finding and correcting errors and hence ascertain that the entire programs of the software performs to the required users' expectations .

Testing is an important phase in software development life cycle (SDLC) because it ensures that user requirements and appropriate specification are met before deploying the software to the end users . Software testing takes up to like 60% of the process of software development because it is not just the development of the software that really matter but how the software will meet up with the users' requirements and system specifications .

User requirements can be regarded as attributes defined before building software product. They are sets of conditions that are to be met by system components in other to satisfy a contract, standard or specification . They can also be referred to as fragments structured to a greater extents that could be interpreted by stakeholders or developers. Users' requirements can be defined in terms of functional requirements (i.e. major services rendered by the software to the end users) and non – functional requirements (i.e. quality attributes describing the behavior of the software in terms of performance, security, scalability etc.) . Requirements definition and representation serve as the foundation of software development, therefore software develop-

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ment project team need to be careful not to make wrong assumptions or use approaches and tools that could lead to incorrect description of users' requirements. In view of this lots of tools have been developed to aid requirements elicitation and provide clarity to translating business processes into software products. Some of the tools are: Context diagram, Functional decomposition, Use case diagram, Sequence diagram, AS-IS and TO-BE process model, User stories and Mind maps. In this paper we focused on various model of software testing vis-à-vis the adoption of user story model in developing an enhanced software testing model that will be mostly user centric.

There are different software testing approaches such as white box testing that is concerned with the internal structures of a program with the paths through the code and determine the appropriate outputs ; the black box testing examines the functional aspect with no regard to the internal implementation but concerned with what the software is expected to do; static testing approach involves verification in order to check syntax errors and dataflow; dynamic testing is carried out during the execution of the program; the specification based testing that requires thorough test cases to be provided to the tester who then can simply verify that for a given input; the output value will either be or not be the same as the expected value specified in the test case which is according to the specification requirement ; visual testing provides the developer with what is happening at the point of software failure by providing a quality communication between the tester and the developers; the grey box testing combine the attribute of white box testing and black testing.

There are strategies that software testers use based on the level at which a test is specified during the software development process. The first one is the unit testing and it is defined as the smallest collection of lines of code that verifies the functionality of a specific section of code . An aspect that relates with the program structure to expose defects in the interfaces and interaction between modules is the integration testing strategy and the handling of data passed between various units or component is done by component interface testing while the system testing of software or hardware verifies that the system meets its requirements or to check if the system comply with requirement specification.

In this paper we focused on carrying out systematic literature review (SLR) using customized search strings derived from our research which include: software testing, user story, artificial neural network (ANN), Bayesian network (BN), ant colony optimization (ACO), genetic algorithm (GA). Exclusion was made based on some criteria. The following steps of SLR were performed: study design, search strategy and information sources; study selection and data collection process; and quality assessment and data systematic review. Scholarly articles in Google scholar were carefully selected. We identified 875 articles based on our search term and upon removal of duplicates, 527 were left. Reviewing paper titles and abstracts we had 95 left and out of which 69 articles were removed because they did not meet the inclusion criteria and we had 26 articles available for review after qualitative analysis. There were 8 papers on ANN, 3 on ACO, 4 on BN, 4 on GA and we had 7 papers on other unclassified techniques. Paper distribution based on country of research origination is as follows: 9 papers originated from India, 3 from UK, 3 from USA, 3 from Canada, 2 from Australia, 1 from Nigeria while 5 were from Malaysia, Germany, China, Israel and Iran. We establish from our results that soft computing techniques exhibit some qualitative properties that complement each other and this suggests that research should be directed towards developing hybrid models for testing software with the view to improving software testing model performance. In addition, we found out that little or no interest is shown in the development of software testing model in African context; hence our future works should will be directed towards this.

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The rest of the paper is organized as follows: Materials and Methods were presented in Section 2. Results were presented in section 3. Summary and Discussion were presented in Section 4 while Conclusion was presented in section 5.

2. MATERIALS AND METHODS

Systematic review processes was adopted following the PRISMA algorithm and therein are the steps involved: study design, search strategy and information sources; study selection and data collection process; and quality assessment and data systematic review . Details on these steps are described in the following subsections. The research did not require ethics board approval neither was the consent of any individual necessary.

2.1 Study Design, Search Strategy and Information Sources

Related research papers were reviewed about software testing that meet up with the inclusion and exclusion criteria. Irrelevant words, phrase, comments, letters and editorials that are not in line with the keywords were excluded. The search strategy was a plan to: (1) construct search terms by identifying the keywords that are needed to give the expected results; (2) get alternative spellings and synonyms for major keywords; (3) establish exclusion criteria to make exclusion in the course of search; and (4) apply Boolean operator notation to construct the expected search term. We applied the search strategy to derive the search term below that was used in this research:

> *model intitle:testing software OR application OR technique "software testing" -hardware -estimation -requirement -machine -medical -health -cost -student -security -ecosystem -mathematics -smoke -telecommunication -grammar -uml -car*

This research adopted peer- reviewed articles from Google scholar database for selection criteria and adhere strictly on software testing technique model. Resources checked are: conference proceedings, specific journals, book chapter and books. The numbers of publications found, exclusion and final selection are stated in the PRISMA diagram (Figure 1).

2.2 Study Selection and Data Collection Process

Selected literature was screened based on title and abstract. Publications that referred to software testing were included. Reviews, editorials, and literature which described software costing and estimation, software requirement as it applies to health and education were excluded. Also, literature that referred to security, ecosystem, mathematics, telecommunication, Unified Modeling Language (UML) was excluded. Moreover, literature that has to do with testing carried out in cars not considered. Aside from the stated exclusion criteria, other studies excluded were those based on: empirical data only; incomplete/inappropriate study design; non English literature and incomplete papers. Figure 1 presents the flow diagram of the selection of studies. In the case of uncertainties, inclusion or exclusion was based on consensus. Studies were categorized on the type of technique and models used . Risk of bias was assessed at the study level.

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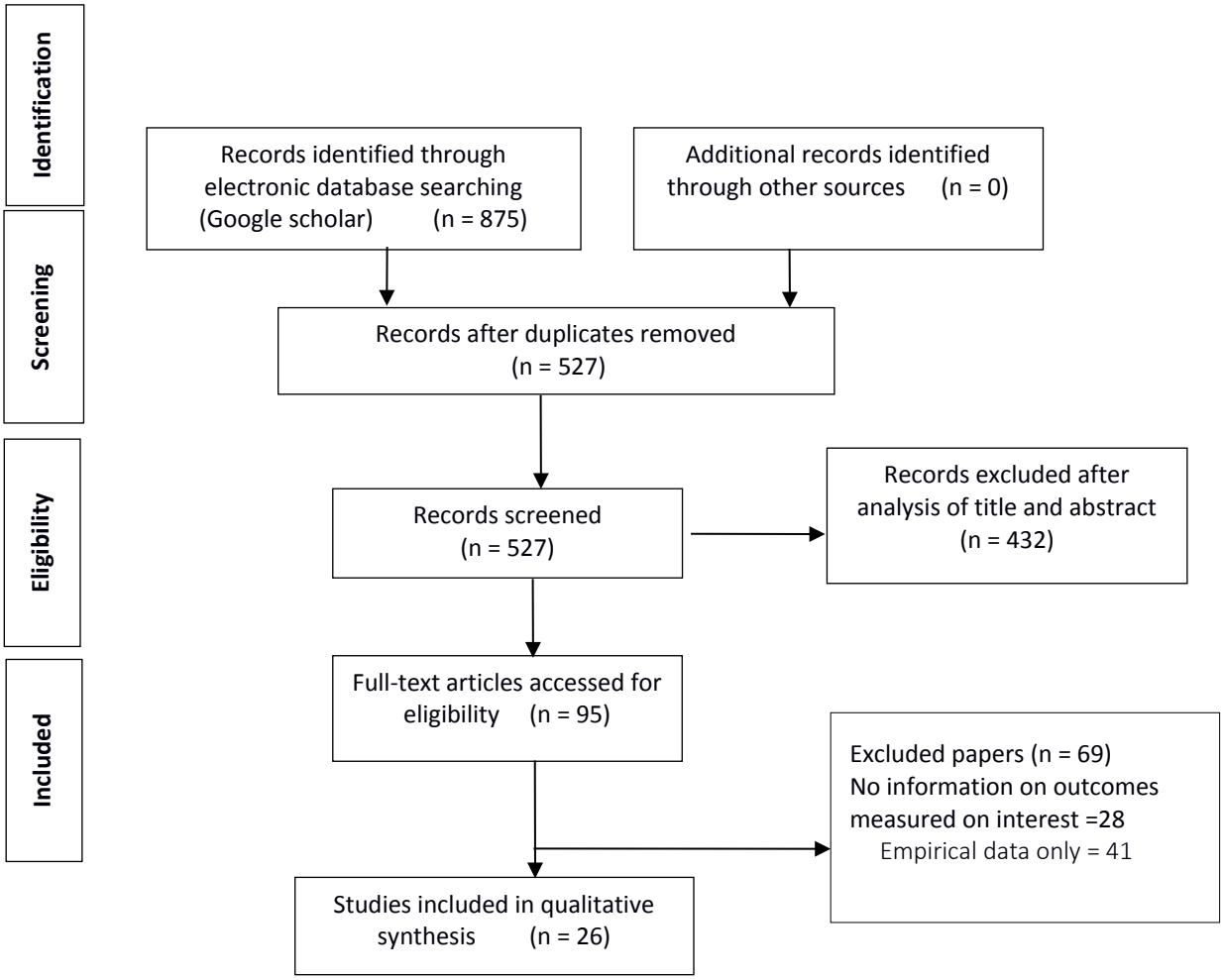

Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Flow Diagram of Included Studies (HYPERLINK \l "_ENREF_25" \o "Khan, 2008 #49" S. U. Khan, Niazi, & Ahmad, 2008).

the work. Selection was also made based on the publication assessment quality. The assessment of publication quality was made based on the following with the view to minimizing bias: If the technique or model is applied in software testing or evaluation; if the technique identified is clearly computational; if the technique is clearly on software only. Selection was also made based on title of the studies and abstracts.

Publications was reviewed based on the title, author, reference, database, journal, successful papers (related papers on techniques used for software testing), methodology, parameter used was also of interest, quality of publication description and year published. A thorough review was done to really ascertain the main focus of each paper and final selection of 26 papers for primary sources from screened articles was not based only on the titles and abstracts of the paper but an extended full reading of the papers.

3. RESULTS

3.1 Literature search results

We identified a total of 875 references using the search strategy. Of these, we removed all duplicates and have 527 left. Of these, 432 were rejected after reviewing

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the paper titles and abstracts and we have 95 remaining. We exclude 69 publications because they did not meet the inclusion criteria and this led to the final number of 26 articles that were available for review in this research work.

3.1.1 Study characteristics

The details observed from the 25 studies included in this systematic review are as follows: based on approach of software testing, there were two papers on functional testing for requirement specification and analysis of what is expected of the software development ; five papers relate to test case generation and test sequence , five papers on the internal implementation of a software (i.e. the structural or the white box testing) , based on black box testing, articles of interest are , others were based on new trend of hybrid system and optimization systems. In addition we identified five papers on software predictions and two papers on systematic review . Year of publication of relevant papers were from 1996 to 2017. Based on country of origination of publications, 9 papers were from India , a total of 3 papers from UK , 3 Papers originating from USA and also 3 other papers from Canada , there were 2 papers from Australia while other papers were from Malaysia, Germany, china, Israel and Iran. We could not find any paper originating from Nigeria.

3.2 Main Study Results

3.2.1 Computational techniques and other emerging models for Software testing with their Strength and Weaknesses

Presented below are various computational techniques for software testing.

a. Bayesian Network Approach (BN)

Strength

Bayesian networks also known as Bayesian belief network is a description of dependence relations between data variables in a graphical representation mode and perform some deductions on the available data sets . It is a combination of artificial intelligence, probability theories, graphic theories and decision theories which provide people with convenient frame structure to explain causal relations for uncertainty deductions to become more explicit and more comprehensive . Bayesian network have been successfully applied in statistical or quantitative representation of data variables, it is useful for software testing as it will combine expert knowledge together and test results describing both the functional and non- functional requirements of the software by providing the probabilistic description, structural analysis of the confidence a user is expected to get . It could assist in test planning by helping to identify the likely period and cost of testing and also during test preparation to help create a good test suite.

Weaknesses

Possibility of a user that wish to violate the distribution of the stored probabilities or inference could frustrate the user expectations. Also the prior beliefs applied in Bayesian inference processing could distort the validation of results . Probabilistic and statistical knowledge and no experience by testers in the application of Bayesian network is an issue of concern, also the time expected and resources available to use may be different to the application.

b. Ant Colony Optimization (ACO)

Strength

Ant colony optimization is a technique to stochastic combinatorial optimization based on an observation of ants that are able to succeed in a task to find the shortest path between the nest and food source. It was observed that ants deposit a chemical substance called pheromone during their movement and this serves as a motivation

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for other ants to follow the path with a high probability . Ant colony have been applied to software testing in generation of test path and software coverage to generate test data sequence within the domain being used as inputs of the same generated paths and also in state transition testing applied to real time web based software systems .

Weaknesses

When applying the ant colony optimization there are difficulties in theoretical analysis due to derivation of results made from this technique and more experimental, the sequence of random decisions, probability distribution changes iteration and time to convergence uncertainty .

c. Genetic Algorithms (GA)

Strength

Genetic algorithm in software engineering has been a search techniques used for complex problems by nature of natural selection of species of fittest individuals based on evolutionary ideas. It is an algorithm that expresses intelligent exploitation of a random search to solve a problem . It is divided into five distinct part having the first part to be (1) chromosome that represent the guess or string of binary digits and makeup the gene, (2) initial population of chromosomes, (3) the fitness function that measures how suitable the chromosomes are to meet up with the required objective i.e. their capability to survive and reproduce, (4) selection that determine which chromosome that will be executed in the evolution stage of the algorithm, (5) selection function is subdivided to be crossover operator and mutation operator. Genetic algorithm is applicable to software testing to check the test scenarios that covers certain branches of a program, to increase the speed of operation of test case generation , improve the efficient and effectiveness of test checking and also in path testing using control flow graph to search a program domain covering possible path in a software under test .

Weakness

One of the drawbacks of genetic algorithm is that it may get stuck in extreme ends of a code during testing because of its operation in a search space, parallelism is another important part of genetic testing characteristics . They cannot be applicable in real world analysis and when applied to path testing there may be difficulty in covering sections of infinite number, path testing of large test case program and number of branches may be unfeasible.

d. Artificial Neural Network (ANN)

Strength

Artificial neural network is a resemblance of the human brain with respect to knowledge and inter-neuron , it is a complex parallel distributed computing system that has the capability of storing experimental knowledge for it usability. The knowledge of a neural network is acquired through learning process called training while the inter-neuron connects as the synaptic weights used identified for knowledge storage. Artificial neural network is a computing system excellent in pattern recognition, data classifier and good for generalization, optimization, matching of two or more pattern . Following the ability of neural network being able to learn with the capability of adapted weights to changes with its application in the area of testing process by which neural network is trained by the back propagation algorithm on a set of test cases applied to the original version of the system , also for faults detection using a proposed methodology to test with the provision of a set of test cases covering the functional aspect in software automatically and prediction using components analysis on raw data that yields a neural-network model whose predictive standard is better than a neural-network model developed using the raw data alone .

Weakness

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Since Artificial neural network is a parallel distributed system, machines of serial architecture may find it difficult to be applied to software testing and the knowledge base can only be acquired through training, so it is implicit and data dependent. Also there may be lack of defined rule to develop the neural network considering other factors like learning algorithm to be used, number of neurons or synaptic weights, layers and representation of data . Artificial neural network cannot be tested on large complex programs and when expecting time utilization it can be very slow in processing or testing a program and since neural network is trained it has the deficiency of missing out some area to complete the testing process if it is based on supervised training algorithms.

3.2.2 Application of User Story Model in Software Testing

User story is a statement or short description of users' requirements. It reveal the users' requests and not the technical details of the software development. It is used in Agile software development for capturing the functionalities of a software from the perspective of the end-user . It gives a description of the type of users, what they want and why. It simplifies the description of users' requirements and makes software development to be user involving . User story provides the gateway in building software and hence simplifies users-developers communication that takes place during software requirements definition, analysis and representation. User story is applied in order to facilitate fruitful dialogue among clients and the technical group at all stages of SDLC (Software Development Life Cycle) and hence produce best software solution . A user story template as proposed by mike Cohn is presented in Figure 2. It helps a product owner to express the description of requirements in a natural language specification what the functional and non-functional system part will look like.

User Story Template

As a <<user role>>

I want to <<do something>>

so that <<value/benefit>>

Figure 2: A sample of Mike Cohn User Story template

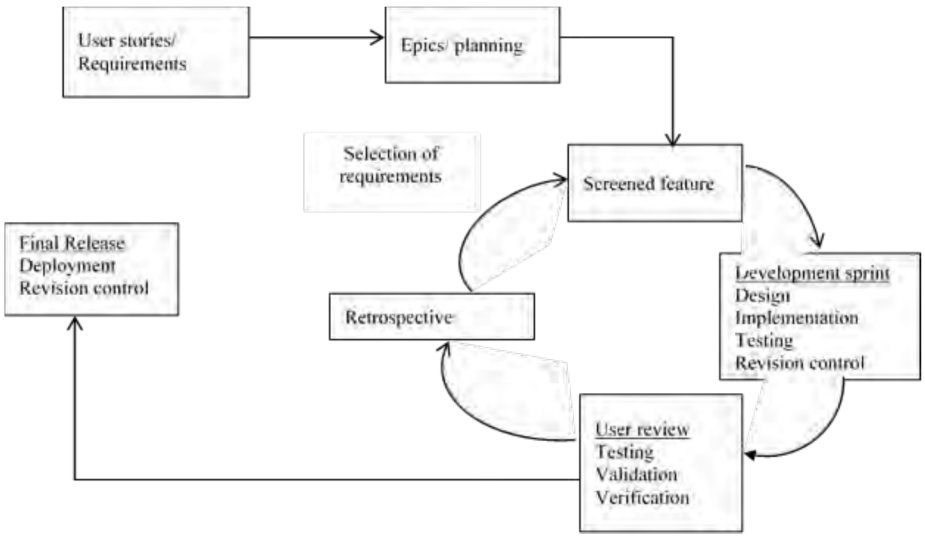

Figure 3: The Conceptual Diagram of User Story Model

Figure 3 presents the conceptual diagram of a user story model. User stories are been gathered together based on the requirements of the user/clients and thereafter

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the stakeholders put the requirements in a logical grouping i.e. in epics through planning to check if the requirements are complete and specified. A qualitative analysis of the selected feature of each user story cards is then carried out by putting it in a product backlog arrangement format and this is used to guide the development of the software, implementation. Thereafter revision control is done with the user/clients and during this process the stakeholders carry out the required testing, validation and verification on the software with the end user. This process is done iteratively until the final release of the software .

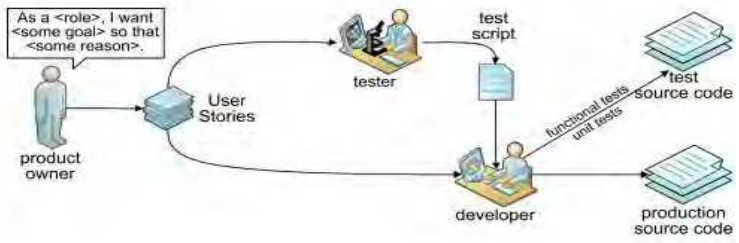

Figure 4: Conceptual Diagram of User Story Model in Software Testing

Presented in Figure 4 is the conceptual diagram of user story model in software testing. User story is part of agile requirement definition and both the software tester and the developer are involved during the application of user story model while the product owner gives it requirements in the form of stories while the software tester analyzes and applies the users requirements stated in the user stories to evaluate the source codes with the view to removing irregularities before final release of the software system. According to user story will be a better practice in software testing process with the view to closing the gap between end users and developers. It will help in locating errors early because it is easy to find the story points related to the bugs, which will enhance the software quality. Clients will fill more satisfied and knowledgeable about the software development and using it becomes easier. Moreover, the developer and software tester will have more precise testing arrangement which in turn will reduce extended cost and schedule estimation and completion of software project within the budget and . Furthermore the end users have assurance of the system reliability, performance, usability and robustness because they were actively involve .

4. SUMMARY AND DISCUSION

In this study, we did critical review of existing soft computing techniques applied in software testing. We also studied user story framework vis-à-vis its application in the development of software testing models. The study was carried out to: (1) understand the concept of these techniques, (2) understand user story framework and the extent to which the framework is applied in the development software testing models, (3) identify the strengths and weaknesses of the soft computing techniques as applied to software testing, (3) give a direction for further improvement in software testing models. In consequence, these could aid in creating a pathway for developing a more enhanced user-centric software testing model.

We found that most of the research works in software testing originated from India and one research work was reported from Nigeria. None from other African countries. In present time the adoption of application software for service delivery is increasing in the African continent and thus more emphasis is placed on developing indigenous application software with more of local contents (Akinnuwesi, Uzoka, Olabiyisi, Omidiora and Fiddi, 2013). However little or no emphasis is placed on the development of suitable software testing model with the African context. This buttresses the fact that more research works are needed in Nigeria and Africa as a

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whole in the area of developing practical user-centric computational techniques for software testing in African context.

Moreover we categorized the existing computational techniques for software testing based on the soft computing concepts used. That yielded five categories as presented in Figure 5. These are Artificial Neural Network (ANN), Genetic Algorithm (GA), Bayesian Network (BN), Ant Colony Optimization (ACO) and others that are unclassified. We identified the qualitative properties of each of these techniques in terms of strengths and weaknesses. This was done to identify the possible ways at which these techniques could complement one another and hence have hybrids with more enhanced features and good level of performance. We equally studied the application of user story framework in the existing testing techniques and found out that none of the techniques adopted user story framework. They were not user oriented but developers oriented and this buttress the fact that there is relationship gap between the end user and developer as established in literature (Akinnuwesi et. al, 2013). Thus more research works are needed to develop user-centric software testing techniques using user story framework as tool to facilitate automatic user requirements gathering, analysis and validation.

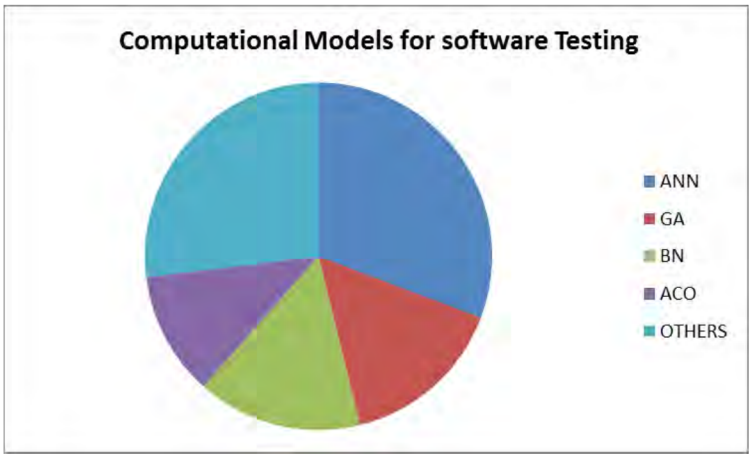

Figure 5: shows the illustrative pie chart of the rate of computational models used.

5. CONCLUSION

In this study we define software testing and the various approaches used for software testing as well as providing explanation on users' requirement as it relate to the development of software testing model. We did a qualitative review of computational techniques used for software testing in order to understand the concept of these techniques and an analysis on the strength and weakness of the selected computational techniques was carried out to aid the discovery of an improve techniques or model for software testing. Our results suggest that soft computing techniques are adopted in software testing models but none of these model make use of user story as basis for testing neither were end users actively involved in the model development. Moreover the soft computing techniques exhibit some qualitative properties that complement each other and this suggests that research should be directed towards developing hybrid models for testing software with the view to improving model performance. In addition, we found out that little or no interest is shown in the development of software testing model in African context; hence future works should be directed towards this.

One of the limitations of this study is the use of one database, i.e. Google scholar. We chose Google scholar because it actually indexes many databases and it is free

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but it is quite possible that we might have missed out some articles which are only available in commercial databases. We were constrained by funds for subscription to some commercial databases. Future work will explore funding opportunities and include commercial databases.

COMPETING INTERESTS

The authors declare that there are no competing interests regarding the publication of this paper**.**

SUBMISSION DECLARATION

The authors declare that the research reported in this paper is original and has not been published previously and it is not under consideration for publication elsewhere. The publication is approved by the authors and if accepted for publication, it will not be published elsewhere.

AUTHORS' CONTRIBUTIONS

Dr Boluwaji Akinnuwesi designed the study, developed the research methodology, managed the literature searches, performed the literature review, wrote the first draft and final copy of the manuscript, did the final editing of the paper. He supervised the study. Mr Gboyega Adenaike did literature searches, perform literature review and contributed in writing the first draft of the manuscript. Dr Obinna Nwokoro contributed in the literature searches and did part of the literature review. He proofread the manuscript.

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Software Requirement Validation Techniques: An Overview

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Abstract - Software requirement validation involves checking that the specification conform to users' perceived needs and it is essential to all phases of software development life cycle (SDLC). Software requirements undergo proper validation in order to check if the software will fulfill its intended functionalities. Thus this research paper focused on carrying out qualitative survey on the existing software requirement validation techniques vis-à-vis their implementation. We emphasized on their strengths and weaknesses and the involvement of users in the validation process. Systematic Literature Reviews (SLR) process was adopted with the view to carefully select scholarly articles in Google scholar. We identified 489 articles based on our search term and upon removal of duplicates, 420 were left. Reviewing paper titles and abstracts we have 80 left and out of which 52 articles were removed because they did not meet the inclusion criteria and we had 28 articles available for review after qualitative Analysis. Our results show that traditional methods of requirement validation are adopted in the process of validating users' requirements. The methods are not yet implemented and hence remain theoretical concept. A proper software is not yet developed to validate users' requirements both on a small or larger scale. Users are more accustomed to the traditional prototyping thus making it difficult for developers to introduce them to new techniques because of their shallow knowledge.

Keywords: Requirement Validation, Techniques, Requirement Analysis, User Requirement, Software, Systematic Review

1. INTRODUCTION

Requirement management process (i.e. requirement definition, analysis, validation and verification) plays very important part in software engineering process. In order to meet the needs of the customers, high-quality users' requirements management process is expected with the view to accurately describe and represent the software requirements . Operations in private and government organizations are being automated with the use of customized software. These software require analysis, validation, verification and implementation of all users' requirements. Our focus in this paper is on requirements validation.

Requirements are elicited through consultation with stakeholders during requirements engineering phase. The stakeholders are end users, customers, decision-makers or developers. Additionally, the elements of the business environment (i.e. Political, Social-cultural, Economic, Information and Communication Technology, and Legal environment) form part of the variables to be considered by stakeholders when defining operational requirements for their businesses . Thus the process of gathering users' business requirements for software development can be a difficult task especially when the requirements are driven by the elements of the business environment which are mostly controlled by policies of the government, beliefs of people (i.e. culture and religion) and technological advancement.

User requirements are critical factors in the success of a software project. If user requirements are not well understood, the software may not meet the needs of the

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customers and eventually the software will be abandoned . Thus understanding user requirements is an integral part of information systems design and is critical to the success of software systems (Akinnuwesi, Uzoka, Olabiyisi, Omidiora, and Fiddi (2013), Akinnuwesi, Uzoka, and Osamiluyi (2013), Akinnuwesi, Uzoka, Olabiyisi, and Omidiora (2012)). It is understood that successful systems and products begin with an understanding of the needs and requirements of the users. As specified in the ISO 13407 standard (ISO, 1999), user-centered design begins with a thorough understanding of the needs and requirements of the users. The benefits can include increased productivity, enhanced quality of work, reductions in support and training costs, and improved user satisfaction.

Requirements analysis is not a simple process. Problems faced by the analyst are: addressing complex organizational situations with many stakeholders; users and designers thinking along traditional lines, reflecting the current system and processes, rather than being innovative; users not knowing in advance what they want from the system; rapid development cycles, changing situation of the business environment etc.

This paper focused on the review of software requirements validation techniques with emphasis on their implementation, merit and demerits. The rest of the paper is organized as follows: Section II presents the materials and Methods. Presented in Section III are the results while Discussion is presented in Section IV. Conclusion is presented in Section V.

2. MATERIALS AND METHODS

Systematic review processes was adopted following the PRISMA algorithm and therein are the steps involved: study design, search strategy and information sources; study selection and data collection process; and quality assessment and data systematic review . Details on these steps are described in the following subsections. The research did not require ethics board approval neither was the consent of any individual necessary.

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analysis OR validation OR verification OR evaluation OR using OR "Fuzzy Logic" OR "artificial neural network" OR "Genetic algorithm" OR "Bayesian network" "intitle:software intitle:requirement"

This research adopted peer-reviewed articles from Google scholar database for selection criteria and adhere strictly on software requirement validation model. Resources checked are: conference proceedings, specific journals, book chapter and books. The numbers of publications found, exclusion and final selection are stated in the PRISMA diagram (Figure 1).

2.2. Study Selection and Data Collection Process

Selected literature was screened based on title and abstract. Publication that referred to requirement validation were included. Manuscripts that were comments, letters, and editorials were excluded. Apart from the stated exclusion criteria, other studies excluded were those based on: empirical data only; incomplete/inappropriate study design; non English literature and incomplete papers. Figure 1 presents the flow diagram of the selection of studies. In the case of uncertainties, inclusion or ex-

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clusion was based on consensus. Studies were categorized on the type of technique and models used . Risk of bias was assessed at the study level

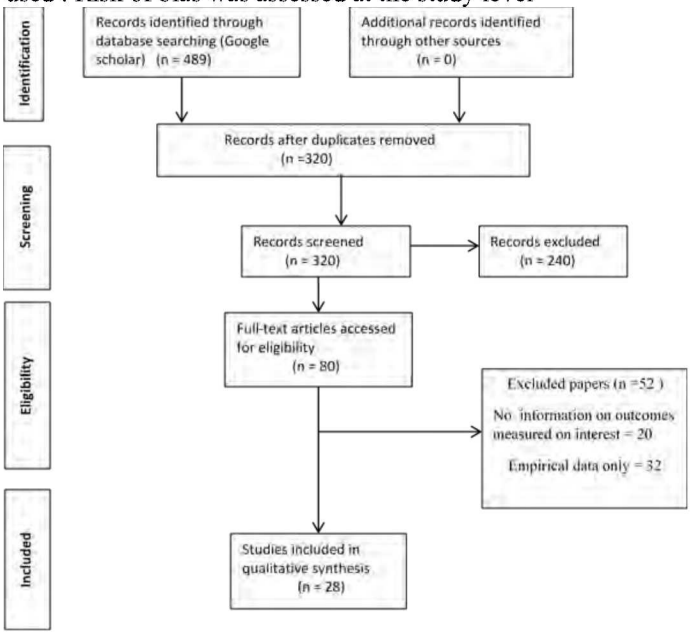

Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram of included studies .

2.2 Selecting Primary Sources and Quality Assessment of Publications

The initial selection of primary sources was from the results of studies identified based on the search term and having any element of keywords related in any way to the work. Selection was also made based on the publication assessment quality. The assessment of publication quality was made based on the following with the view to minimizing bias: if the technique is applied in requirement validation or evaluation; if the technique identified is clearly computational; if the technique is clearly on software only. Selection was also made based on title of the studies and abstracts.

Publications were reviewed based on the title, author, reference, database, journal, successful papers (related papers on existing techniques used for validating requirement) methodology, parameter used was also of interest, quality of publication description and year published. A thorough review was done to ascertain the main focus of each paper and final selection of 28 papers for primary sources from screened articles was not based only on the titles and abstracts of the paper but an extended full reading of the papers.

3. RESULTS

3.1 Literature Search Results

We identified a total of 489 articles using the search strategy and out of these, we removed all duplicates and 320 articles were left. Out of these 240 articles were rejected after reviewing the paper titles and abstracts and we have 80 articles remaining. We excluded 52 publications because they did not meet the inclusion criteria and this led to the final number of 28 articles that were available for review in this research work.

i. Study Characteristics

The details observed from the 28 studies included in this review are as follows: based on approach of software requirement validation, there were three papers on software testing methods for requirement validation , two papers were scenario based technique for requirement validation , four papers were added on formal specifications , two papers adopted the use case method ; two papers were on prototyping , three papers relate to test case generating and test sequence ; we also identified

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papers with unclassified technique and event-driven for requirement analysis. In addition, two papers are on machine learning ; articles of interest are . Year of publication of relevant papers were from 1990 to 2016. Based on country of origination of publications, 12 papers originated from Asia , 2 from USA , 5 were from Uk , 1 from Australia , 2 from Malaysia . 1 from Nigeria , 5 were from Sweden , Croatia , Portugal , Italy and India

3.2 Main Study Results

Requirement Validation techniques

The goal of using Requirement validation techniques is to guarantee that specified user specifications have been stated completely and there is no faulty requirements in the Software Requirement Specification (SRS) document. Several techniques for requirements validation are being adopted in industries, which includes, requirements prototyping, requirements reviews, viewpoint-oriented requirements validation and use-case based modeling. Presented below are various validation techniques for software requirement validation:

a. Requirements Prototyping

Requirements prototyping is a fundamental technique for validating users' requirements as it represents the shell of an actual system to be built. Prototypes facilitate validating requirements by providing a valuable insight into the system. Prototypes are good tool for validating requirements especially when you are not confident that you have a good set of requirements. Two types of prototypes have been discussed in the literature, i.e. throw-away prototypes, and evolutionary prototypes.

Throwaway prototypes aids in identifying the requirements that were not properly understood. Throwaway prototypes are discarded or thrown away after the user feedback once the initial set requirements are built in the prototype. It helps in resolving requirements conflicts between the development team and the customers by taking feedback on the prototype.

Evolutionary prototyping on the other hand, is performed on a set of settled requirements and is subject to quality constraints as imposed in the software development. Evolutionary prototypes are built from initial requirements and gradually refinement is made with depending upon feedback from the user.

Strengths and Weaknesses

Prototypes help the customers to get a visual insight of the developing software system. With the help of prototypes, it is easier for them to identify issues with requirements and define the need for any additional requirements if they are not available in the current prototype.

Some of the drawbacks of the prototypes are listed below.

i. It takes more time to prepare prototypes and hence results in more cost.
i. If the paper prototypes are approved by the customer, they could not be converted into executable versions after validation.

b. Requirement Testing

The aim of executing requirements testing is to ensure the validation of the requirements at the SRS level instead of validating them at the level of the software system during and after deployment. For this purpose, test cases are generated for all the stated requirements. Requirements testing aids in the identification of ambiguous or incomplete requirements in a way that if there some problem occurs while executing a test case for any specific requirement, it gives an indication that there is some issue with that requirement. The following are the strengths and weaknesses of this approach.

Strengths and Weaknesses

There are many positive roles of requirements testing techniques to eliminate the unwanted and ambiguous requirements. The main strength of requirements testing is

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that different test cases are generated to remove faulty requirements and use these test cases in final testing. This technique is very effective for those software industries with large human resource and separate departments for quality assurance and testing. Its major weakness is that it demands extra cost and those industries having small human resource cannot get effectiveness of this technique. This technique also demands extra experienced tester and quality assurance people.

c. Viewpoint-oriented Requirements Validation

Viewpoint oriented validation technique provides validation of requirements of a complex system in an early phase of the requirements elicitation. Viewpoint resolution identifies differences among different viewpoints, performs their classification and evaluation of those differences and integration of different alternative solutions into a single illustration .

Strengths and Weaknesses

Viewpoint-oriented requirements validation technique is very helpful to identify ambiguous and inconsistent requirements using different viewpoints. To eliminate different bugs from faulty requirements, different viewpoints are incorporated. This approach to validate the requirements is not so common and almost not practiced in software industry and hence a bit tough to highlight the core weakness of this validation technique.

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3.3 Summary of Literature Reviewed

Presented in table 1 is the summary of the reviewed literature on the requirement validation techniques.

Table 1: Summary of the reviewed literature on the requirement validation techniques.

Author(s)	Research Description	Requirement validation Technique Adopted	Strengths	Weaknesses	Country
	Presented a pseudosoftware, a conceptual framework that enables the creation and validation requirements	Requirement testing	Pseudo software makes requirements readable in their most relevant context.	The Approach is still facing a challenge in managing requirement changes.	Asia
	It proposed an effective requirement analysis technology based on event-driven.	Event-driven	This approach promotes effective requirement analysis and also helps to obtain the functional requirements of system	It is very difficult for users to describe the future system function.	Asia
	Proposed an approach to facilitate the user validation process based on executable formal specifications	Prototyping	The method allows for software requirements to be modelled, formalised and validated to improve the quality of user requirements and to elicit additional information to evolve them with the users.	Usually ineffective in the user validation process	United Kingdom
	Described an approach, based on the construction of executable interactive prototypes, to support the validation of workflow requirements.	Unified Modelling Language (UML)	It allows the use of CPN Tools to operationally implement the interaction with the stakeholders within their efforts to validate	Transformations are executed manually.	Portugal

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	This provided enhanced structure of the use case where dependencies and interaction issues can be delineated as a means to requirements validation	Use-Case	It addressed the adequacy of the use case description for the specification and validation of software requirements	The approach do not include a mechanism for consideration of dependencies among events in the use case description	United Kingdom
	Proposed a way to validate the user requirements based on generation of product/service concept within a CASE (Computer aided software Engineering) tool environment.	Requirement testing	It provides information on what are the users' preferences to certain features of a product as well as their attitude towards certain levels of its features.	The model has Not been fully tested. It remains a theoretical concept.	United Kingdom
	Proposed TestMeReq. A tool that generates abstract and executable user interfaces to facilitate the requirements validation process.	Requirement Testing	It generates abstract test cases and executable UIs to facilitate the requirements validation process.	the approach only looks at the abstract level of the specification without concern about the internal behaviour of the program.	Malaysia
	Proposed a customer requirement validation technique (CURV), a mental model technique which is used for analyzing customers' behaviors and their mental states.	Use of Formal specification	Developers can identify whether the services and functions they are providing are truly helpful to customers, or whether a service is absent, and based on this information reformulate their software design and business strategy.	The Weakness of the model is that if there is no matching requirements, important requirements related to important behaviors are overlooked	Asia
	It proposed an approach to requirements validation using an extended version of the formal language Timed Abstract State Machine (TASM).	Use of Formal Specification	TASM provides a toolset to execute the pertaining TASM models for the purposes of analysis.	The Challenge faced with this approach was the issue of model validation.	Sweden

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	It proposed a technique called MEDoV. This paper showed how method for Elicitation, Documentation and Validation of Software User Requirements	Use case	The MEDoV helped stakeholders in their everyday work with minimal impact on agility.	The challenges of MEDoV showed that they lack structure in requirements engineering activities.	Croatia
	It proposed a scenario-based specification testing approach to requirements validation of Automated Train Protection (ATP) software.	Use of Scenario	The approach achieves a higher error detection rate and while it reduces the time costs	It has a limited ability to handle a large scale system that involves complex interactions among variables.	Asia
	This paper proposed an approach to acquiring requirements automatically an automated planning techniques and machine learning methods	Requirement testing	It obtained a complete planning domain and convert it into software requirement specification	It has not yet been applied in the problem of system re-configuration at runtime.	Asia
	Introduced a scenario-based approach to assist software engineers in validating the varying requirements of context-aware adaptive services.	UML sequence diagrams	This approach enumerates and generates the service variants form the service scenarios	The use of this approach makes the users find it difficult to articulate their needs as a set of goals	Australia
	a novel approach to static testing of software requirements was proposed in which requirements definitions are tested on a set of task scenarios by examining software behaviour in each scenario described by an activity list.	Requirement testing	The approach helps to automatically generate a set of task scenarios according to user selected adequacy criterion and to generate an activity list for each task scenario.	information about the user's behaviour are not well contained in the requirements definition.	Asia
	Introduced a Formal Concept Analysis (FCA), a mathematical technique for analyzing the	Requirement Testing	a minimal set of test scenarios generated can sufficiently cover all the transitions for the	It does not guarantee test adequacy with respect to user requirements	Asia

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	association between a set of test scenarios with a set of transitions specified in a UML state machine model.		purpose of requirements validation.		
	In this paper, we propose an approach to acquiring requirements automatically, which adopts automated planning techniques and machine learning methods to convert software requirement into an incomplete planning domain.	IPRA (Intelligent planning requirement analysis) technique	This method can be used to acquire software requirement automatically and learn action models with uncertain effects.	It cannot yet generate action models under uncertain conditions.	Asia
	This paper presents an approach to validation of requirements with UML using Model based testing	Requirement Testing	It improves the efficiency and effectiveness of test cases generation and also provides engineers with a means to early validation	It is hard to determine the adequacy of testing	Asia
	a requirements validation technique, called Virtual Requirements Prototype (VRP), that reduces cost and stakeholder feedback time by allowing stakeholders to validate embedded software requirements through the interaction with a virtual prototype.	Prototyping	Provides Flexibility to accommodate changing requirements	Limited user participation in the requirement validation	United State of America
	A feedback-based requirements validation methodology that provides an interactive and systematic way to validate a requirements model.	Scenario Question	The technique is useful in detecting expected and unexpected behavior in a requirements model	The method is too over-reliant on user's framing of the questions	USA

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3.4. Role of User in Requirement Validation

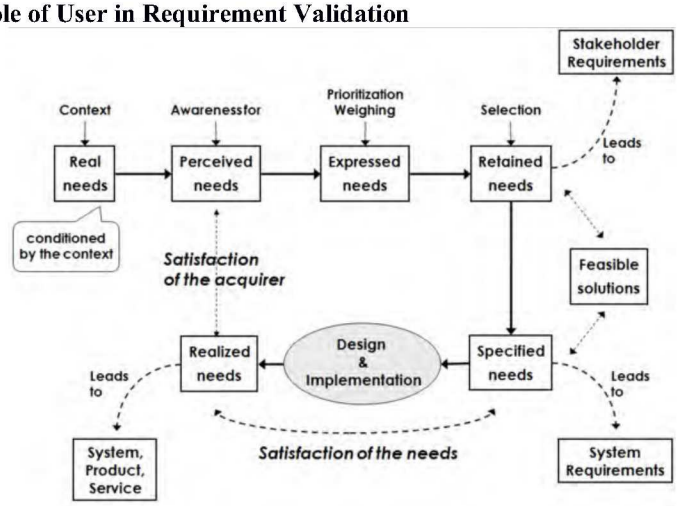

Figure 2. Conceptual Diagram Capturing User needs to the Definition of User Requirements

Figure 2 presents the conceptual diagram capturing user needs to the definition of user requirements. At the early stage, users are to be interacted with to establish all their requirements (functional & non-functional) so that they are understandable by system users who do not have detailed technical knowledge. Their needs are to be completely established and in the course of establishing the requirements. The expected services or functions that the software should carry out are equally established in the course of requirement gathering or process of requirement engineering. In view of this, there is a possibility that the developer interact with the stakeholders which are the end users of the software product to collect all their requirements as far as the system is concerned. Users can also make a list of all their requirements in a way they understand it and then be able to say a requirement and be able to map it with the expected services that the system is meant to carry out. Therefore there is need to carry out a proper classification of all the requirements listed by the user and map them to the required system services vis-à-vis the users final expected output from the software.

4. DISCUSSION

In this study, a critical review of existing techniques used in validating requirements was carried out. This was done to understand the concept of this techniques, identify their strengths and limitations as well as give a direction for further improvement. In consequence, these could aid in creating a pathway for developing a more functional system. The major issue deduced from these literatures are as follows:-

i. The techniques adopted for validating user requirements across all the literatures are not yet tested in practice and hence, they remain theoretical concepts. A software is yet to be developed to validate user requirements both on a small or larger scale.

ii. There is always a challenge between the developer and the user in terms of interpreting requirements to develop a requirement validation system.

iii. The techniques adopted in the above literatures cannot yet handle varying requirement changes and managing requirements.

iv. Users are more accustomed to the traditional prototyping thus making it difficult for developers to introduce them to new techniques because their shallow knowledge.

v. Research works on software requirement validation techniques are few across continents. Our results show the paper distribution based on country of research origination as follows: 12 papers originated from Asia, 2 from USA, 5 from UK, 1 from Australia, 2 from Malaysia, 1 from Nigeria, 5 were from Sweden, Croatia, Portugal, Italy and India.

5. CONCLUSION

Requirements validation assesses whether a product actually satisfies the user needs. It is not a separate phase and can occur at many levels and in different stages. The validation activities occur throughout the elicitation, analysis and specification process. We recommend three levels of validation during the requirements management phase: simple checks of scenario tables, storyboard of use cases, and formal review and prototype of SRS. From the literatures reviewed on existing techniques used for validating user requirement, we deduced based that most of these techniques are not yet fully tested hence remain a theoretical concept. Thus, based on the aforementioned we propose that future work on this paper should explore how to develop a proper validation technique for validating user requirements and also seek to look into how users can be actively involved in requirement validation process. Moreover research works are expected in the area of model development for requirement validation.

One of the limitations of this study is the use of one database, i.e. Google scholar. We chose Google scholar because it actually indexes many databases and it is free but it is quite possible that we might have missed out some articles which are only available in commercial databases. We were constrained by funds for subscription to some commercial databases. Future work will explore funding opportunities and include commercial databases.

COMPETING INTERESTS

The authors declare that there are no competing interests regarding the publication of this paper.

SUBMISSION DECLARATION

The authors declare that the research reported in this paper is original and has not been published previously and it is not under consideration for publication elsewhere. The publication is approved by the authors and if accepted for publication, it will not be published elsewhere.

AUTHORS' CONTRIBUTIONS

Dr Boluwaji Akinnuwesi designed the study, developed the research methodology, managed the literature searches, performed the literature review, wrote the first draft and final copy of the manuscript and did the final editing of the paper. He supervised the study. Mr Patrick Owate contributed in the literature searches and did part of the literature review. He proofread the manuscript. Mr Stephen Tanimowo did literature searches, perform literature review and contributed in writing the first draft of the manuscript.

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Application of Gaussian Primes in 5G QAM Modulation Using Lattice Power Allocation Scheme

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Abstract: There exist a class of quadrature amplitude modulation schemes that map to a class of factors of prime numbers. This paper uses this class of prime numbers to define locations of lattice mobile phones (LMP). We define the transmitted power to LMPs in terms of a power allocation scheme based on prime factors. Simulation of the scheme leads to increased signal-to-noise ratio and hence increased system capacity when compared with the tradition power allocations in quadrature amplitude modulation systems. Also given in the paper is an algorithm for determining how many lattice-points lie on the circular lattices.

Keywords: prime numbers, lattice circles, prime factors, power allocation, multiple access scheme, 5G.

1 Introduction

Power allocation is a central theme in the design of modulation schemes specifically the non-orthogonal multiple access (NOMA) modulation for the fifth generation (5G) systems. In NOMA power is divided among transmitting flows and successive interference cancellation (SIC) is used at the receiver to progressively decode signals for different users [1, 2]. Hence power allocation and multiple-access decision are combined. The approach also provides for sharing of the same spectrum by multiple users concurrently. NOMA does not however eliminate the need for power control by base stations. Besides NOMA energy-efficient resource allocation is a central part of sensor network design and planning for Internet of things in 5G. Sensors despite their lower power footprints, in general they must remain alive for extended lengths of time and continuously provide sensing and monitoring of conditions. This requires energy planning and allocation. Another area where power allocation is essential is in device-to-device-communication and Internet of Things (IoT) [3]. This paper is focused on power allocation for beacon applications and 5G systems. Beacons provide points of reference for transceivers within their domain of influence.

There has been a significant number of publications in relation to symbol mapping in digital modulation schemes [5-7]. Variants of quadrature amplitude modulation (QAM) schemes, quadrature phase modulation keying (QPSK) schemes on rectangular and circular lattices are two of the most popular digital modulation schemes in modern telecommunication systems. In these schemes, symbols are mapped to coordinates on complex axes with integer and non-integer coordinates and angles. The use of non-integer coordinates precludes and limits detection of such symbols since the detected symbols are floating point values and mostly inaccurate due in part to their nature and to noise in the channel. There is a great deal of achievable benefit if the symbol coordinates are integers as they can be uniquely reproduced at the receiver for channels with very low noise and indeed in general. There are still greater benefits if symbol mapping rely on coordinates created with prime numbers with whole number factors as real and imaginary coordinates. Some Gaussian prime factors lie on circular lattices

with integer coordinates. They decompose to sums of real and imaginary values and provide the mapping scheme. Examples are prime numbers whose modulo 4 result is unity. These prime numbers factor into distinct Gaussian integers thereby making it possible to determine the coordinates of symbols in digital communication systems.

This paper therefore has several major objectives. The first is application of Gaussian primes in quadrature modulation schemes. The second objective is to identify how many lattice points are on circles whose radii are equal to the square roots of Gaussian prime numbers.

The third objective is to identify a set of rules or algorithms which makes it possible to identify which prime numbers factor into Gaussian primes and those factors lie on lattice points on the circumference of circles whose radii are square roots of Gaussian integers. Lastly, we use the Gaussian prime factors on lattices to define symbol positions in regular quadrature modulation mapping schemes.

In the rest of the paper, we describe in section 2 some fundamental theories of prime numbers. This is followed in section 3 with how to factor prime integers using prime number factors. A description of approach of how to use the prime factors to define circular lattices and how many prime factors lie on such circles are given in sections 4 and 5. Section 6 is a description of our proposal on how to use the theory described in sections 2 to 5 for power allocation in quadrature amplitude modulation schemes. An example of use and a demonstration of multiple access scheme and its diversity gain in terms of system capacity increase is given.

2 Prime Number Theory

The fundamental theorem of arithmetic states that we can express every number greater than 1 as a product of primes in an essentially unique way. The importance of such prime numbers is that we can use them as building blocks for solving problems. Here are some prime numbers below 100.

Table 1: Arrangement of Prime Numbers Below Integer 100 as Factor of 6

1	2	3	4	5	6
7	8	9	10	11	12
13	14	15	16	17	18
19	20	21	22	23	24
25	26	27	28	29	30
31	32	33	34	35	36
37	38	39	40	41	42
43	44	45	46	47	48
49	50	51	52	53	54
55	56	57	58	59	60
61	62	63	64	65	66
67	68	69	70	71	72
73	74	75	76	77	78
79	80	81	82	83	84
85	86	87	88	89	90
91	92	93	94	95	96

Prime number obey certain simple rules. For example, every prime number in the universe is one more than a multiple of six (p=6n+1) or one less than a multiple of six (p=6n-1). We know to within a small limit of error the number of prime numbers less than a number x as $\pi(x) \approx x/\ln(x)$. This is the so-called prime number theorem. We would like to know how many of these prime numbers lie on a lattice of radius r where r is the square root of a prime number. Table 2 shows all prime numbers below the integer 100. They are coloured in blue.

Table 2: Prime Numbers Below Integer 100

1	**2**	**3**	4	**5**	6	**7**	8	9	10
11	12	**13**	14	15	16	**17**	18	**19**	20
21	22	**23**	24	25	26	27	28	**29**	30
31	32	33	34	35	36	**37**	38	39	40
41	42	**43**	44	45	46	**47**	48	49	50
51	52	**53**	54	55	56	57	58	**59**	60
61	62	63	64	65	66	**67**	68	69	70
71	72	**73**	74	75	76	77	78	**79**	80
81	82	**83**	84	85	86	87	88	**89**	90
91	92	93	94	95	96	**97**	98	99	100

Table 2 shows pairs of prime numbers which differ by 2! This is called the infinitely prime conjecture. It states that there are infinitely many prime numbers p such that p+2 is also a prime number.

Prime numbers may have factors if we admit complex factors. For example, the number $z = a + jb$ is a Gaussian prime if the sum $a^2 + b^2$ is a prime number and a and b are non-zero. Also the integers a and b are individually prime if $|a| = 3 \bmod (4)$ and $|b| = 3 \bmod (4)$.

Some of the characteristics of Gaussian primes are enumerated in this section. The characteristics will be used in developing the theory of symbol mapping in modulation schemes (with the exception of prime number 2):

i) Prime numbers whose remainder mod 4 is 1 can be factored into exactly distinct Gaussian primes. Examples are 5, 13, 17, 29, 37, 41, etc.

ii) Any circle whose radius is the square root of one of these prime numbers always passes through a set of distinct number of lattice points (on the circle) given by the Gaussian prime factors. As a fact they always hit 8 lattice points

iii) Prime numbers whose remainder mod 4 is 3 cannot be factored to exactly two distinct Gaussian primes. In other words, circles with radius equal to the square root of such prime numbers hit zero lattice points. Examples are 3, 7, 11, 19, 23, 31, etc. Their Gaussian prime factors may lie inside the circles whose radii are square roots of prime numbers but never lie on the circumference of such circles. Such lattice points are not of interest in this paper.

The case for prime number 2 is unique in that we can factor 2 as (1+j)(1-j) which are rotations of each other and when any of the two factors is multiplied by j it results to another (they are not unique).

3 Algorithm for Factoring Prime Numbers

Prime numbers that are always one above a multiple of 4 always hit 8 lattice points which lie on the circumference of a circle whose radius is the square root of the prime numbers. The lattice grids are of 1x1 square. Examples are 5, 13, 17, 29 and 37. First, consider the real integer factors of the prime number P. For each factor F of P there are complex factors or Gaussian primes which lead to the complex conjugate product

$$P = (a + jb)(a - jb) \quad \forall \|P\|^2 = a^2 + b^2 \quad (1)$$

Using integer lattice points for the intersections mean that detecting symbols at the receiver is a search for integer values instead of floating point numbers.

4 Determining the Number of Gaussian Lattice Points

4.1 Modulo 4 Variables

In this section three definitions are given based on modulo 4 results for three types of integers. Specifically, the definitions are for members of prime numbers and even numbers.

i) Definition of modulo 4 variable of prime numbers p

$$\rho(p) \bmod 4 = 1 \qquad (2a)$$

Where p is a prime number. The expression stats that if 4 divides p leaving a remainder 1 then we define a variable +1 for such a number. For example:

$$\rho_0(p) \bmod 4 = \rho(1) \bmod 4 = \rho(5) \bmod 4 = \rho(13) \bmod 4 = \cdots = 1$$

ii) Definition of modulo 4 variable of prime numbers q

$$\rho(q) \bmod 4 = 3 \qquad (2b)$$

Where q is a prime number. If 4 divides q leaving a remainder of 3, then we define a variable -1 for such a number. For example:

$$\rho_1(q) \bmod 4 = \rho(3) \bmod 4 = \rho(7) \bmod 4 = \rho(19) \bmod 4 = \cdots = -1$$

iii) Definition of modulo 4 variable of even numbers e

$$\rho(e) \bmod 4 = 0 \qquad (2c)$$

Where e is an even number. If e divided by 4 leaves remainders 0 or 2, then we define a variable 0 for such a number. For example:

$$\rho_2(e \text{ is even}) \bmod 4 = \rho(2) \bmod 4 = \rho(4) \bmod 4 = \rho(6) \bmod 4 = \cdots = 0$$

With the above equations we can create the output sequence for all integers n>0 as

n	1	2	3	4	5	6	7	8	9	10	11	. . .
$\rho(n)$	1	0	-1	0	1	0	-1	0	1	0	-1	

The resulting sequence is periodic with period {+1, 0, -1, 0}. This period spans four consecutive integers of the positive number system (they need not be prime numbers). Prime numbers however span the sequence with period {-1, +1}.

4.1.1 Laws of Modulo Products of Prime Numbers $\rho(p)$

The quantity $\rho(p)$ has multiplicative property [4].

1) Multiplicative property

$$\rho(p.q) = \rho(p)\rho(q) \qquad (3)$$

Example: $\rho(15) = \rho(3)\rho(5) = (-1)(1) = -1$

In this section three laws of modulo products of prime numbers are defined. Examples are given for each case for illustrations.

2) The law of Modulo Product of Prime and Even Numbers

Consider two numbers, p and e where p is a prime number and e is an even number. Their modulo 4 product is always zero. For k a positive integer and p even number

$$\rho(4k-1)\rho(even) = -1 \times 0 = 0;$$

Examples: Consider the prime number when k=1 so p=4k-1, the product

$$\rho(3)\rho(4) = -1 \times 0 = 0$$

The product for any two even numbers is zero. For example

$$\rho(4)\rho(6) = 0 \times 0 = 0$$

3) The law of Modulo Products of Twin Primes.

This law applies to twin primes. The law of modulo products is stated as: *The modulo product for twin primes is always negative 1 (-1). The modulo product either of the members of the twin primes is always unity and positive.*

Consider any twin primes p and q such that q=p+2. For example, the twin primes (p, q) = (3, 5). The product

$$\left.\begin{aligned} \rho(p)\rho(q) &= \rho(p.q) = -1 && (i) \\ \rho(p)\rho(p) &= \rho(p.p) = (-1)(-1) = 1 && (ii) \\ \rho(q)\rho(q) &= \rho(p.p) = (+1)(+1) = 1 && (iii) \end{aligned}\right\} \qquad (4)$$

This means that $\begin{matrix}\rho(4k+1) = 1 \\ \rho(4k-1) = -1\end{matrix}$. Then the product of these two terms is

$$\rho(4k+1)\rho(4k-1) = \rho\big((4k-1)(4k+1)\big)$$

Therefore by using our definition

$$\rho(4k+1)\rho(4k-1) = \rho\big((4k+1)(4k-1)\big) = 1 \times (-1) = -1$$

For examples

$$\rho(7)\rho(5) = \rho(35) = (-1)(1) = -1$$
$$\rho(7)\rho(7) = \rho(49) = (-1)(-1) = 1$$
$$\rho(5)\rho(5) = \rho(25) = (1)(1) = 1$$

4.2 Number of Lattice Points on Circle of Radius $\sqrt{P}$

The set of points (a, b) which lie on the circle C(r) of radius r with center at point (0, 0) or the origin are points which satisfy the Gauss circle $a^2+b^2=r^2$. The points (a, b) and radius r may be defined using Gauss prime numbers in the complex plane such that the point (a, jb) in the complex plane lie on a circle of radius $\sqrt{P}$ and P is a prime number other than 2. Let us segment the region of interest into two regions, one defined by C(r) and the other by a closed disk S(r) where S(r) define the set of points which lie inside the circle C(r) but not on it. Those points satisfy the expression $a^2+b^2<r^2$. These two regions combine to define the area of the circle such that $C(r)+S(r)\approx A(r)=\pi r^2$. While it is easy to state this equation, it is a lot difficult to determine the number of integer points which lie inside or on the circle. In this paper, the search and application is limited to numbers which are both real and complex and are Gauss prime numbers. This is a simplification of the problem and is suitable for our application.

Assume the number P can be factored with prime numbers. We will therefore use the unique properties of the number to determine the number of lattice points on the circle of radius $\sqrt{P}$ defined by the Gaussian prime factors.

5 Algorithm

The number of lattice points is obtained by factorizing P. The factors of P are:

$$\zeta(P)=\prod_{k=1}^{K} p_k \qquad (5)$$

Each p_k is a prime number. For example, the number P = 45 has prime number factorization as:

$$\zeta(P)=\zeta(45)=3\times 3\times 5=3^2\times 5$$

This is expressed further in a manner which permits determining the number of lattice points on the circle defined by $\sqrt{45}$. Powers of a prime are expanded into the products of the prime number. For example $\rho\left(p^n\right)$ is expressed as the product $\prod_{j=1}^{n}\rho_j(p)$ where $\rho_j(p)=k;\ k\in\{1,-1\}$. For example $\rho\left(3^4\right)=\rho(3)\rho(3)\rho(3)\rho(3)$.

The number of lattice points on the circle of radius $\sqrt{P}$ is given by equation (6).

$$L=4\zeta(P) \qquad (6)$$

Therefore, we can now evaluate the number of lattice points defined by the number 45. The number of lattice points on the circle of radius equal to the square root of 45 is

$$L = 4\zeta(45) = 4\left[\left(\rho(1)+\rho(3)+\rho(3^2)\right)\times\left(\rho(1)+\rho(5)\right)\right]$$

The factors of 45 are 1, 3, 5, and 9. These factors are shown in the equation for L. We will solve this equation first without expanding it. The same solution will be obtained if the two terms are expanded by multiplying them. The result is:

$$\begin{aligned} L = 4\zeta(45) &= 4\left[\left(\rho(1)+\rho(3)+\rho(3^2)\right)\times\left(\rho(1)+\rho(5)\right)\right] \\ &= 4\left[\left(\rho(1)+\rho(3)+\rho(3)\rho(3)\right)\times\left(\rho(1)+\rho(5)\right)\right] \\ &= 4\left[\left(1-1+(-1)(-1)\right)\times(1+1)\right] \\ &= 4\left[1\times(2)\right] = 8 \end{aligned}$$

Other than calculating the number of factors and adding them to get L, a table may also be used to find the number L. This table is given below.

Table 3: Template for Determining Number L below Primed Number 13 [4]

$\sqrt{P}$	$\rho(1)$	$\rho(2)$	$\rho(3)$	$\rho(4)$	$\rho(5)$	$\rho(6)$	$\rho(7)$	$\rho(8)$	$\rho(9)$	$\rho(10)$	$\rho(11)$	$\rho(12)$	$\rho(13)$
$\sqrt{1}$	$\rho(1)+$												
$\sqrt{2}$	$\rho(1)+$	$\rho(2)$											
$\sqrt{3}$	$\rho(1)+$		$\rho(3)$										
$\sqrt{4}$	$\rho(1)+$	$\rho(2)+$		$\rho(4)$									
$\sqrt{5}$	$\rho(1)+$				$\rho(5)$								
$\sqrt{6}$	$\rho(1)+$	$\rho(2)+$	$\rho(3)+$			$\rho(6)$							
$\sqrt{7}$	$\rho(1)+$						$\rho(7)$						
$\sqrt{8}$	$\rho(1)+$	$\rho(2)+$		$\rho(4)+$				$\rho(8)$					
$\sqrt{9}$	$\rho(1)+$		$\rho(3)+$						$\rho(9)$				

$\sqrt{10}$	$\rho(1)+$	$\rho(2)+$			$\rho(5)+$					$\rho(10)$			
$\sqrt{11}$	$\rho(1)+$										$\rho(11)$		
$\sqrt{12}$	$\rho(1)+$	$\rho(2)+$	$\rho(3)+$	$\rho(4)+$		$\rho(6)+$						$\rho(12)$	
$\sqrt{13}$	$\rho(1)+$												$\rho(13)$
$\vdots$	$\rho(1)+$												$\vdots$

Prime numbers that are always one above a multiple of 4 always hit 8 lattice points. The lattice grids are of 1x1 square. Examples are 5, 13, 17, 29 and 37. In the rest of the paper we admit complex factors into the factorization of prime numbers.

6 Gaussian Lattice Communication

Consider a lattice as a periodic grid of points in an n-dimensional space. The coordinates may be defined by some number system such as integers, prime numbers or some other type of numbers. The Gaussian lattice is defined by Gaussian integers. Thus a lattice $\Lambda \in R^n$. A lattice formed by a basis

$B = \{b_1, b_2, \cdots, b_n\}$ is defined by the expression $\Lambda = \sum_{i=1}^{n} \square .b_i$. This is a set of integer combinations of vectors.

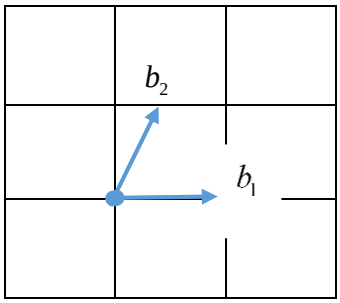


Figure 1: Gaussian 2D Basis

The radius of the Gaussian circular lattice defines a minimum distance measured from the center of the lattice $\Lambda \subseteq \square^n$ where

$$d_{min}(\Lambda) = \min_{\lambda \in \Lambda^*} \|\lambda\| \qquad (7)$$

This radius may be seen as equivalent to the power transmission from a base station at the center of the lattice to a mobile phone at distance $d_{min}(\Lambda)$. This phone at distance $d_{min}(\Lambda)$ will be referred to henceforth as the lattice mobile phone (LMP). The transmission power allocated to a mobile is proportional to the distance of the lattice

mobile phone to the base station. We will assume that the power transmitted to an LMP uses a QAM modulation scheme on a ring as shown in Figure

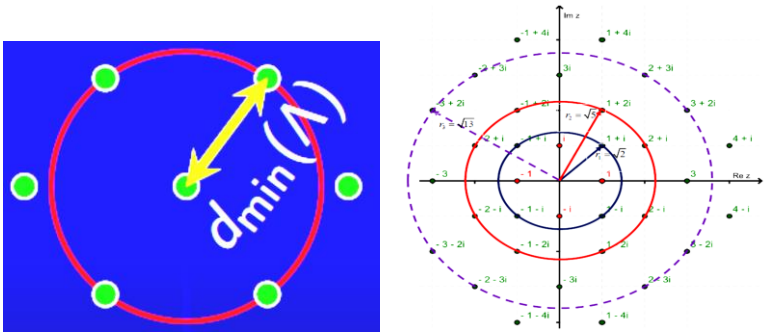


Figure 2: (a) Distance of Lattice Point From Lattice Center (b) QAM Points as Lattice Points

Assume also that at the LMP, the detected vector uses Nearest Neighbour quantizer (NNQ) in the lattice. The NNQ is the vector which leads to the minimum error with respect to a valid lattice point. This detection method is a decoding problem and is

$$\wp_{\Lambda}^{(NN)}(x) = \arg\min_{\lambda\in\Lambda}\left(\|x-\lambda\|\right) \qquad (8)$$

The decoding problem most suitable to Gaussian integers is one in which the decoded vector is closest to lying on the circle defined by the Gaussian integer. The inverse $\left[\wp_{\Lambda}^{(NN)}(\lambda)\right]^{-1}$ is a Voronoi region of λ. The canonical lattice for QPSK modulation may thus be seen to be equivalent to Figure 3.

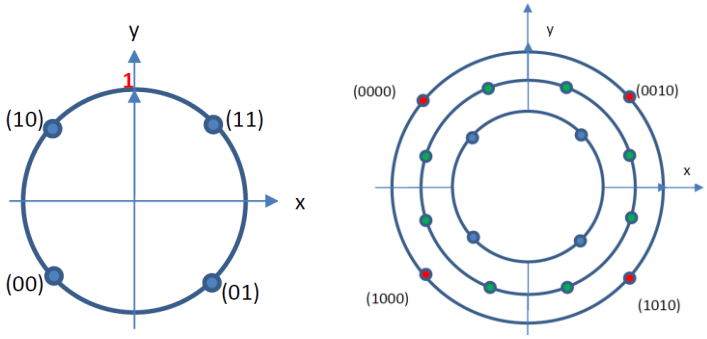


Figure 3: (a) Canonical QPSK Lattice (b) Canonical QAM Lattices

As an example Table 3 shows a 16-QAM symbol allocation scheme using Gaussian lattices. The symbols are formed from a lattice of radii $\sqrt{2}$, $\sqrt{2}\times\sqrt{5}$ and $3\sqrt{2}$ distances from the beacon.

Table 4: A Set of 16-QAM Symbols Using Prime Numbers

Array Index (Input Symbols to 16-QAM modulator)	Array Index Represented in Binary	Array Value -> AB + j CD (Output of 16-QAM modulator)
0	0000	-3 - 3j
1	0001	-3 - 1j
2	0010	-3 + 3j
3	0011	-3 + 1j
4	0100	-1 -3j
5	0101	-1 -1j
6	0110	-1 +3j
7	0111	-1 +1j
8	1000	+3 -3j
9	1001	+3 -1j
10	1010	+3 +3j
11	1011	+3 +1j
12	1100	+1 - 3j
13	1101	+1 - 1j
14	1110	+1 +3j
15	1111	+1 +1j

Since the transmitter at the centre of the lattice transmits a large power so as to reach the LMPs at the outer lattices at reasonable power, the LMPs on the inner lattice would normally see very high power. Hence in beacon transmission systems these LMPs must scale down the received power in proportion using the relation:

$$p_j = \left(\frac{d_j}{d_{\max}} \right)^2 .P_T ;\ j \in R \qquad (9)$$

P_T is the transmitted power from the base station or beacon and R is the number of rings in the lattice. Notice the power reduction factor uses a quadratic ratio in line with how radio frequency power decays with distance.

6.1 Hypergeometric Gaussian Ball

In a case where the beacon transmits power into a uniform ball or sphere, for analysis with Gaussian primes we define a region in an n-dimensional space called Ball. In the $\mathbb{R}^n$ space this is shown in Figure 3.

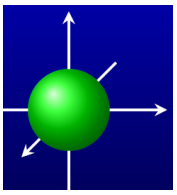


Figure 4: Ball

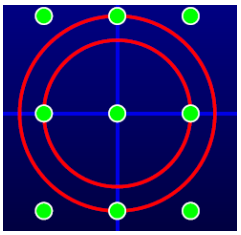
Define the ball by the expression

$$B_r = \left\{ x \in \mathbb{R}^n : \|x\| \le r_p \right\} \qquad (10)$$

The Gaussian lattices of interest to this paper are thus defined on hypergeometric surfaces of balls of radii r_p where p is a Gaussian prime. The surface of the ball contains L lattice points. In the Euclidean space the surface of such balls are circles of radii r_p. Consider such two balls of radii r_{p_1} and r_{p_2} such that $p_2 > p_1$ with both of them being Gaussian primes. The larger ball $B_{r_{p2}}$ due to the nature of lattices defined by Gaussian

primes may (or may not) contain the same number of lattice points as $B_{r_{p1}}$. The larger ball is defined by the set $x+R=\{x+y:y\in R\}$ a scale factor R rather than a translation.

Figure 5: Circular Lattices with Points



The lattice points on the smaller ball are a subset of the lattice points inside the larger ball. We write this as $B_{\Lambda_S}(N')\subseteq B_{\Lambda_L}(N)$. N' and N are the Gaussian lattice points inside the smaller and larger balls respectively. The lattice points in the smaller ball are said to be '***resident***' inside the larger ball, where Λ_S and Λ_L are the small and large lattices respectively. The two lattices are also called the coarse and fine lattices respectively.

Lattices can be blurred intentionally by using blurring algorithms. In telecommunication a blurred lattice is one in which the detected points are corrupted by noise. Therefore, we can estimate the rate of blurring. A uniformly blurred lattice in an R^n space occurs when the standard deviation of the Gaussian is greater than the length of the shortest basis. This can be done in matlab using the Gaussian blur function. When applied, the picture becomes progressively blurred until it is uniform and no lattice points are distinguishable. This provides the lower bound on the amount of noise which leads to non-detection of the symbols. It would therefore be more practically useful if the distance between the lattice points defined by the Gaussian primes is significantly more than unity to ensure that blurring of symbols by noise is minimized and takes a large space before symbols are wiped out. The largest blur in the Gaussian prime lattices cannot therefore be more than the radius of the Gaussian prime circle and not less than the smallest separation between two symbols on the Gaussian prime circle lattice.

6.2 Power Allocation Scheme and Simulation

New power allocation schemes developed for 5G systems for transmission assign different power levels to different users or devices. In this section we propose a new power allocation scheme for symbol transmission based on the radii of the symbol lattices. Let the allocated power for symbols on a lattice be proportional to the ratio of the radius of the lattice on which they are defined as a proportion of the overall transmitted power. Suppose there are N circular lattices of radii $\{r_1,\ r_2,\ \cdots,\ r_N\}$ with symbols on them, the power allocated to symbols on circular lattice k is given by the relationship

$$p_k=\frac{r_k}{\sum_{j=1}^{N} r_j}P_t \qquad (11)$$

Where r_j is the square root of a Gaussian prime and P_t is the total transmitted power in all the circular lattices. Since devices located in the inner lattices are closer to base stations, they can operate efficiently at smaller power determined by their distance from the base station. Devices far away towards the edge of the cell require more transmitted power by the base station for them to capture the same amount of received power near the edge of the cell. This method therefore implements a fair algorithm for power control right at transmission. The powers received on lattices are proportional to the radii of the circular lattices. This power is

$$P_r = \frac{G_t G_r P_k \lambda^2}{(4\pi d_k)^2} = \frac{G_t G_r \lambda^2 r_k P_t}{(4\pi d_k)^2 \sum_{j=1}^{R} r_j} \qquad (12)$$

We assume that this received power level is the same for devices on R circular lattices within the cell range. Power received by LMPs at two lattice circles of radii r_1 and r_2 with lattice point power allocation scheme is given by the expression

$$\frac{P_2}{P_1} = \frac{r_2}{r_1}\left(\frac{d_1}{d_2}\right)^2 \qquad (13)$$

Power received by LMPs at comparable locations without the lattice-point power allocation (LPPA) scheme is the expression

$$\frac{P_2}{P_1} = \left(\frac{d_1}{d_2}\right)^2 \qquad (14)$$

Note that in both expressions we have assumed that the influences of noise on symbols in the channel are negligible. The comparable impact of noise on the lattice power allocation scheme is being studied further. Simulation of the lattice power allocation scheme was undertaken in matlab. The coding gain over the canonical QAM power allocation is given in Table 5.

This improvement in received power at the LMPs is also quantified in terms of improved system capacity defined by Shannon's equation as

$$C = B\log_2\left(1+\frac{G_k S}{N}\right) \qquad (15)$$

Table 5: Improved System Performance Using Lattice Power Allocation Scheme

d_1 (km)	d_2 (km)	Canonical	VGLG (G_k)	Gain (dB)	C (bps)
1	2	1/4	$\sqrt{2.6}$	2.075	1.3854B
	3	1/9	$\sqrt{3.4}$	2.66	1.5079B
	4	1/16	$\sqrt{5.8}$	3.82	1.769B
	5	1/25	$\sqrt{7.2}$	4.29	1.881B
	6	1/36	$\sqrt{8.2}$	4.57	1.9499B

Notice for example that when $d_2 = 6km$ there is a 4.57 gain in the received power. Thus by keeping S and N constant and $1 << G_k S/N$, there is more than two times improvement in system capacity.

7 Conclusions

This paper has demonstrated how to factor integers using prime numbers. We also show that circular lattices can be defined with such factors. The radii of the lattice circles are mapped in the paper using a power allocation scheme for terminals lying on such lattices. It is shown that the power allocation scheme leads to increase in the received signal-to-noise ratio and hence increase in system capacity as well. The increase in system capacity is proportional to the ratio of the radii of the circular lattices.

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Bayesian geostatistical modeling to assess spatio-temporal variations and elapsing time for malaria incidence risk in Swaziland

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Abstract

Malaria has drastically declined in Swaziland and the country aims for elimination by the year 2016. Spatially explicit maps on micro epidemiological variations in malaria incidence risk are needed to aid the country to target and prioritize interventions in the high risk areas for impact. The study developed a polynomial distributed lags model of up to three months to assess the relative contribution of climatic factors, mosquito breeding sites and human related factors in space and time. A Bayesian geostatistical and temporal negative binomial model was fitted on malaria incidence data to predict the disease at high spatial and temporal resolutions. Thus we produced the country's first model based monthly maps of malaria incidence risk. The results showed that LST day and NDVI lags were associated with malaria after about 1–months (Lag 4) while LST night was important from the first two weeks up to 1 month (Lags 2 & 4). On the other hand rainfall was negatively associated with malaria on the first month (lag 2) and became important in the second and third month (Lags 5 & 6). Maps of malaria incidence prediction showed high rates in the months of July and September (> 8.2 cases per 1000 people). February and March had the lowest incidence rates at less than 5.3 cases per 1000 people. This could be attributed to the heavy rains that are received around this time, thus inhibiting transmission while the peak in the drier period of July could be a result of previous rainfall episodes. These maps could be useful for timing and targeting of control interventions by the control programme.

Keywords: *malaria elimination, Bayesian modeling, remote sensing, Swaziland*

Introduction

Recent declines in malaria transmission in Southern Africa shifted the focus of national control programs in the region towards elimination (Cohen *et al*., 2013; Hsiang *et al*., 2012). Swaziland, Namibia, Botswana and South Africa constitute the elimination frontline countries, whereby Swaziland is already on its elimination path which was first targeted to begin in 2015 until certification by the World Health Organization in the year 2018. During the interval from the target year to certification, there should be zero locally acquired malaria cases, however bringing cases down to zero remains operationally challenging (Moonen *et al*., 2010). For instance, the country recorded about 603 malaria cases in the transmission season of July 2014-June 2015 forcing the National Malaria Control Programme (NMCP) to shift its goal of elimination by one year from 2015 to end of 2016. Indeed with recent funding from the Global Fund, the country is geared towards implementing its revised Malaria Elimination Strategic Plan of 2015 to 2020. Consequently, strong surveillance and sustained control with evidenced based intervention strategies is needed in the critical phase of elimination to qualify the country as malaria free.

Swaziland, a landlocked country located in Southern Africa has already scaled up its malaria interventions in an effort to eliminate local transmission by 2016 (Ministry of Health, 2015). According to Churcher *et al.,* (2014) Swaziland has already halted endemic transmission. Nonetheless, recent malaria data show that the country will continue to struggle with emerging cases and importation from neighboring regions resulting in seasonal uncertainties on the national incidence rates. For instance, a study by Koita *et al*., (2013) showed that importation from Mozambique accounts for over 90% of malaria transmission in Swaziland. Furthermore, data from the Swaziland malaria control programme for the transmission season proceeding the then target year of 2015 showed an alarming 82% increase in local cases (112 to 204 malaria cases) for the seasons July 2012 to June 2013 and July 2013 to June 2014. Such seasonal upsurge in cases reemphasizes the need for sustained interventions and watchfulness even when endemic transmission has been halted.

In Swaziland, malaria transmission occurs on the eastern part of the country where it shares a border with Mozambique and on the south eastern part bordered by South Africa (NMCP, 2010). Seasonal low unstable transmission characterizes the malaria

situation where its peak is associated with episodes of high rainfall during the summer season between November and May each year (Ministry of Health, 2012). Surveillance is an integral part of the malaria elimination efforts in Swaziland and as such since October, 2009 it has been strengthened to include reactive surveillance through follow up of individual cases reported at health facilities (Cohen *et al*., 2013). This involves collection of demographic information about the patient, travel history which helps in classification of cases as either local or imported based on onset of symptoms. GPS coordinates of the case's residence are also captured.

Studies on spatio-temporal variations in malaria incidence are important not only to assess the problem of malaria in a given region, but also to analyze the effectiveness of preventive strategies (Zacarias and Andersson, 2011). Geostatistical spatio-temporal models are useful for identifying spatial heterogeneities and for assessing those environmental factors associated with disease incidence. These models can be used as tools for assessing both primary and secondary response prevention measures, as well as their effect and impact. In addition spatially explicit model-based maps on micro epidemiological variations are important for malaria elimination as endemic transmission declines to residual foci. These maps are still needed in order to aid surveillance and vector control efforts and to better target and prioritize planned interventions (Giardina *et al*., 2012; Gosoniu *et al*., 2012).

Currently, existing malaria maps in the country are descriptive geolocation of individual cases with little information about the explaining background factors responsible for transmission. Planning and implementation of intervention in a cost effective manner requires more explicit and reliable maps on the geographic distribution of malaria incidence at high spatial and temporal resolution (Kulkarni *et al*., 2010). These maps estimate incidence risk over gridded surfaces of factors driving the micro epidemiology of the disease. A number of factors have been associated with malaria micro-epidemiology such as distance to water body, breeding sites, vegetation cover including population movements (Bousema *et al*., 2012). The contribution of these factors to malaria transmission depends on the local conditions which can be derived from climatic and environmental proxies. In Swaziland studies investigating the contribution of these micro epidemiological factors together with climatic proxies

associated with local malaria transmission are limited and have until recently been not available.

Geostatistical models for mapping survey data have been developed to produce high resolution maps of malaria risk (Gosoniu *et al*., 2010), however very few efforts have been made for modeling incidence data in very low endemic settings characterized by diminishing malaria and episodic individual cases such as observed in Swaziland. Spatial heterogeneities at fine geographic scales can be used to identify patterns in malaria transmission and therefore understand the variations in time and space of the driving factors for better planning, preparedness and response (Amek *et al*. 2012). A combination of Bayesian modeling with Geographic Information Systems (GIS) have led to advancements in the field of spatial epidemiology and disease mapping. Consequently, it is now possible to explore and characterize different sets of spatial disease patterns at a very fine geographical resolution (Banerjee, 2004).

In this study we used Bayesian geostatistical modeling to assess the association between climatic factors and malaria incidence in space and time. A Bayesian geostatistical negative binomial model was fitted on malaria incidence data using a polynomial distributed lag function. We chose distributed lag models (DLMs) because they are useful when the outcome of interest is a result of a cumulative effect from previous time periods. They provide the estimate of the best distributed lag function which describes changes in risk factors for the outcome of interest. This function can be used to assess if the effect of risk factors on the outcome is immediate or rather slowly as a result of a build up from previous conditions. In case of malaria, studies have shown that the elapsing time between climatic factors and onset of malaria depends on past weather conditions Najera *et al.,* (1998) in what is termed epidemic buildup. Understanding the elapsing time and its effect on malaria transmission is important for planning, preparedness and response. Geostatistical models relate the disease data with potential predictors and quantify spatial dependence via the covariance matrix of Gaussian process facilitated by adding random effects at the observed locations (Karagiannis *et al*., 2013). In this study potential predictors included: environmental variables such as rainfall, temperature and normalized difference vegetation index (NDVI) as well as distance to water bodies, altitude, landuse and landcover.

Methods

Malaria incidence data

Geolocated malaria incidence data for a 5 year period (2010-2015) was obtained from the National Malaria Control Programme (NMCP) of Swaziland. The data comprised of reactively investigated symptomatic cases that have presented at health facility. Cases were already classified into either imported or local based on travel history of patients by investigating officers from the NMCP. Local cases with valid geographic coordinates were aggregated by enumeration area (EA) which is the lowest census unit and analyzed. In addition cases identified via active cases detection in the neighboring households of the index case were also included in the analysis. The population in each of the EA was used as an offset in the negative binomial model in order to take into account the spatially contextual background. Landuse of the EA was also assessed in the model. The data were organized according to the malaria transmission season which is July to June each year. Out of a total of 1229 malaria cases, 43% were local cases and only these were used during analysis.

Environmental data collection and processing

Remotely sensed climatic data were downloaded from the Reverb ECHO system (NASA, 2007). These data included a 1 km resolution normalized difference vegetation indices (NDVI) available biweekly and 1 km day and night land surface temperature (LST) emissivity indices both available weekly. The data are products of the Moderate Resolution Imaging Spectroradiometer (MODIS). Eight km resolution dekadal rainfall was obtained from the Africa Data Dissemination Service (ADDS), a data portal for the Famine Early Warning Systems (FEWS) network. In addition, a 30m resolution Digital Elevation Model (DEM) from ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) and a 1 km resolution landcover image from MODIS was obtained for Swaziland. To understand the association between malaria incidence and environmental conditions, all remotely sensed climatic factors were extracted at each EA centroid with a reported malaria case. A summary of remote sensing data is presented in Table 4.2.

Table 4.2: Variables used in analyzing malaria incidence

Variables	Spatial Resolution	Temporal Resolution	Period	Source
Normalized Difference Vegetation Index (NDVI)	1km	16-days	2009-2014	MODIS
Land Surface Temperature (LST)	1km	8-days	2009-2014	MODIS
Rainfall Estimates	8km	10-days	2009-2014	ADDS
Land Cover	1km	Yearly	2010-2012	MODIS
Altitude	30m	Yearly	-	ASTER

Bayesian geostatistical modeling

A Bayesian model based on distributed lags was formulated and implemented in order to better understand the association between environmental factors and an increased number of malaria reported cases (malaria incidence risk) at distributed lags of up to 12 weeks (3 months). This was done to take into account the possible elapsing time (lag) between the predictive variables which included rainfall, LST and NDVI and the outcome variable (malaria case) and also to determine the best combination of lags that predicted malaria incidence risk. Other factors which consisted of fixed terms included landcover, landuse, altitude and distance to water bodies. Extracted environmental data and malaria incidence data were first processed in STATA version 13.0 and then fitted to a negative binomial model in WinBUGS using a polynomial function constrained to power two as follows: Let Y_i be the average number of malaria cases at a given location s= i,….n with likelihood Y_i ~dnegbin(P_i, r) where is the proportion of malaria cases in a defined location and is the dispersion parameter and $\mu_i = r$ —— while . The model was written as:

ε , where μ_i is the number of malaria cases in each location and β are the regression coefficients, X are the model covariates and ε are temporal random effects. The distributed lag model was restricted to a polynomial function of power 2 which was formulated as follows:

$$\sum$$

Where k is the categorical variable for the covariate corresponding to coefficient and a is the intercept for locations n. The model describes the relationship between an independent value of and the corresponding dependent mean Y_i. This is summarized as). The model gives the expected μ_i of malaria cases given the corresponding value of each categorical variable at location s.

Determining important lags using Bayesian variable selection

We applied Bayesian variable selection to determine the most important lag time between environmental factors and the onset of malaria incidence. We used a Stochastic Search Variable Selection method that tries to find those independent variables that are greatly associated with the outcome variable of interest thus allowing us to fit the model only for those variables that are important in the final model. The set of β_i predictors were fixed into polynomial function describing the distribution of each set of predictors where the third power was selected following first stage testing of the different polynomials. The model was then restricted to power 4 for all the predictors comprising of LST, NDVI and Rainfall. For each of the polynomial functions x_i we introduced a binary indicator with 50% chance of inclusion into the final model by restricting the variable selection to a Bernoulli distribution with probability of inclusion whereby the best set of covariates was indicated by the model with the highest posterior probability ranging from 0 to 1. Any variables with coefficients above 50 % were selected for the final model. An inverse gamma prior was used. To enable prediction we ran the model for 444 parameters using Markov Chain Monte Carlo (MCMC) where prior distributions were assigned to the parameters in order to complete the model formulation. We then applied Bayesian kriging to predict the malaria incidence risk at unsampled locations and produce a parasitaemia risk map at 1 km spatial resolution. We used a randomly selected sample of 150 locations as a training set for fitting the final prediction model.

Results

Bayesian geostatistical modeling

Spatial variations of malaria incidence with climatic and environmental factors were estimated for each full transmission season in Swaziland. Results were predictions of malaria incidence presented in smoothed surfaces showing monthly variations in malaria incidence making it possible to visualize months of initial and peak transmission in the country. The predictions were based on bi-weeks polynomial lags of up to power 4 which were aggregated up to three months. There was a positive association in increase of temperature, rainfall and NDVI and malaria cases at polynomial lags of up to three months. For instance the current bi-week (LST day[1]) was positively associated with malaria incidence 2.18 (95% CI: 0.98 to 3.19) while the first lag or power 1 (LST day[2]) was negatively associated with malaria cases -2.63 (95% CI: -2.89 to -2.34).

Interestingly, third bi-week or power 2 (LST day[3]) and fourth bi-week or power 3 (LST day[4]) were again positively associated with malaria cases (0.1, 95% CI: 0.05 to 0.17 and 0.22, 95% CI: 0.22 to 0.2357) until the situation start to change in bi-week or power 4 (LST day[5]) which is negatively associated. In LST night, the effects of the lags was different in the sense that the current week and the first lag were not associated with malaria incidence until the second bi-week or power 2 (LST night[3]) which was negatively associated with malaria (-0.12 95% CI: -0.13 to -0.10). The third bi-week or power 4 was also positively associated with malaria which again changes in bi-week of power 4 with negative association. On the other hand NDVI was negatively associated with malaria until the third power (NDVI[4]) which was yet again positively associated (0.06, 95% CI: 0.05 to 0.06). Rain showed negative association in the power 1 (Rain[2]), power 3 rain (Rain[4] and power 4 (Rain[5]) and was only positively associated with malaria in power 2 (Rain[3]) with mean 0.23 (95% CI: 0.22 to 0.25). The results are summarized in Table 4.3 which shows the posterior probabilities of the variables polynomial functions (x^2)

Table 4.3: Posterior estimates of the distributed lags constrained to power four

Variable(x^2)	mean	sd	val2.5pc	median	val97.5pc
LST day[1]	2.18	0.657	0.9857	2.326	3.19
LST day[2]	-2.631	0.1884	-2.89	-2.662	-2.341
LST day[3]	0.1064	0.03389	0.05612	0.09868	0.1741
LST day[4]	0.2284	0.004625	0.2206	0.2295	0.2357
LST day[5]	-0.02924	3.96E-04	-0.03004	-0.02922	-0.02875
LST night[1]	0.006163	0.3635	-0.5658	0.1021	0.5285
LST night[2]	0.2757	0.2006	-0.00967	0.2314	0.5429
LST night[3]	-0.124	0.008557	-0.1372	-0.1264	-0.1077
LST night[4]	0.02868	0.00142	0.02657	0.02925	0.03084
LST night[5]	-0.00271	3.32E-04	-0.00326	-0.00258	-0.00221
NDVI[1]	-0.3156	0.3682	-0.996	-0.2119	0.2182
NDVI[2]	-0.2407	0.1474	-0.4127	-0.2853	0.008079
NDVI[3]	0.001152	0.01623	-0.01974	-0.00238	0.04276
NDVI[4]	0.06359	0.003442	0.05515	0.06441	0.06808
NDVI[5]	-0.00881	2.29E-04	-0.00917	-0.00876	-0.00847
Rain[1]	0.4434	0.4889	-0.9898	0.6221	0.9489
Rain[2]	-0.7833	0.1917	-0.9561	-0.8864	-0.1917
Rain[3]	0.2381	0.01018	0.22	0.2379	0.2587
Rain[4]	-0.01037	0.002428	-0.01754	-0.0102	-0.00579
Rain[5]	-0.00132	2.69E-04	-0.00197	-0.0013	-7.94E-04

The bi-week lags were also fitted into the negative binomial model as fixed covariates in order to assess the effects of each lag on malaria cases. Other fixed non time varying covariates like altitude, waterbody and seasonality, were also added into the model. The earlier lags of the 2nd and 3rd bi-week for LST day were negatively associated with malaria compared to later lags of the 4th, 5th and 6th bi-weeks. The effects changes from a negative association to a positive one after about one month. Interestingly LST night was positively associated with malaria cases in the 2nd and 3rd bi-week lags with means 0.49 (95% CI: 0.17 to 0.91), 1.9 (95% CI: 1.55 to 2.52) and 1.66 (95% CI: 1.39 to 1.62) respectively which jointly are also equivalent to an effect of about one month. Similarly NDVI was negatively associated with malaria in the earlier lags of about 1− month (bi-week lags 1, 2 & 3) and was positively associated in the latter lags of the 2nd and 3rd months (bi-week lags 4, 5 & 6). Rainfall was negatively associated with malaria case on the 2nd bi-week lag and positively associated in the 5th and 6th lags of the 2nd and 3rd months with means 0.35 (95% CI: 0.09 to 0.93) and 0.36 (CI: 0.16 to 0.67) respectively. The results are summarized in Table 4.4 and the resultant maps are displayed in Figures 4.3.1, 4.3.2 and 4.3.3.

Table 4.4: Posterior probabilities for fixed bi-week lags of environmental factors

variable	Lag	mean	sd	val2.5pc	median	val97.5pc
LST day	**Lag 1**	-0.1451	0.445	-1	-0.05983	0.5578
	Lag 2	-1.297	0.2059	-1.739	-1.261	-0.9551
	Lag 3	-0.9561	0.09027	-1.122	-0.9623	-0.7872
	Lag 4	0.4922	0.2407	0.1771	0.4447	0.9126
	Lag 5	1.963	0.3005	1.555	1.892	2.528
	Lag 6	1.668	0.1928	1.393	1.625	2.091
	Lag 7	-2.883	0.2861	-3.391	-2.884	-2.448
LST night	**Lag 1**	0.1838	0.1798	-0.1447	0.2328	0.4541
	Lag 2	0.2475	0.07481	0.1214	0.2427	0.4208
	Lag 3	0.2718	0.1498	0.03271	0.2404	0.577
	Lag 4	0.2662	0.199	-0.0304	0.1975	0.6114
	Lag 5	0.1751	0.1532	-0.04733	0.1231	0.4599
	Lag 6	-0.1222	0.1056	-0.3501	-0.1102	0.06071
	Lag 7	-0.8112	0.479	-1.7	-0.6842	-0.03606
NDVI	**Lag 1**	-0.5004	0.2157	-0.9203	-0.459	-0.1579
	Lag 2	-0.4247	0.07643	-0.5662	-0.4235	-0.27
	Lag 3	-0.02417	0.112	-0.1951	-0.05566	0.1894
	Lag 4	0.554	0.1873	0.3336	0.4903	0.9159
	Lag 5	0.9512	0.1771	0.7373	0.8958	1.299
	Lag 6	0.5974	0.0683	0.4687	0.595	0.7303
	Lag 7	-1.289	0.3305	-1.922	-1.184	-0.8273
Rain	**Lag 1**	-0.1135	0.3018	-0.9562	-0.02793	0.2342
	Lag 2	-0.2749	0.1329	-0.5975	-0.2561	-0.07677
	Lag 3	-0.1505	0.09798	-0.3069	-0.1598	0.08106
	Lag 4	0.1186	0.1824	-0.1032	0.06273	0.6572
	Lag 5	0.3595	0.2065	0.09986	0.2959	0.9364
	Lag 6	0.3677	0.1306	0.1619	0.3469	0.6715
	Lag 7	-0.0928	0.1959	-0.5978	-0.0567	0.189
Wet season	**-**	1.532	0.9761	0.04397	1.381	3.896
Dry season	**-**	-0.07404	9.999	-19.6	-0.07795	19.65
Altitude	**-**	-0.2638	0.1592	-0.5927	-0.2573	0.03222
Waterbody	**-**	0.01113	0.09569	-0.1697	0.007787	0.2111

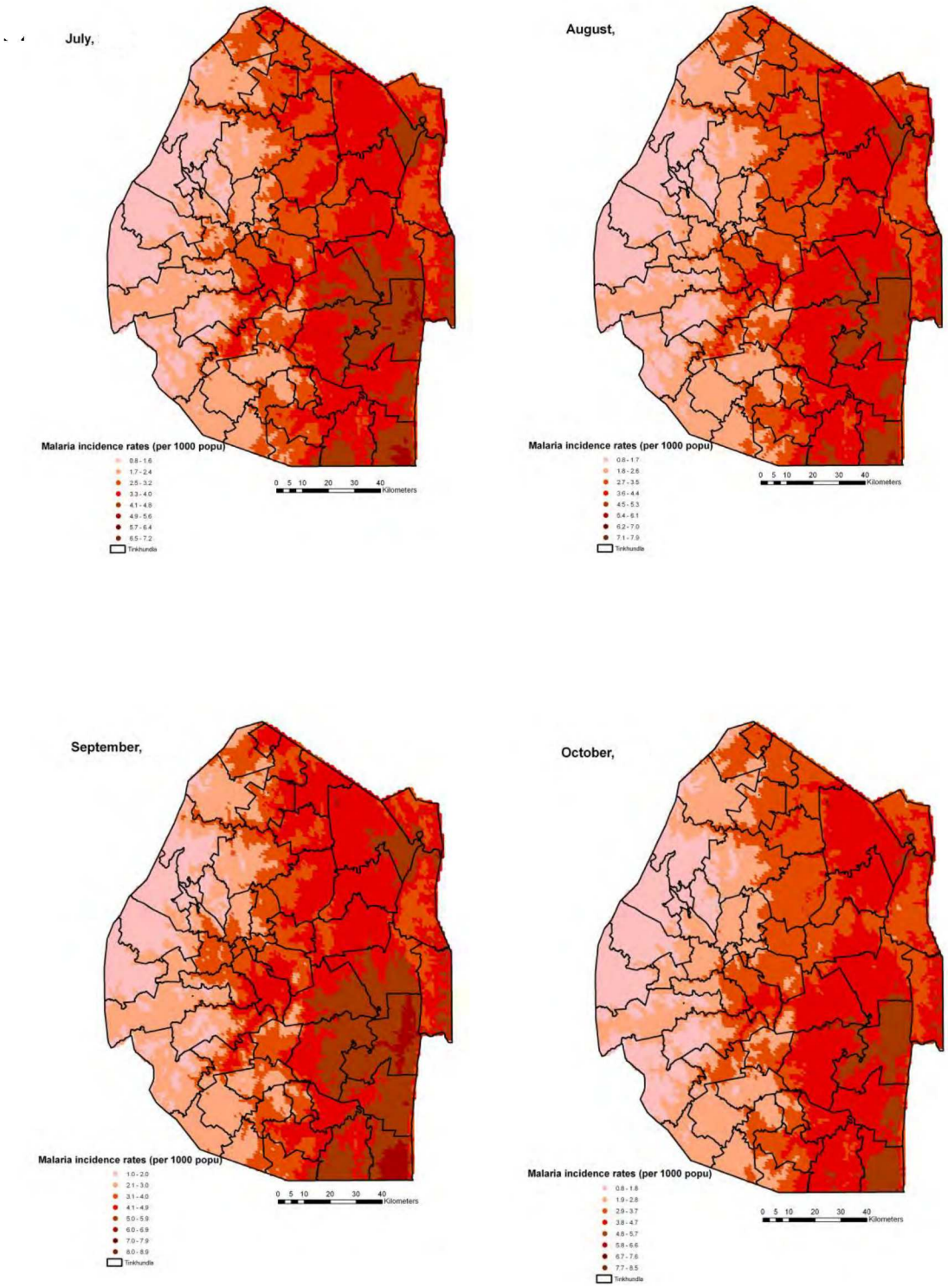

Figure 4.3.1: Predicted malaria incidence for July-October

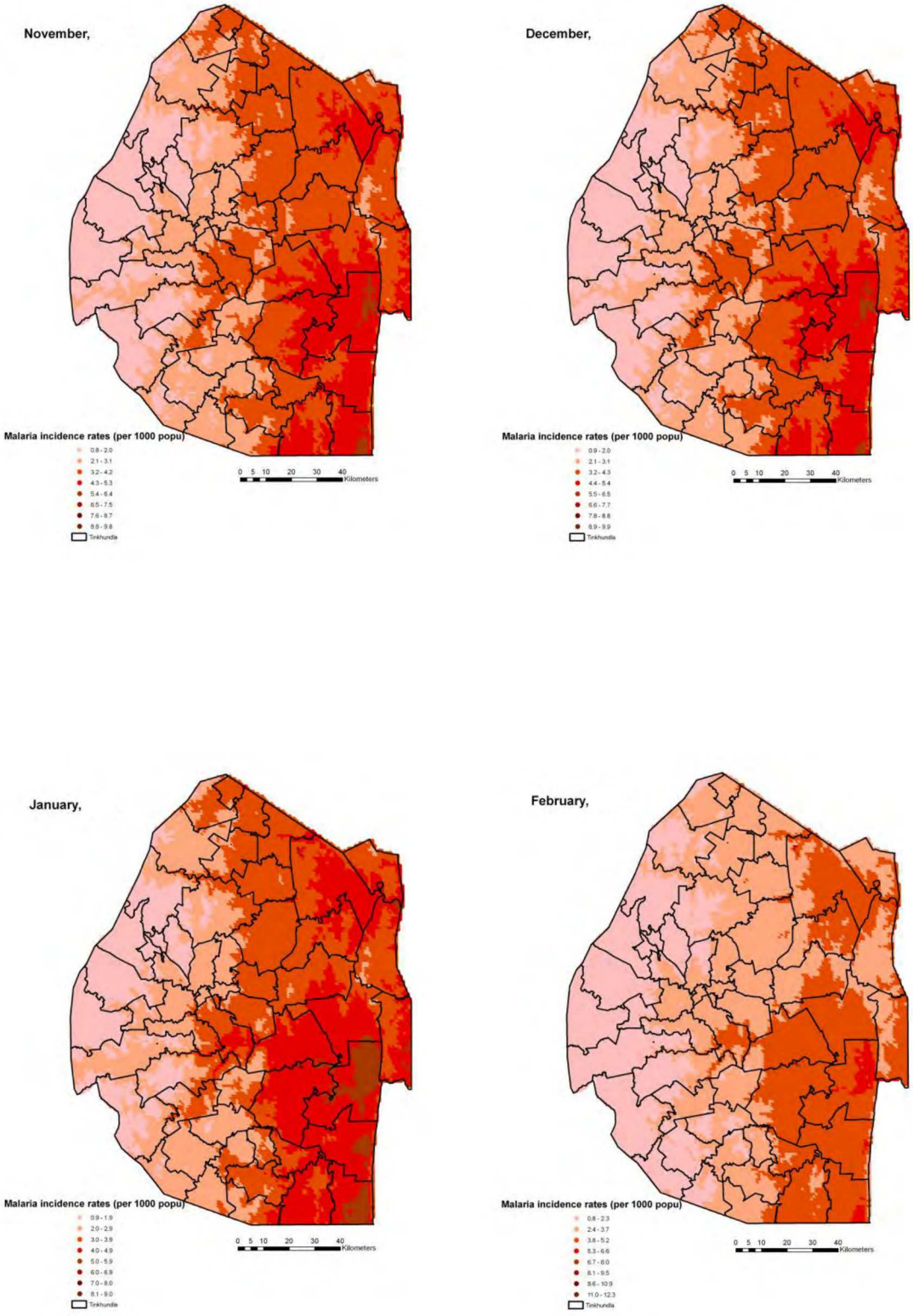

Figure 4.3.2: Predicted malaria incidence for November-February

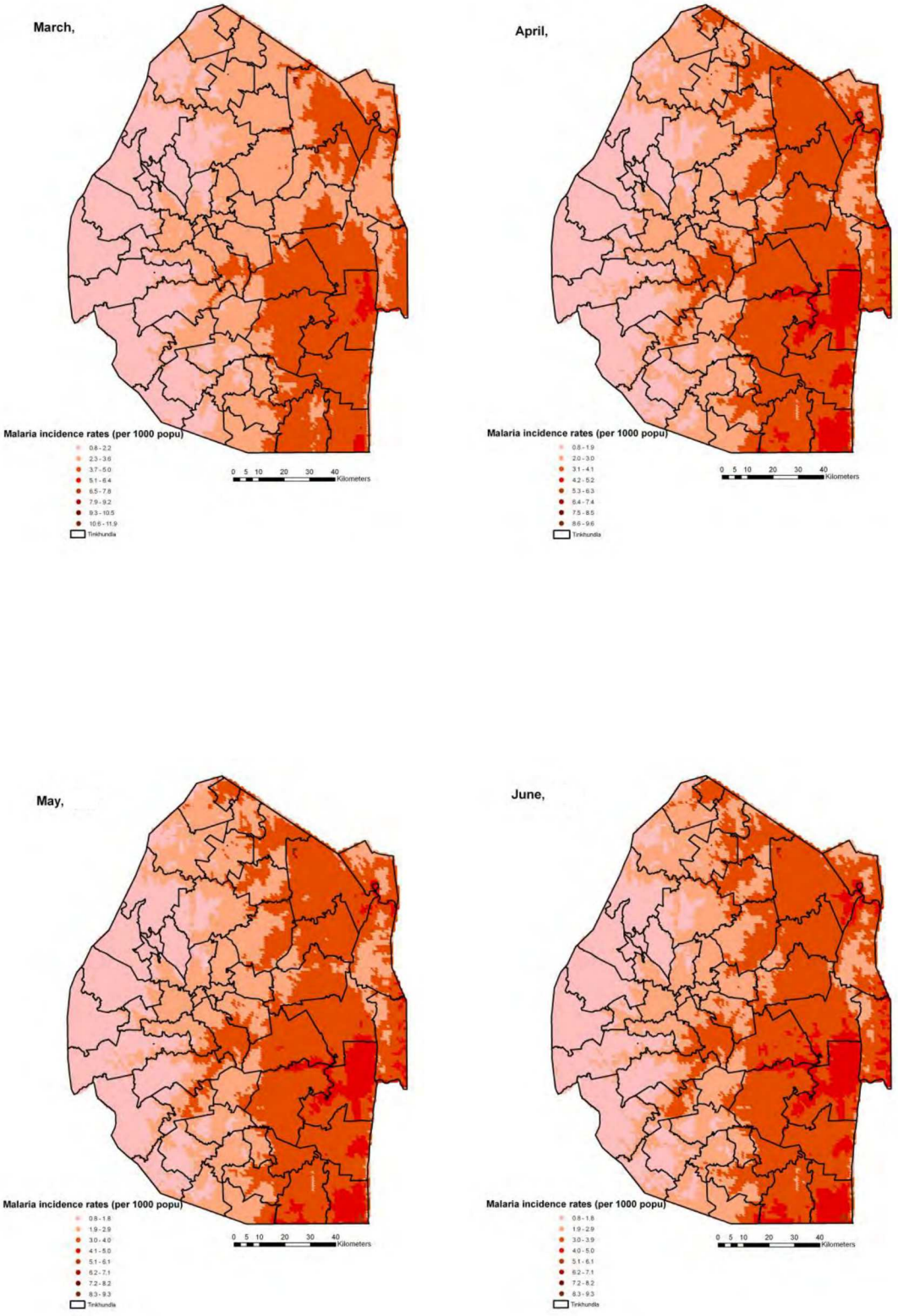

Figure 4.3.3: Predicted malaria incidence for March-June

Discussion

This study showed a consistent spatio-temporal correlation between climatic factors and malaria incidence risk and as such the maps provide an explicit guide for resource optimization as they show the areas to be targeted with intervention to achieve high impact. While high incidence risk is predominantly in the eastern lowlands of the country its magnitude varies from month to month and the results also suggest that additional non-climatic factors including socio-economic conditions, elevation, etc. also influence malaria transmission. Most of the areas at risk are below an altitude of 400 meters and also dominated by rural settlements. Although the influence of climatic and environmental factors on malaria transmission is known, this study is the first to identify a geostatistically significant correlation between climatic factors and malaria incidence risk in Swaziland. The maps depict a considerable month to month fluctuation in malaria incidence with highest incidence rates occurring in September and January respectively. In sharp contrast, very low incidence rates were observed for the months of February and March. It can be noted that a high proportion of cases that are seen in the months of December to March are usually a result of importation from nearby endemic countries, hence it can be concluded that local transmission essentially begin in the months April to November.

At three months lags, the study was able to quantify, the delay or buildup period for climatic factors and onset of malaria cases. Therefore, the algorithm used in this modeling can be adopted and used by the control programme for short to medium term forecasting of epidemics thus enabling intervention measures to be timely and well placed. Since the study produced the first monthly explicit maps of spatial variations in the country, these can be used as on-the-ground guide for not only timing interventions but also identifying priority areas for high impact as shown in the smoothed maps of monthly predicted malaria incidence in Figures 4.3.1, 4.3.2 and 4.3.3. These predicted maps illustrated spatial variations between months with areas of high predicted malaria incidence risk occurring in the eastern low part of Swaziland and a few locations with low predicted malaria incidence spreading towards the western part of the country. Of note is that the spread towards the west follows areas of low altitude which are channels with the same elevation as the eastern high incidence risk areas.

Conclusions

The Bayesian modeling methods developed and used in this study can be built on and modified for rapid forecasting models to assist countries with very low malaria incidence rates understand the micro epidemiology of the disease over very small areas and therefore optimally deploy malaria interventions in accordance with the severity of the observed malaria episodes. High resolution maps are useful in analyzing factors influencing transmission for very low endemic settings like Swaziland. Results show that the country is on track towards elimination as average predicted malaria cases become less in some months and the area predicted to be at risk demonstrate clearly a case of diminishing malaria.

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Information Technology Policy Formulation and Implementation for Socio-economic Growth and Development

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Abstract Socio-economic growth and development is today hinged on access to information and communication technology (ICT) tools. This is because growth and development are deemed to thrive on the wheels of ICT. Nations have invested time and money in the growth of the information sector all in a bit to revamp other sectors to fast-track the benefits of ICT and the needed growth and development. Policy formulation and implementation is a drive to enforcing standards in/for the usage of resources to foster growth and development. The political class are to be at the fore-front of policy formulation as a means of implementing their vision for the growth and development of the populace. Manifestos are manifested at policy formulation and implementation. However, problems ensue when the interest of the populace differ from that of the political class, thereby neglecting the feelings of the electorate. Policy formulation and implementation cannot be by fiat; it must be by dialogue. Policy formulation and implementation will be stalled where there is no agreement between the parties the electorates and the political class. Policy formulation and implementation in the ICT as a springboard for growth and development are the main subject in the presentation in this paper.

Keywords Policy · Socio-economic Growth · Development · ICT · Policy implementation

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1 Introduction

A causal study over the years has grouped economic growth and development under theories following the pattern of noticeable growth and development in ancient and modern nations. Economic growth involves an increase in aggregate product (total or per capita) without the consideration of changes in the cultural and social value system or the structure of the economy. The growth and changes in social and cultural value systems represent economic development. Therefore, theories of growth and development have been said to be theories related to ways of achieving desirable economic changes, and changes in the cultural, social and political systems, respectively respectively [11]. Modernisation Theory, Dependency Theory, Neoclassical Theory, World-systems Theory, Post-development Theory and Human Development Theory (the last two are grouped under recent trend theories) are the existing theories of economic growth and development. Other related references on development theories are found in the works of L von Bertalanffy and Joseph Henry Woodger [8]; P. W. Preston [21], P. W. Preston [22]; Muhammad Naveed Baqir [6]; Richard D Wolff and Stephen A Resnick [30] and William Crain [10].

Industrialised and developed nations consider information as a powerful and reusable tool or resource for development. Information is considered a catalyst (and an essential input), serving as a product of change. Developing nations now use information as a precious fuel in the process of transformation [16].

Several studies [4], [28] have been conducted associating information with development, while unravelling the value, usefulness, relevance, and impact of information. Several sectors now employ information systems (ICT) in service delivery, and ICT forms the fulcrum upon which other sectors revolve and is a springboard for development. ICT helps to facilitate medical information, administrative responsibilities and research. It also has the capacity for improving access to healthcare, the quality of the service delivery, the quantity of health professionals through training and collaboration, and the effectiveness of public healthcare and public healthcare interventions [31].

An ICT system without information will not only be vague but confusing, as it will be unclear what should be communicated. Bertram C Brookes [9] equation of information science [7] presents a bridge between the concepts of information as a process and information as a change agent. Brookes' equation:

$$\delta(I) + (K) = (K + \delta(K))$$

where K is a recipient's knowledge structure; $(K + \delta(K))$ represents a modified structure caused by the arrival of an increment of information, $\delta(I)$; and the plus sign is really *not* the usual addition. Thus, the equation should be read as, "An increment of information *combined with* (first +) an existing knowledge state *leads to* (=) a new knowledge state that includes the *result*

of integrating (second +) the new information". Therefore, information can be considered as a commodity, a resource, and an infrastructure [19]. As a commodity, information can be tangible by its services and activities. The effect of such services and activities can result in an action or object that can be paid for. One pays to receive information that is important to one. The commodification of information defines its worth and ability to bring development. Therefore, as a commodity, information can be considered an object or set of objects of predictable uniformity. As a resource, information is a source of support and supply for individuals as well as organisations. As a resource, it can be managed by an individual, an organisation or a government. The efficiency of managing this resource – information – is what determines its impact. As an infrastructure, information thrives on a system referred to as an information system, and the impact of the information is felt through information systems. In short, an information system delivers information. For example, the use of telephones, computer networks and the Internet are means of delivering information. A broader, modern and more specific reference to an information system is the ICT. Without ICT, it is unlikely that one would feel the presence or impact of information.

To examine the relevance and impact of information, irrespective of the sector, according to the information attributes highlighted by [19], the following features of information are important: Firstly, one must consider the value of information in problem solving. Information must meet the value qualifying it to be tagged 'information' before it can be accepted as information, in other word, information must be of relevance before it is accepted. Secondly, the reliability and authenticity of the content and source of the information determines the response rate. Both the content and the source of the information must be reliable. A reliable content from an unreliable source will be very suspicious. When a reliable source produces unreliable content, this could spell death to an individual or an organisation because the content will be taken as real, meanwhile it is the opposite. Instead of growth and development, there will be retrogression, and false security alerts will end up destroying rather than building the system. Thirdly, information must be comprehensive and clear, and detailed information that clearly defines its perspective will surely yield the expected results. Fourthly, information that will impact positively must be timely, otherwise it will be irrelevant, thus information must be made available when needed. Information availability is of importance to direct and lead the recipients to appropriate decisions. The confidentiality and integrity of information are vital characteristics for health and security. Generally, the volume of information received can also determine to what extent it will affect the recipients. The amount, specificity, generality, novelty and subject domain of the information go a long way to determine its usability.

Socio-economic development may be considered as behavioural changes in individuals. It also involves the resultant consequences and benefits induced by information. Such development occasioned by information and fos-

tered by information systems or ICT can be termed as sustainable development. Lankester (1996) has the following view of sustainable development:

> Sustainable Human Development (SHD) is development that does not merely generate growth, but also distributes benefits accordingly; it regenerates the environment rather than destroying it. Sustainable human development empowers people rather than marginalising them; enlarges their choices and opportunities and it provides for peoples' participation in decisions affecting their lives. SHD is development that is pro-poor, pro-nature, pro-jobs, and pro-women. It stresses growth, but growth with employment, growth with environment, growth with empowerment, and growth with equity [18, p. 2]

If information can result in sustainable development, then the means by which information is delivered deserves commendation. ICT, therefore, has a great impact on development (specifically that which is sustainable). The mere availability of information, however, does not bring about the desired development; rather, the available information must be useful enough to bring about the desired change. Conversely, information gaps or the deprivation of information results in poverty.

The International Development Research Centre (IDRC), as a front-line advocate of development in Africa, has embarked on several development research studies in sub-Saharan Africa in an attempt to fast-track development in Africa. The principal object in most of the research studies involves the impact of information and ICT on the development of Africa. As far back as 1995, a few nations within sub-Saharan Africa, among which were Tunisia, Egypt, South Africa and Zambia were considered fully connected to the rest of the world via the internet [15]. Hafkin and Menou (1995) consider that Africa offers great hope of ending her information gap with the application of electronic communication devices, otherwise referred to as ICT. Most African nations are now in the advanced stages of developing their own viable ICT frameworks and from the facts above it is certain that ICT has contributed to facilitating the socio-economic development of these nations. According to [13], there have been questions and criticisms of the hype around ICT for development, but notwithstanding, over the past years ICT has become a facilitating element in the provision and sustenance of economic growth and the reduction of poverty. The question asked by some of these critics [13] is whether developing nations should dedicate their resources to the ICT sector and hence the expansion of a more knowledgeable society, or invest in other sectors such as education, health, electricity, or agriculture (food security)? Without any bias, ICT is an enabler that aids the growth of all the other sectors, and the world may be seen as a global village owing to the intervention of ICT and software technology using the World-Wide-Web and the Internet [27]. The development resulting from ICT is evident in commerce, governance, health and education, among others [2], however, ICT does not necessarily result in development for all without some actions. Development tied

to ICT is subject to the power dynamics of information system innovation [5], purely because ICT is not an end in itself, rather it is a means to growth and the reduction of poverty involving organisations and people using computers to collect, process, store, use (analyse) and distribute information.

2 Policy Formulation Models

The first step in delivering reforms and socio-economic development is policy making. The choice of policy formulation model depends largely on the scope of the change (transformation) project. There are several existing models employed in the creation and application of policy to identify key aspects of public policy. These models are: The Institutional Model, Elite-mass Model, Group Model, Systems Model, and Streams and Windows Model [1]. A brief overview of the models is given below.
The next step, presented in the next section, involves policy implementation strategy.

2.1 Institutional Model

The Institutional Model centres on the organisation of government - the direction of flow of policy and formal arrangements such as federalism, with an authoritative determination to implement and enforce public policy. Public policy here refers to the policy that is already adopted and implemented by governmental institutions. The disadvantage of this model is that there is a focus on institutional structures, organisations, duties and functions without investigating the impact of these on the public policy [17], [20], [29].

2.2 Elite-mass Model

The Elite-mass Model has powers emanating from the select few elites to the masses [3]. These are the powerful few that lord over the powerless majority. The Elite-mass Model has the advantage of engaging the elites in decision making, tapping from a possible wealth of knowledge. The disadvantage of this model is that it is "an environment characterised by apathy and information distortion, and governs a largely passive mass" [1, p. 2].

2.3 Group Model

The Group Model has policy emanating from agencies, interest or pressure groups. Pressures on the executives and legislative arm of government often force them to enact policies. The group now forms a bridge between the masses and the government, forcing them to establish rules through compromises and the balance of interests [1].

2.4 Systems Model

The System Model relies on Information Theory concepts. The policy process is cyclical, as in input, output and feedback. Significant variables of input and output are dependent on the environment which is purely physical, demographic, and political. As in a normal system, the elements are interrelated; they respond to forces in the environment and attempt to preserve themselves in balance with the environment [1].

2.5 Streams and Windows Model

The Streams Model consists of three streams, the problem stream, political stream and policy stream that converge to form a policy window [26]. The problem stream draws the attention of the policy makers and the public to a particular problem, defines the problem, and calls for a new policy approach to tackle the problem. Monitoring data, the occurrence of focusing events, oversight studies, programme evaluation and feedback on existing policies are key factors that determine the problem stream. In the political stream, policy emanates from the government by enlisting the problems to be solved by the government. The policy stream provides alternatives for decision-making. Policies in this group are personal and intellectual. Key players in this group are the academics, researchers, career public administrators, consultants and interest groups. Alternatives are assessed based on some constraints such as value, technical and budgetary constraints [1].

3 Implementation Strategy

After the process of policy formulation, the next activity involves the development of a strategic approach to policy implementation. Each of the various policy formulation models above presents its peculiar implementation strategy. This is the reason to have a thoughtout implementation strategy during the policy formulation process as argued by students of implementation [12]. Policymakers should think about whether policies could be implemented before it could be passed as a policy statement. There should be logically ordered questions that should be asked by policymakers before arriving at policy decisions which should provide prescriptions for policy actions at the implementation sages. Failure to do this will end the plicymaking process as just a political exercise.

Implementation analysis employs forward and backward mapping strategies. Sabatier postulated the argument that the study of policy change and evaluation research would be disqualified if policy formation was not distinguished from implementation. Thus, when blending the concerns of top-down approaches with the elements of bottom-up approaches and other implementation models, it is stressed that decision makers “should start with

the consideration of policy instruments and available resources for policy change", a process referred to as "forward mapping" [24, p. 37]. Directly following on from this process is that policy makers "should identify the incentive structure of [the] implementers and target groups", a process referred to as "backward mapping" [24, p. 37], [25].

The forward mapping strategy employs a top-down approach which specifies vivid steps that explain the expected implementation strategy at each level. The implementors are given more specific steps to follow at each level of the implementation. The constituents of a satisfactory outcome are measured using the original statement of the policy intent. Backward mapping implementation strategy strongly suggests that policymakers should not determine the outcome of the implementation process. It does not see the influence of "explicit policy directives, clear statements of administrative responsibilities, and well-defined outcomes" [12, p. 604] on the likelihood of a successful policy implementation. Backward mapping directs its focus on the lowest implementation level by considering the ability of the unit of the organisation to implement the target of the policy, and considers the resources needed by the unit to effectively implement the policy. The organisational unit with the highest effect gets more of the resources and attention by policymakers. Backward mapping does not assume that policy is the major influence on the behaviour of people engaged in the process. It "does not rely on compliance with the policymaker's intent as the standard of success or failure" [12, p. 604]. Backward mapping approach instead, offers a standard of success that is in all respects conditional, that is predicated on an estimate of the limited ability of actors at one level of the implementation process to influence the behaviour of actors at other levels and on the limited ability of public organizations to influence private behaviour.

3.1 The Implementation Process

According to Paul Sabatier and Daniel Mazmanian [23], the achievement objectives of the policy implementation process depends largely on some factors, namely, the tractability of the problem, the ability to structure the implementation process, and the cumulative effect of a variety of political variables on the balance of support for the policy objectives.

Considering these factors as listed, the implementation of policies to tackle social problems should be of varied complexities depending on the nature of the problem. Diversities of social behaviour and the complex associated with certain human conditions might make the implementation process of such policies difficult or near intractable. However, there may be other aspects of the social problems that are easier to handle. Most governmental programs have complex implementation process owing to political interests, socio-economic conditions, media attention to the problem, public support, and commitment and leadership skill of implementing officials. Other factors which may influence implementation considered under how tractable

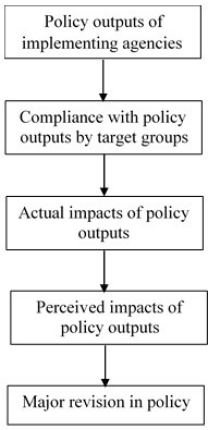

Fig. 1 Stages in the implementation process

the problem is are: the ambiguity of policy directives, financial resources, decision-rules of implementing agencies and the diversity of target group behaviour. On the basis of the tractability of the problem, according to Paul Sabatier and Daniel Mazmanian [23], stages, otherwise considered as dependent variables, emerge in the implementation process as identified in figure 1. Paul Sabatier and Daniel Mazmanian [23] argued that the first three stages of the implementation process is concerned with the extent to which impacts conform to policy objectives, and that the last two is concerned with the "political system's summary" (page 554) evaluation of a policy. Each of the stages serves as input variable to successive stages and can be considered as endpoint or dependent variable.

4 Policy Implementation and Information Technology

As already highlighted, policy forms the bedrock of society. An appropriate policy and implementation strategy drives the economy. The IT industry is not left out. The implementation of IT policy demands a higher degree of political will firstly, owing to the volume of infrastructure needed in the industry, and the impact of and influence from other sectors. Besides, the implementation of IT policy suffers setback in most developing nations because of finance, politics and the inability to sustain development initiatives [14]. Largely, bureaucracy, poor project initiation and technological change management contribute to the failure of effective IT policy implementation. IT has the capability of positively influencing the growth and development of nations, but for the implementation strategy.

5 Conclusion

The paper presented the different models of policy formulation and implementation strategy. The task of policy formulation is vain without some deliberate and painstaking steps towards its implementation. Growth and development can only be achieved through a viable policy backed-up by a coordinated implementation process. IT Policy formulation and implementation is presented in this paper as the fulcrum to growth and development. However, a strong political will is needed to fast-track policy formulation and implementation.

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Performance of Dense Wavelength Division Multiplexing in Ring MAN with Erbium Doped Fiber Amplifier Using Optisystem

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***Abstract*— This paper investigated the Performance of eight (8) Channels Dense Wavelength Division Multiplexing in a Metropolitan Area Network for transmitting signals over different distances with or without Erbium Doped Fiber Amplifiers (EDFAs). Optisystem simulator was used and represents signal quality in an eye diagram, where the opening/closure describes the signal's quality. With optical fiber characteristics of large bandwidth and suitability for long haul links, a distance of 80km was examined with EDFA, while a distance of 32km without EDFA was examined at the multiplexers while 40km and 20km with and without EDFA respectively at the demultiplexer to see how far the signal can reach. It clearly shows that when EDFAs are incorporated in optical transport network, considerable amount of distance can be achieved. Reduces latency as when electrical repeaters/ regenerators are used, because optical amplifiers reduce the need imposed by electrical repeaters/ regenerators for optical to electrical to optical conversion (O-E-O).**

***Keywords*— DWDM, EDFA, MAN and BER**

I. INTRODUCTION

The increase in volume of data (voice, text, multimedia) today being distributed and shared (transportation of data) is very large, this increase will continue to rise as more and more devices and people continue to see the need to be connected. Machines equipped with communication functionalities are not left behind in this. One major challenge of this data transportation is capacity (bandwidth), others are security and the medium to effectively carry these critical information. The high demand for internet, data, image and voice services are responsible for more capacity and bandwidth need in networks (Debbra, 2003). The discovery optical fiber with its characteristic and uniqueness associated with its dynamics has given it an edge over other technologies. This includes less noise susceptibility to various electromagnetic interferences and other undesired effects (Senior, 2009). Further exploiting the technology with Wavelength multiplexing is a promising innovation, capable of conveying optical carrier signals on a single fiber utilizing differently wavelength (light colours) simultaneously which can be either Coarse or Dense (Kartalopoulos, 2000). The Dense Wavelenght utilises the fiber effectively by impressing large amount of signal at the right ITU spacing. As the technology is maturing, studies show the possibility of impressing multiples of wavelengths on a fibre with a channel spacing that is close e.g 50GHz, 100GHz and 200GHz.

The recommendation of ITU – T recommendation (ITU-T) G.92 defines the windows used for DWDM application with 45 channels spaced at 100GHz apart (0.8nm), spanning across c-band from 1528.77nm to 1563nm. DWDM channels of 50GHz, 100GHz and 200GHz are govern by ITU_T recommendation G692, where 100GHz is the first standard and 50GHz and 200GHz being alternative standard to the recommendation was focused on a frequency grid of 193.0THz which correspond to 1552.524nm channels spacing of 200GHz, 100GHz and 50Ghz matching a spectral width of 1.6nm, 0.8nm and 0.4nm respectively. It is often used in public telecommunication networks such as Local Area Network (LAN), Metropolitan Area Network (MAN) and Wide Area Network (WAN) to link heavy group of users over different geographical regions (Kartalopoulos, 2000). The ring topology may currently be preferred only because of familiarization with the already embedded SONET/SDH ring network, and the mesh (fully connected) topology because of superior survivability (Kartalopoulos, 2000).

Signal amplification is necessary, which can be done with EDFA (Erbium Doped Fiber Amplification). EDFA have become popular and dominant in optical communication network, with optical fiber transmission, using EDFAs which has spawned the new generation are being used instead of repeaters (Kumar, 2014) and incorporated into fiber link to provide boost and in-line amplification (Senior, 2009). EDFA amplifies signals along direction of travel without the need to convert to electric form. EDFAs are used widely and have good performance at the 1550nm among other operating windows (850nm and 1300nm) and lowest loss of about 0.2dB/km and frequently used in MAN. EDFAs amplify signals simultaneously and it is this feature that has stimulated the exponential growth of optical network.

II. BACKGROUND

In this section, Ring Metropolitan Area Network (MAN) and Erbium Doped Fiber Amplifier (EDFA) are discussed. Also, related works that are relevant to this study are briefly discussed.

A. Ring Metropolitan Area Network (MAN)

This type of network employs the use of optical fiber in a ring configuration that covers a metropolitan network system for a certain distance for the purpose of deploying high speed internet in order to solve the problem of limited bandwidth within the cities considering factors like; fiber capacity, amplification, channel capacity and channel count, with DWDM ITU-T G.652 specification for low density using inter-channel spacing of 100GHz and ITU-T G655 for high density spacing of 50GHz (ITU-T). The DWDM ring network has some attached advantages which include; Easy scalability, Cost effective, Availability, and Reliability. In

addition, this network is designed with other components like multiplexers, demultiplexers, transmitters, optical add and drop multiplexers standard single mode fiber, connectors etc. Figure 1 presents a typical ring MAN used in interconnecting cities.

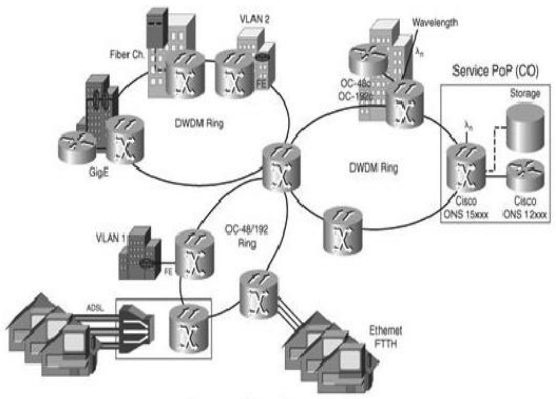

Fig. 1. Ring MAN

B. B. *Erbium Doped Fiber Amplifier (EDFA)*

Among other types of amplifiers, EDFA have become popular and dominant in optical communication network, with optical fiber transmission, using EDFAs which has spawned the new generation are being used instead of repeaters (Kumar, 2014) and incorporated into fiber link to provide boost and in-line amplification (Senior, 2009). EDFA amplifies signals along direction of travel without the need to convert to electric form. EDFAs are used widely and have good performance at the 1550nm. EDFAs amplify signals simultaneously and it is this feature that has stimulated the exponential growth of optical network.

C. *Related Works*

Considerable amount of studies and research has been done on DWDM technology with few as follows: The AMS et al. 2015 investigated the performance of four channels dense wavelength division multiplexing using four channels. Simulation results show that a distance of 108km and 7km was achieved with and without EDFA respectively. However, the efficiency of the DWDM channel was not considered. The Khanaa and Mohanta 2013, perform an intensive research on 10Gbps Data Transmission and its Implementation on DWDM Link with EDFA. However, results indicate that 1310nm cannot be transmitted over DWDM system regardless of the input, provided that the output of the transponder is constant. The Rasheed 2011 studied and examined new trend of forward Raman aamplification for DWDM photonic communication networks. However, with increase in signal power transmitted and fiber link length comes with a corresponding increase in OSNR.

III. METHODOLOGY AND ANALYSIS

This section describes optical components connections with and without EDFA at some specified distance that made up the Ring MAN, as DWDM optical data transport network is used in providing many point to point logical channels, sharing the same physical medium, hence the need to power such network to overcome the detrimental effects of attenuation and other losses, so as signals can be transmitted and received.

A. *Optisystem Software*

The Optisystem is software that is used to test, plan and design transmission in optical network. It offers a user friendly environment to analyze and optimize design parameter of DWDM system such as modulation, channel spacing, propagation length and fiber impairment.

B. *Power Analysis*

In order to get the budget, loss, and margin of the signal power for eight – channel DWDM MAN network design, power analysis was performed using some standards. The power margin is given by (Aliosio et al. 2012) as.

$$P_{M\arg in} = P_{in} - T_{Loss} + Gain - P_{rec} \quad (1)$$

where

P_{in} = Transmitted Power

T_{Loss} = Total loss

$P_{M\arg in}$ = Power margin

P_{rec} = Receiver Sensitivity.

C. *Analysis of Eight-channel DWDM with EDFA*

An eight-channel DWDM network was considered and investigation carried out in the with 8 OADMs and an EDFA using OPTISYSTEM software. The setup includes an optical source or transmitter, pseudo random bit Sequence (PRBS) generator that was connected to a Non-Return to Zero generator (NRZ) that drives a Mach Zehnder (MZ) modulator, a continuous wave (CW) is coupled to the MZ for modulation. All the receivers have same sensitivity. Eye diagrams and Bit Error Rate (BER) were analysed for the signals. Standard values for the parameters used are shown in Table I and II.

The power margin can be calculated at a distance of 10 kilometers apart using the parameters of Table I for signal dropped both at the multiplexer and demultiplexers. Table II presents the Standard Value of parameters for DWDM Design with EDFA.

TABLE I. STANDARD PARAMETERS FOR DWDM DESIGN WITH EDFA

Components/parameters	***Value***
Multiplexer insertion loss	4dB
Demultiplexer insertion loss	4dB
OADM insertion loss	4dB
Fiber Attenuation	0.2dB/km
Receiver sensitivity	-30dB
Transmitter launch power	0dB
Loss due to MZ modulator	3dB
Operating window	1550nm
Channels pacing	100GHz
Polarization	0.2ps/ √ km
Spectral efficiency of modulated channel	0.4Gb/s/Hz
Optical signal to noise ration	42dB
EDFA noise figure	3dB
EDFA gain	28dB
Bit rate	10Gb/s

1) Channel 1: signal dropped at the multiplexer: Optical power budget Pb is given by (DeCusatis, 2002).

$$Pb=Pt-Pr \quad (2)$$

From equation 2 and using the parameters of Table I, we obtained:

$$Pb=0dB-(-30) =30dB$$

From Table I, loss due to attenuation in channel 1 at 10km is calculated as.

$$0.2dB/km \times 10km=2dB$$

Also, Power loss equation is given as:

$$Ploss=M1-La-Lmz+Tlp \quad (3)$$

Using the standard values of Table I

$$Ploss=4+2+3+4 = 13$$

Therefore, the power margin can be calculated using equation 2.

$$Pm\arg in = 0-13+0-(-30)$$

$$Pm\arg in = 17dB$$

Using the same procedures, similar values are for channels 2, 3, 4, 5, 6, 7 and 8 at a distance of 20, 30, 40, 50, 60, 70 and 80km. The results obtained are as shown in Table III.

2) Channel 1:signal dropped at demultiplexer with OADM: From Table I and using equation 1, the optical Power budget is 30dB. Loss due to attenuation at channel 1 at 5km is 1dB. That is, 0.2dB/km x 5km. From Table I and using equations 2 and 3, given the following, total power loss and power margin can also be calculated at demultiplexer. Loss due to 8 OADMs is equal to 8dB. From equation I.

$$Ploss = 8+0.2+4+3$$

$$Ploss = 15.2$$

From equation 3.2

$$Ploss = -15.2+-(-30)$$

$$Pm\arg in = 14.8$$

Similar values are obtained for channels 2, 3, 4, 5, 6, 7, and 8 at their respective distances. Table 3 shows the values of the signal dropped at demultiplexer.

D. Analysis Eight-channel DWDM without EDFA given

Similar one was carried out without EDFA covering 32km with the same power analysis procedures. To perform the power analysis without EDFA, Table II shows the standard parameters of the DWDM eight channel without EDFA. Similar computation can be carried out for signal dropped at the multiplexer and demultiplexer.

1) Channel 1: signal dropped at the multiplexer

Using equations 1, 2 and 3, similar computation can be obtained for channels 1, 2, 3, 4, 5, 6, 7 and 8 but this time using the standard values of table II.

TABLE II. STANDARD PARAMETERS FOR DWDM DESIGN WITH EDFA

Components/parameters	*Value*
Multiplexer insertion loss	4dB
Demultiplexer insertion loss	4dB
OADM insertion loss	4dB
Fiber Attenuation	0.2dB/km
Receiver sensitivity	-30dB
Transmitter launch power	0dB
Loss due to MZ modulator	3dB
Operating window	1550nm
Channels pacing	100GHz
Polarization	0.2ps/ √ km
Spectral efficiency of modulated channel	0.4Gb/s/Hz

TABLE III. SIGNAL DROPPED AT MULTIPLEXER WITHOUT EDFA

Channel	*Distance (Km)*	*Power margin (dB)*
1	4	18.2
2	8	17.4
3	12	16.6
4	16	15.8
5	20	15.0
6	24	14.2
7	28	13.4
8	32	12.6

2) Channel 1: signal dropped at demultiplexer without EDFA. Similar computation is carried out as shown in Table IV but without EDFA.

TABLE IV. SIGNAL DROPPED AT MULTIPLEXER WITHOUT EDFA

Channel	*Distance (Km)*	*Power margin (dB)*
1	6	13.8
2	8	13.4
3	10	13.0
4	12	12.6
5	14	12.2
6	16	11.8
7	18	11.4
8	20	11.0

IV. Simulation Results Discussion

This paper showed the improvement of signal transmission when EDFA was used , how signal was able to cover a distance 80km and 40km at multiplexers and demultiplexers respectively as against 32km and 20km respectively without EDFA which clearly showed impairment as distance increases. The results displayed is only for the first and last channels of signals added or dropped at multiplexers and demultiplexers with and without EDFA due to space.

A. Result with EDFA at Multiplexer

The eye opening indicate good signal at a given distance while the eye closure shows effects of noise, dispersion, jitters and other nonlinearities. At 10km the signal does not suffer from attenuation and dispersion but the signal starts to suffer from non-linearity effects as can see evidently when distance is 80km.going further will have a detrimental effect on the signal.

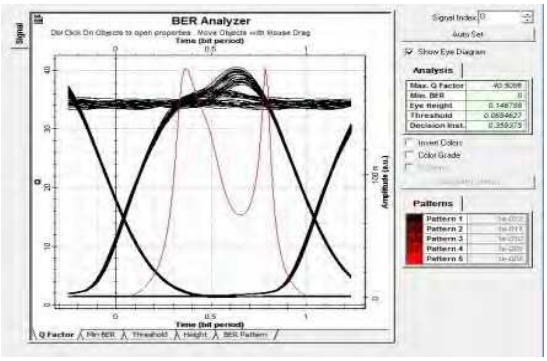

Fig. 2. Shows an eye diagram of signal at 10km

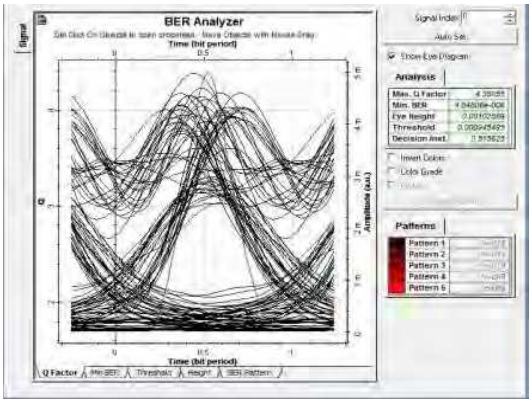

Fig. 3. Shows an eye diagram of signal at 80km

B. Result with EDFA at Multiplexer

Distances at 5km clearly shows good eye opening, meaning signal can sensed and recovered, but 40km shows the effects of noise and nonlinearities but signal can be recovered.

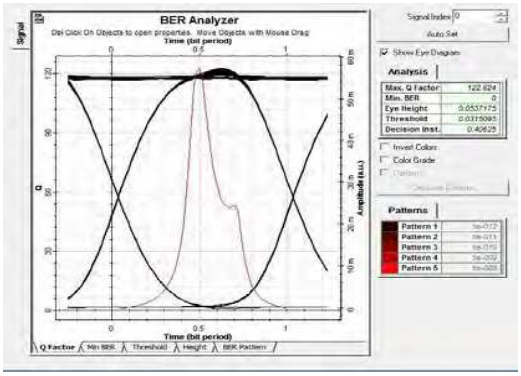

Fig. 4. Shows an eye diagram of signal at 5km

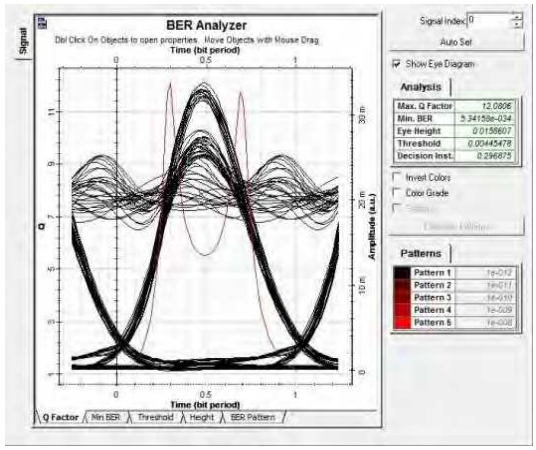

Fig. 5. Shows an eye diagram of signal at 40km

C. Result with EDFA at Multiplexer

At 4km in figure 5 the signal has a good opening even without EDFA while at 32km the need for EDFA is evident because the signal tends to close completely.

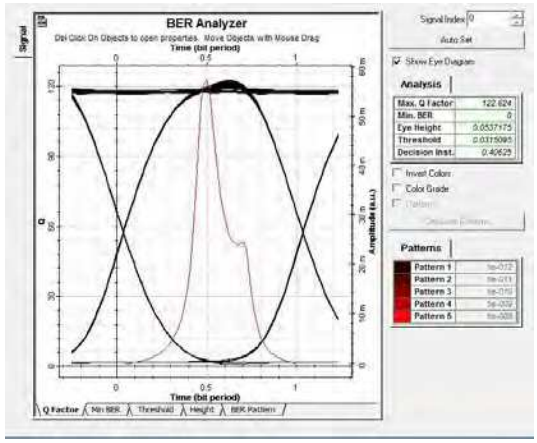

Fig. 6. Shows an eye diagram of signal at 4km

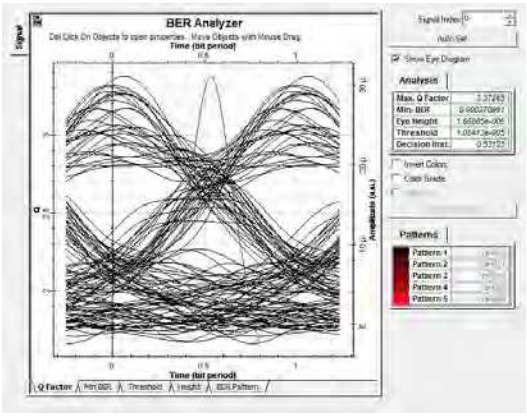

Fig. 7. Shows an eye diagram of signal at 32km

D. Result with EDFA at Multiplexer

The first channel covering a distance of only 6km has good quality as signal can easily be sensed and detected. While at 20km noise and other non-linearities tend to dominate.

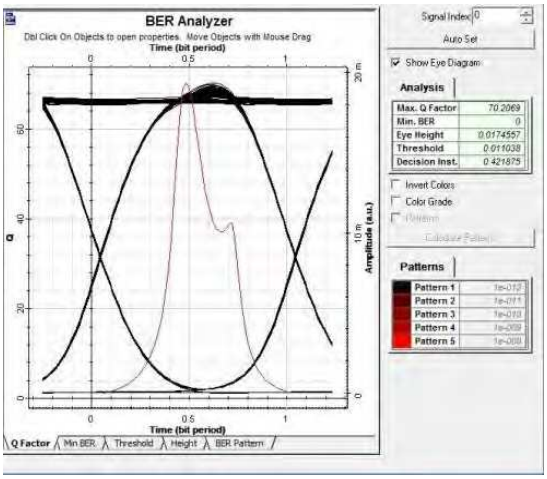

Fig. 8. Shows an eye diagram of signal at 6km

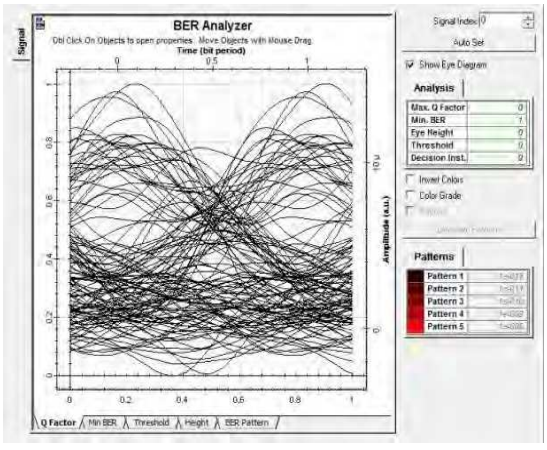

Fig. 9. Shows an eye diagram of signal at 20km

V. CONCLUSION

Optisystem was used for the simulation of DWDM channels when EDFA is deployed and when EDFA is not used. The performance of the DWDM channels was achieved when EFDA is deployed and when EDFA is not deployed in order to determine the strength of the signal and the transmission impairment encountered. A distance of 80km was achieved at the multiplexers and 40km at demultiplexers when EDFA were deployed and it is after this distance that the channels encounter more losses and data cannot be sensed and recovered. Comparing figure IV and figure V with and without EDFA the effects of distance and the advantage of EDFA can be seen.

On the other hand, only a limited distance was achieved when EDFA was not deployed because of the absence of EDFA that was used for amplifying the signal. Only a distance of 32km was achieved at the multiplexer and 18km at demultiplexer. From the interpretation of the Eye Diagram, Expansion beyond these distances is not realistic unless additional EDFA is incorporated beyond that distance. Degradation due to chromatic dispersion, fiber attenuation, insertion / coupling loss have a limiting effects on distance that can be achieved and bit rate.

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Remote Sensing for Sugarcane Crop Yield Estimation in Eswatini: Case of LUSIP Sugarcane Farms

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Abstract

Early estimation of sugarcane crop yield is a key requirement for maximising profits in sugarcane production because most operations are based on yield estimation. These include planning for the season management of labour, transportation, storage and marketing. This study explored the potential for the use of NDVI to estimate sugarcane crop yield in LUSIP project sugarcane farms at Siphofaneni, Eswatini, using Landsat 8 OLI satellite imagery for the years 2013, 2014, 2015 and 2016, sourced from the United States Geological Survey. Computed NDVI values were correlated with the respective sugarcane crop yield data sourced from Eswatini Water and Agricultural Development Enterprise (ESWADE), to establish the relationship between them, using regression analysis. The study concluded that the relationship between NDVI and sugarcane crop yield for the whole of LUSIP project at Siphofaneni was strongest for the month of August when considered at overall farms level (R^2 = 0.973), rather than at individual farmer company scale (R^2 = 0.134). The study also concluded that Landsat imagery was appropriate for sugarcane crop yield estimation in the country, especially in the month of August, even though at large scale than over small project areas.

Key Words: Crop yield estimation, Landsat, NDVI, Remote sensing, Sugarcane.

1. Introduction

Crop yield estimation and monitoring have been proven to be of great importance for planning and taking various policy decisions (Panda and Ames, 2010; Sinha *et al.*, 2016). Innovative tools are therefore needed in the field of agriculture to help in crop yield estimation and monitoring. Agricultural remote sensing application can be traced back to as early as the 1920s (Baumann, 2009; Wulder *et al.*, 2018), and imagery began to be obtained by Landsat in 1978 (Tucker, 1980; Baumann, 2009). Initially, aerial photography was used, before the advancement in satellite imagery (Du and Noguchi, 2017; Panda and Ames, 2010; Sinha *et al.*, 2016). Remote sensing is an effective tool for monitoring agricultural practices (Du and Noguchi, 2017; Wulder *et al.*, 2018). Due to a large variety of on-board sensors and an ever increasing number of civilian satellites (Beward and Skoien, 2015), the spectral and temporal properties of the land surface resulting from human practices can be captured and monitored at different spatial and temporal scales (Du and Noguchi, 2017; Sinha *et al.*, 2016). Remote sensing has provided farmers with a cost effective alternative to agricultural production and monitoring (Duveiler et al., 2013; Rahman and Robson, 2016).

In the production of sugarcane, remote sensing technology is crucial for the estimation of its yield. Duveiler *et al.* (2013), Rahman and Robson (2016), Mulyona and Nadirah (2016), and Lofton et al. (2012) highlight the potential of remote sensing for sugarcane crop yield estimation. Landsat imagery has been used globally for sugarcane crop yield estimation and monitoring. Examples include Abbas and Hag (2013), in the New Halfa, Elhag and Abdelhadi (2018) in South Africa and Henry (2017), in Indonesia.

Sugarcane yield prediction can be undertaken using different approaches, such as the use of a sugarcane growth model based on the Normalized Difference Vegetation Index (NDVI), one of the vegetation indices that are derived from visible and near-infrared channels (Gumma *et*

al., 2016). NDVI is a measurement of the greenness of a given area, thus in the long term NDVI provides an indication of the trend of intensity of any agricultural activity.

Vegetation indices (VIs) that have specific features concerning the range of vegetation cover have been developed. These indices indicate the amount of vegetation cover and/or intensity, as well as distinguish between vegetated and non-vegetated areas (Panda *et al.*, 2010). The NDVI stands out among the vegetation indices and is regarded as an all-purpose index. It is simple to calculate, has the best dynamic range and the best sensitivity to changes in vegetation health and cover (Geilen and de Wit, 2001; Andrew *et al.*, 2000; Singh *et al.*, 2002; Johnson *et al.*, 2017; Davey, 2018). Also, it can be used to provide weekly vegetation maps, monitor vegetation changes and estimate biomass (Panda *et al.*, 2010; Xue, 2017; Bramley, 2015; Somard *et al.*, 2018).

This highlight how remote sensing has provided farmers and researchers with a cost-effective alternative to the use of primitive field-based methods of agricultural monitoring (Rokhmana, 2015), which are usually time-consuming and costly. The technology gives accurate information of agricultural activities such as different crop identification and classification (Johnson, 2013; Son *et al.*, 2017; Lai *et al.*, 2018), crop condition/health monitoring, crop growth, crop area and yield estimation (Azzari *et al.*, 2017), mapping of soil characteristics, precision farming (Baumann, 2009; Vibhute and Gawali, 2013) and crop status assessment (Gitelson *et al.*, 2012; Simic Milas and Vincent, 2017). In most cases ability to pin down crop production problems and launch timely intervention strategies leads to higher profitability.

Even though the technology has been widely used for agricultural monitoring, and specifically for sugarcane crop yield estimation, there is no general agreement on the critical spectral regions to use for agriculture and the sensor specifications for a dedicated, orbiting agricultural sensor. Similarly, even though NDVI has been used for different purposes, there has been minimal research on the use of remote sensing for sugarcane crop yield estimation in Eswatini. Thus, the aim of the study was to investigate the potential use of remote sensing data for sugarcane crop yield estimation in the country, and in the process explore the appropriateness of Landsat data for sugarcane crop yield estimation in Eswatini.

2. Study Area

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The study area is Siphofaneni, an area located in the eastern part of Eswatini. It is about 50 km from the city of Manzini, and about 68 km away from capital city of Mbabane (Dlamini, 2012). It lies between longitudes 31°32'0" E and 31°50'0" E, and latitudes 26°42'0" S and 26°52'0" S, with an altitude of 164m above sea level (Dlamini, 2015). Dlamini (2015) further noted that the area lies on the banks of one of the largest rivers in the country, the Usutu River.

Siphofaneni is one of the warmest areas in Swaziland with average summer temperature of 32.2 °C, and its climate is classified as a subtropical steppe (low-latitude dry), with a subtropical dry forest biozone (Dlamini, 2012). The vegetation is savanna, and dominated by acacia tree species. The dominantly grown crop in the area is sugarcane (Figure 1), which is irrigated over an area of about 6500 ha. This is as a result of the poverty alleviation initiative called Lower Usuthu Smallholder Irrigation Project (LUSIP) which assisted the establishment of 54 farmers companies in the project area, with 2 745 shareholders (SWADE, 2017).

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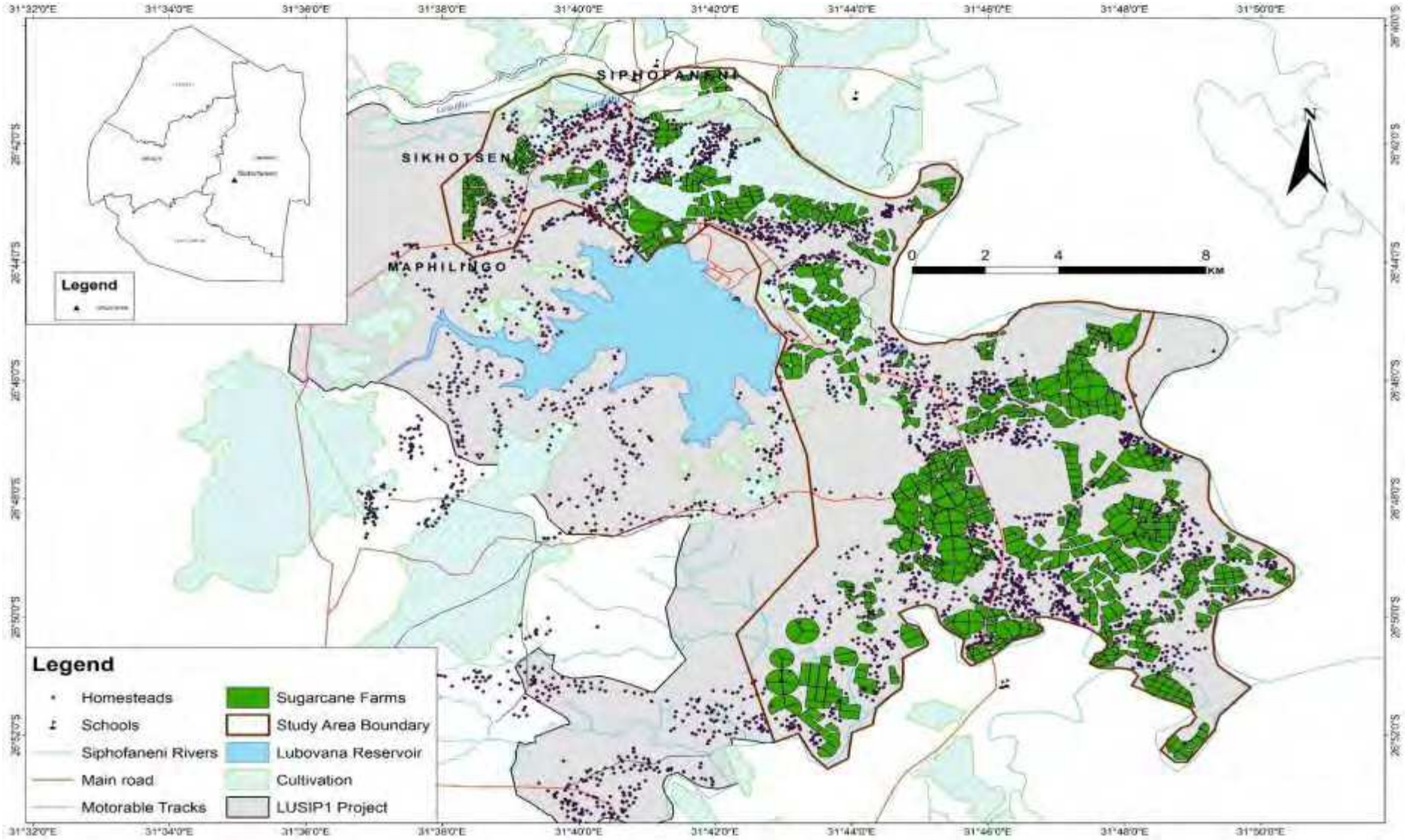

Figure 1: LUSIP 1 sugarcane fields in Siphofaneni, Eswatini

3. Datasets

12 Landsat 8 OLI atmospherically corrected analysis ready data (ARD) from 2013 to 2016 over LUSIP sugarcane farms (Path 168 and Row 79) were acquired from United States Geological Survey (USGS) Earth Explorer (USGS, 2013). Landsat 8 OLI is an American Earth observation satellite launched on 11th February 2013. It is the eighth satellite in the Landsat program, with a temporal resolution of 16 days, a spectral resolution of 11 bands and a spatial resolution of 30 m, and a radiometric resolution of 8 bits (Mabaso, 2015).

Actual sugarcane crop yield statistics for the years 2013 – 2016 were sourced from Eswatini Water and Agricultural Development Enterprise (ESWADE). The time frame of the study was influenced by data availability both from ESWADE and USGS Earth Explorer. Crop yield data records only started from the year 2011 and went up to the year 2016, while there were no appropriate Landsat imagery over the study area for the years 2011 and 2012. For the latter, Landsat 8 was launched in 2013, Landsat 7 images have gaps and scan lines, which makes its imagery inappropriate for use, and Landsat 5 satellite ceased operation in 2011 (Jensen, 2013).

4.0 Methods

4.1 Data pre-processing

Landsat 8 level 2 individual bands images were stacked together using winRAR layer stack module to form a floating scene and to group the bands together. After layer stacking, images were clipped from the Landsat tile to remove unnecessary data (Figure 2). Image enhancement was performed on the clipped images, which according to Jote (2017), is a process undertaken to process a given image so that the result is more suitable than the original image for a specific application. A non-linear enhancement method was used, where the original histogram was redistributed so that each brightness level has approximately equal number of pixels (Ehlers, 2000). Due to low level of cloud cover over the study area, cloud masking was not conducted. Jia et al., (2014) states that there is no universal way to pre-process data for land cover and land use mapping but the decision is made based on the specific needs of the data you have access to. In Beijing, Jia *et al.*, (2014) used Landsat 8 imagery without pre-processing and the same was adopted for this study.

Figure 2: Clipped true colour image before pre-processing

4.2 Computation and extraction of NDVI values

According to Tucker (1979), NDVI divides the difference between reflectance values in the visible red and near-infrared wavelengths by the overall reflectance in the wavelengths to give an estimate of green vegetation abundance. It also isolates vivid increase in reflectance over the visible red to near infrared wavelengths, and normalizes it by dividing by the overall brightness of each pixel in those wavelengths. From each image, NDVI was extracted in ArcGIS 10.5.1 software using the formula: $NDVI = (\frac{(N}{\quad})$

Thereafter, using the merge function tool, fields belonging to the same company were merged together. This was then followed by performing zonal statistics in order to derive the average NDVI values for each farmers company.

4.3 NDVI values and sugarcane crop yield correlation

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The actual sugarcane crop yield and the extracted average NDVI values were coded into Statistical Package for the Social Sciences (SPSS) software, and subjected to linear regression analysis. This was undertaken at four levels; crop yield and NDVI values per company per month, crop yield and NDVI values per company per year, crop yield and NDVI values for the whole of the LUSIP project per month, as well as crop yield and NDVI values for the whole LUSIP project for each year. Scatter plots were produced with the NDVI values being the independent variable and the sugarcane crop yield values being the dependent variable.

5.0 Results

5.1 NDVI Maps for LUSIP Sugarcane Farms at Siphofaneni

NDVI maps for the LUSIP Sugarcane farms at Siphofaneni were produced. Each NDVI map indicates the NDVI range of the sugarcane crop. For the year 2013-2016 the lowest NDVI value was -0.0959515 and the highest value was 0.551159 (Figures 3, 4, 5 and 6).

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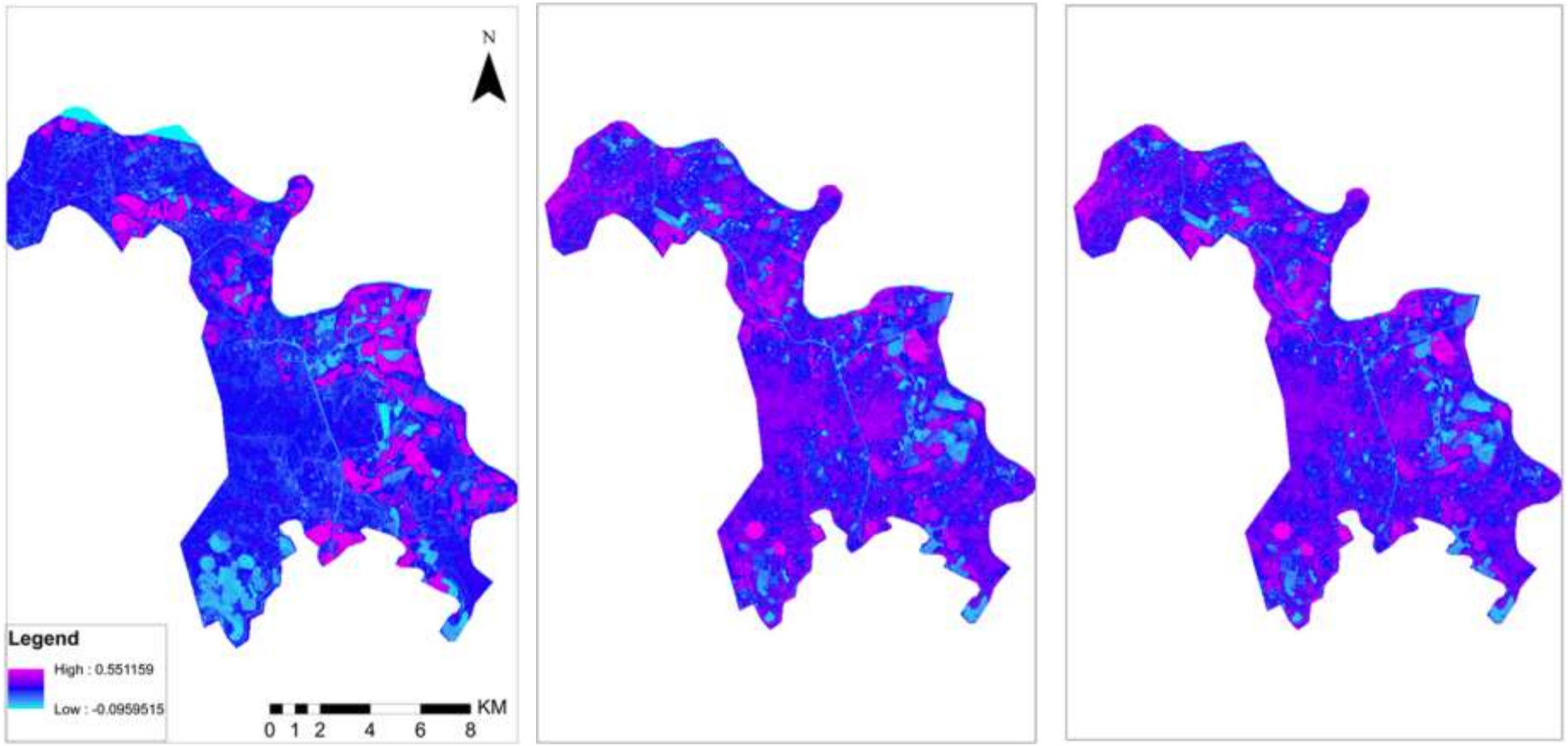
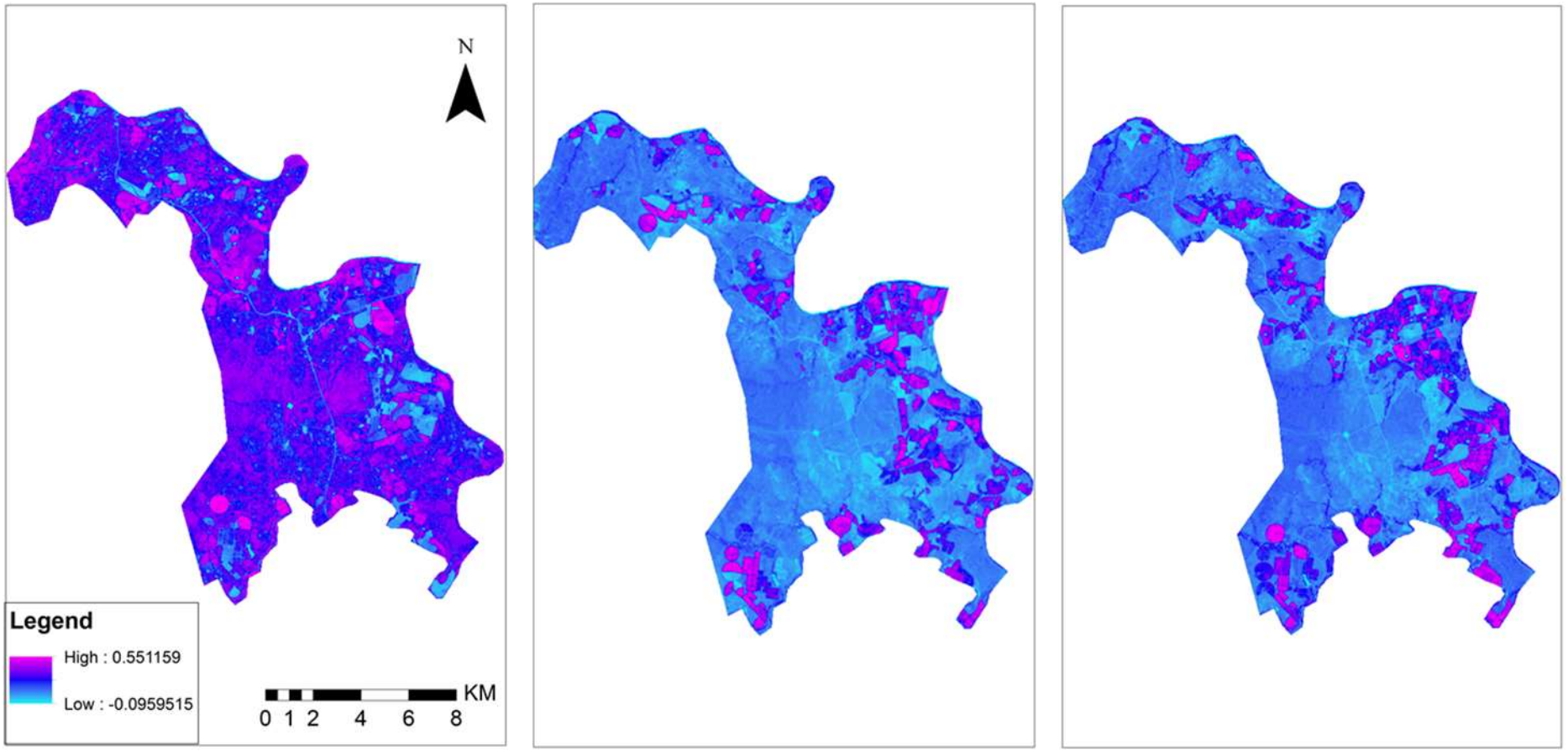


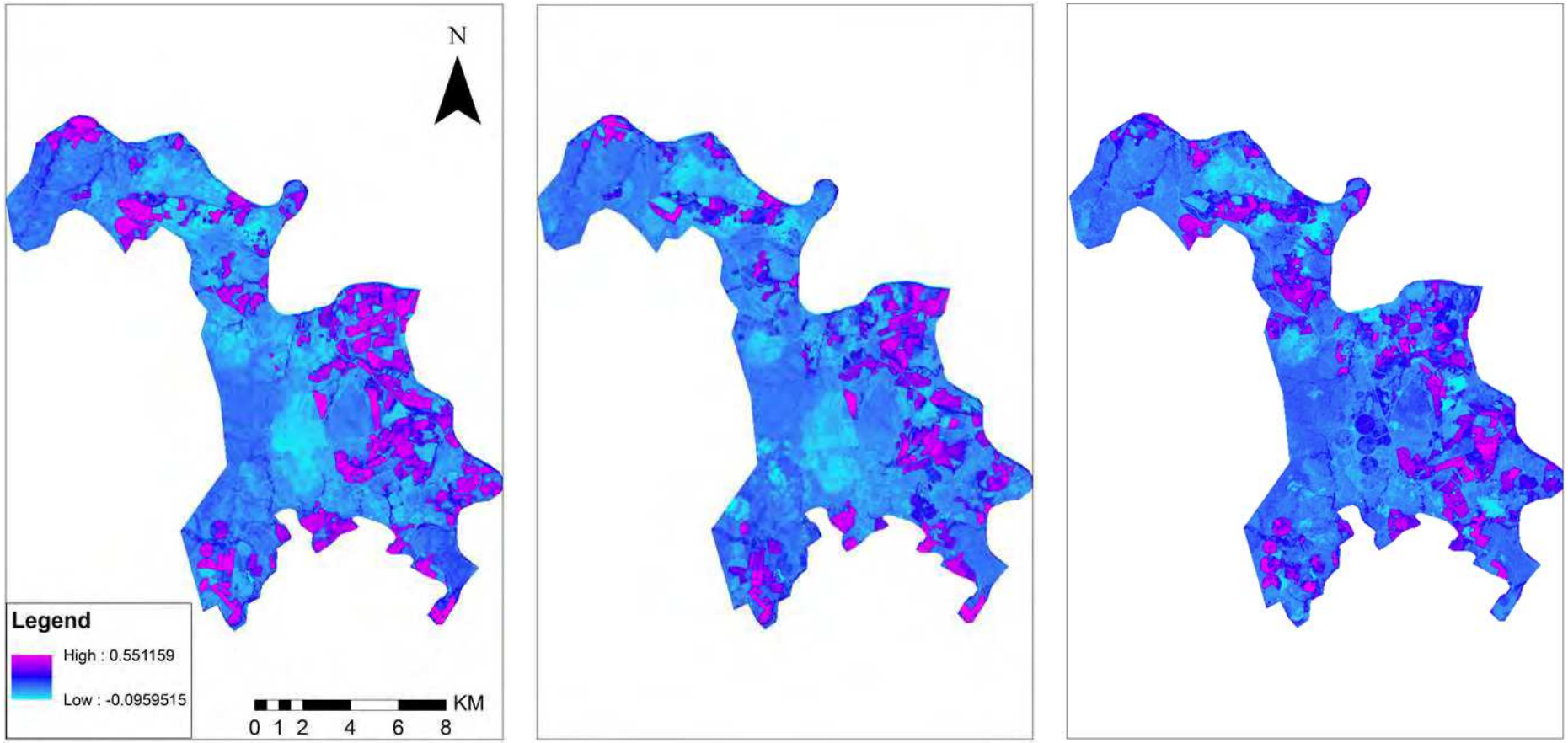
May August November

Figure 3: NDVI maps for LUSIP project sugarcane farms for 2013



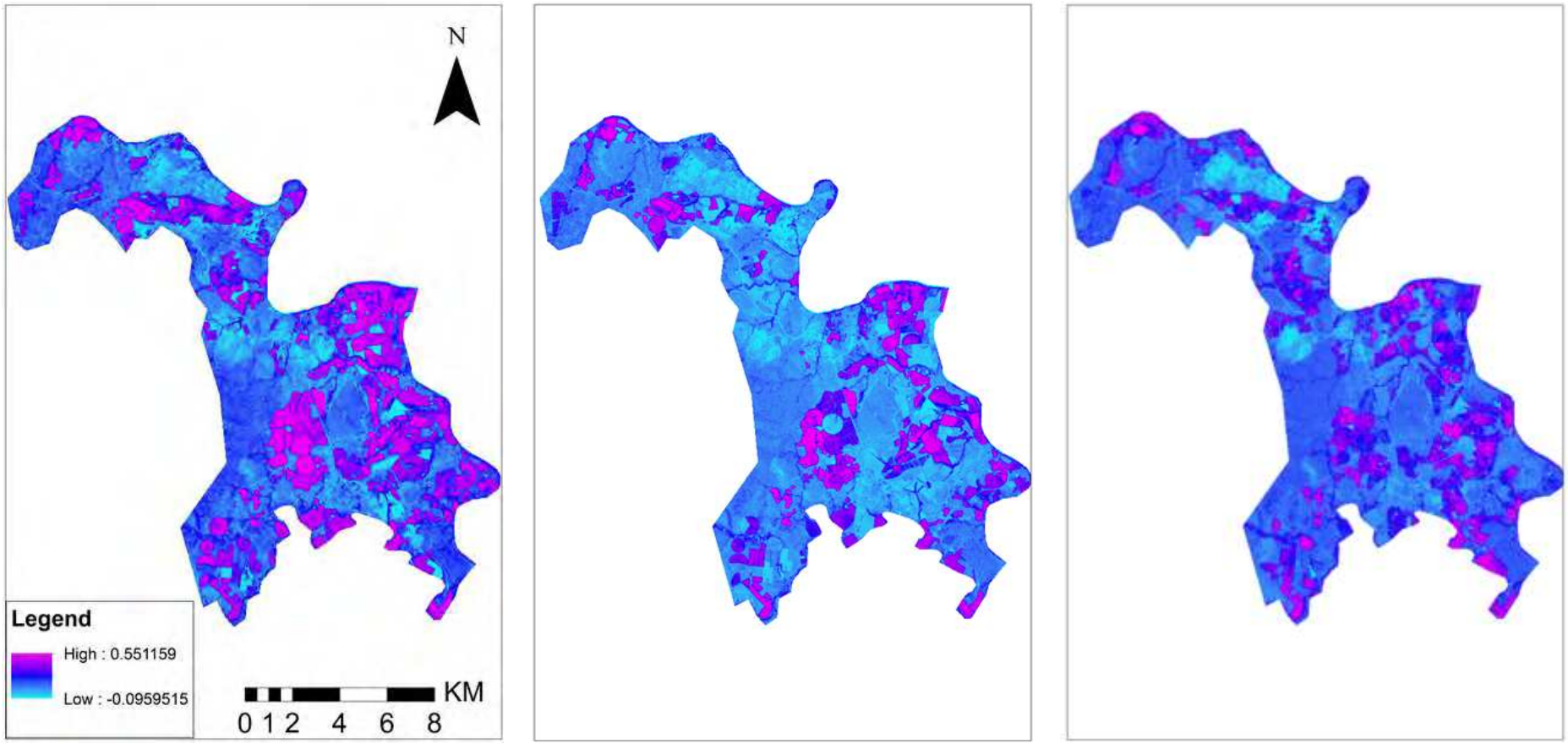
May August October

Figure 4: NDVI maps for LUSIP project sugarcane farms for 2014



May August November

Figure 5: NDVI maps for LUSIP project sugarcane farms for 2015



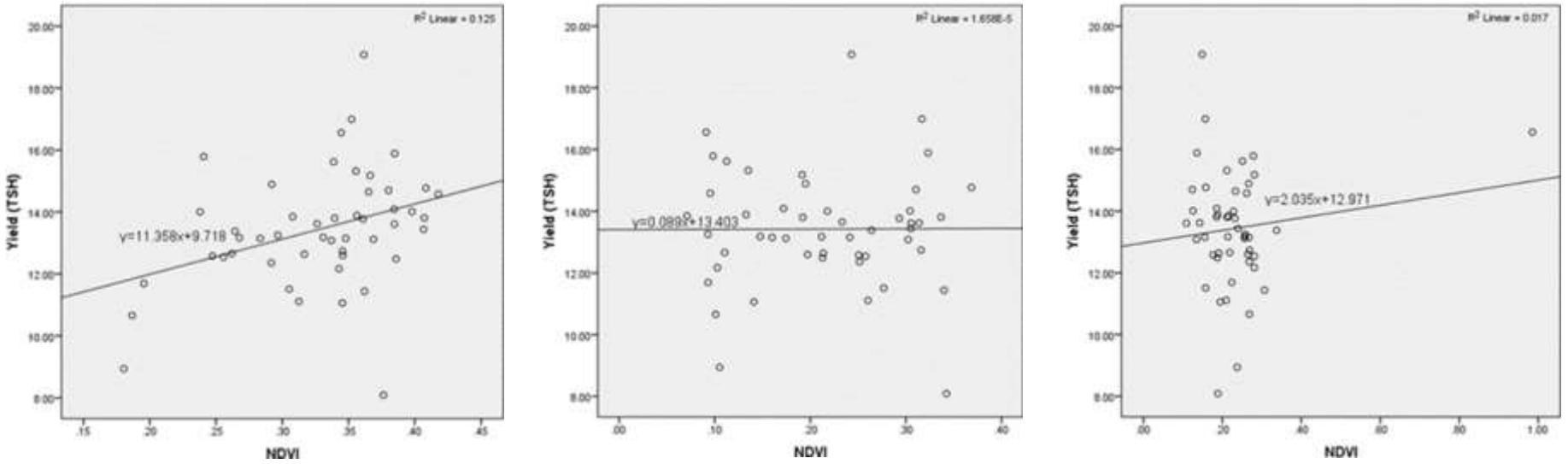
May August October

Figure 6: NDVI maps for LUSIP project sugarcane farms for 2016

5.2 Relationship between NDVI and sugarcane crop yield in the LUSIP project

5.2.1 NDVI and crop yield correlation for each month in each year per farmers company

First, for each farmer company NDVI and yield values correlation was found for the three respective months in each year. For the year 2013 a correlation of $R^2 = 0$ in May, $R^2 = 0.134$ in August, $R^2 = 0.108$ in November was found. For the year 2014 the correlations were $R^2 = 0.043$ for May, $R^2 = 0.005$ for August and $R^2 = 0.013$ for October. For the year 2015 the correlations were, $R^2 = 0.140$ for May, $R^2 = 0.023$ for August and $R^2 = 0.025$ for November. Figure 5.7 shows the correlations between NDVI and sugarcane crop yield values. Lastly, for the year 2016 the correlation was found to be $R^2 = 0.125$ for May, $R^2 = 0.000$ for August and $R^2 = 0.017$ for October. Figure 7 shows the correlations between NDVI and sugarcane crop yield values for the respective months in 2016.

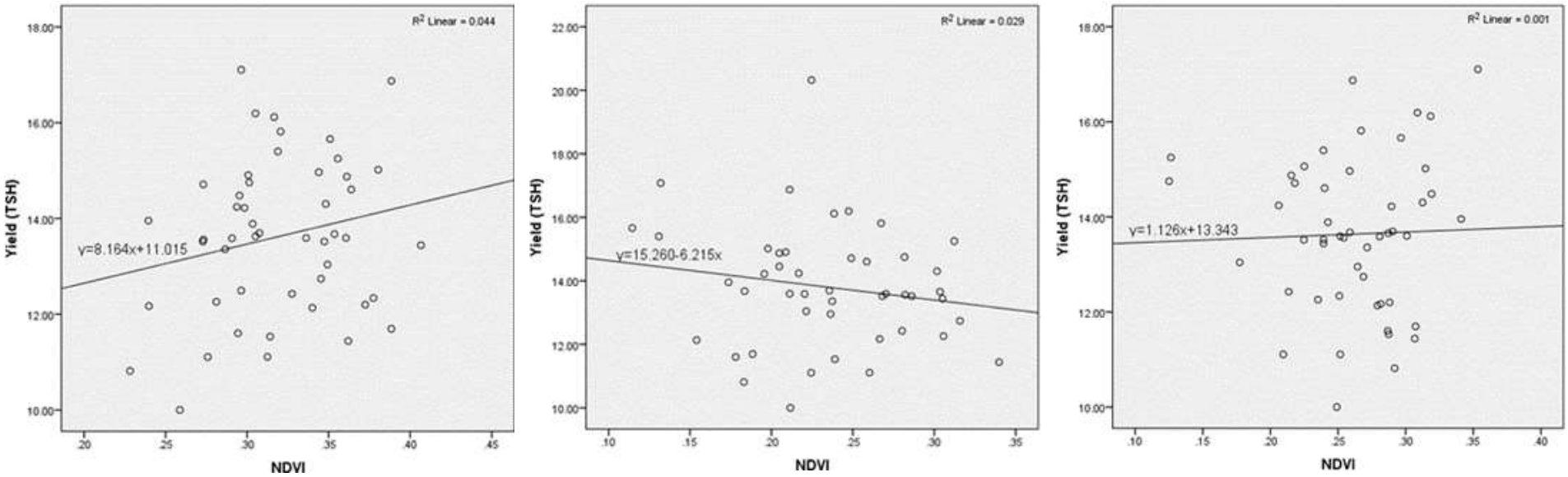


May August October

Figure 7: Correlation between NDVI and crop yield for farmer companies for 2016

5.2.2 NDVI and crop yield correlation for each month across all years of study per farmers company

NDVI and sugarcane crop yield values for the respective months for each farmer company were further averaged across the four years of study (2013 - 2016). The correlation values for May, August and November were found to be 0.044, 0.029 and 0.001, respectively. Figure 8 shows these correlations.

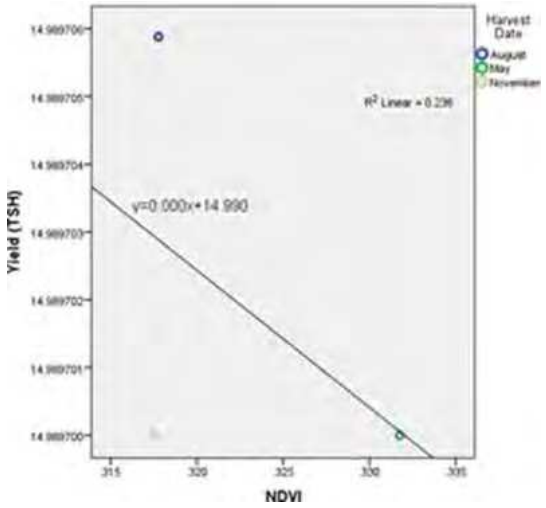


May August November

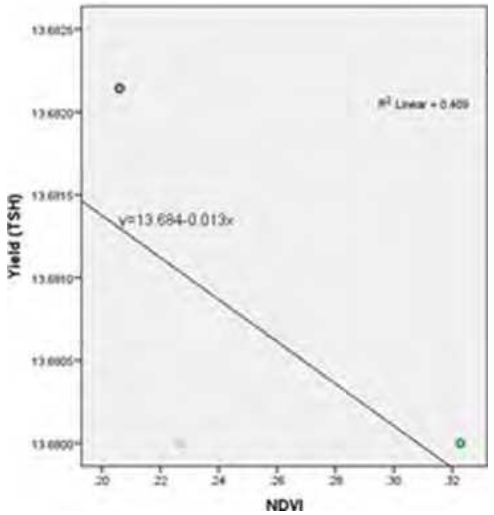
Figure 8: Correlation between NDVI and sugarcane crop yield for farmer companies per month across four years

5.2.3 Average NDVI and crop yield correlation for each month in each year for the whole project area

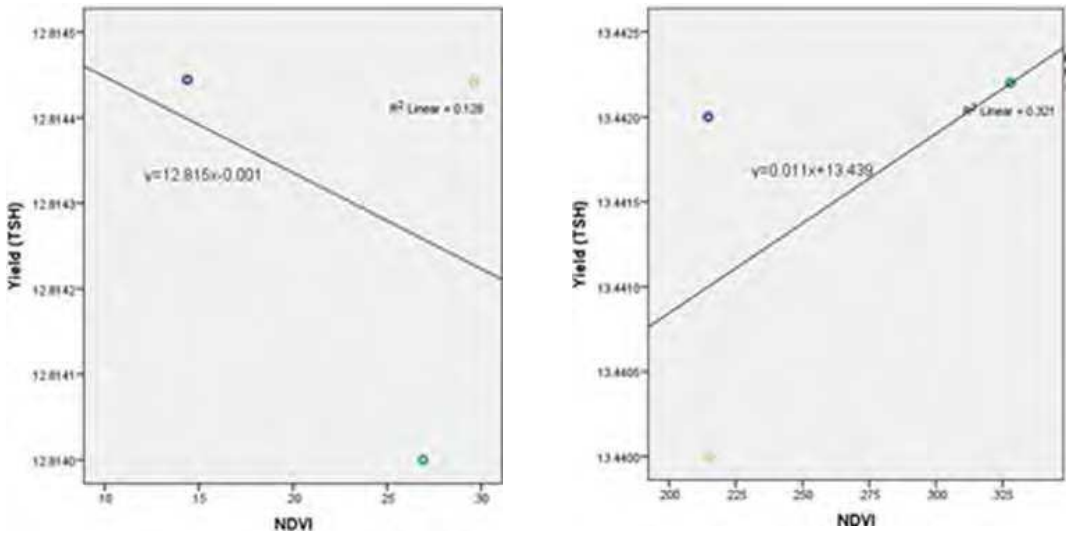
NDVI and sugarcane crop yield values were also averaged for the whole of LUSIP project per year, and the correlation values for the years 2013, 2014, 2015 and 2016 were found to be 0.236, 0.409, 0.128 and 0.321 respectively. These relationships are shown in Figure 9.



2013



2014

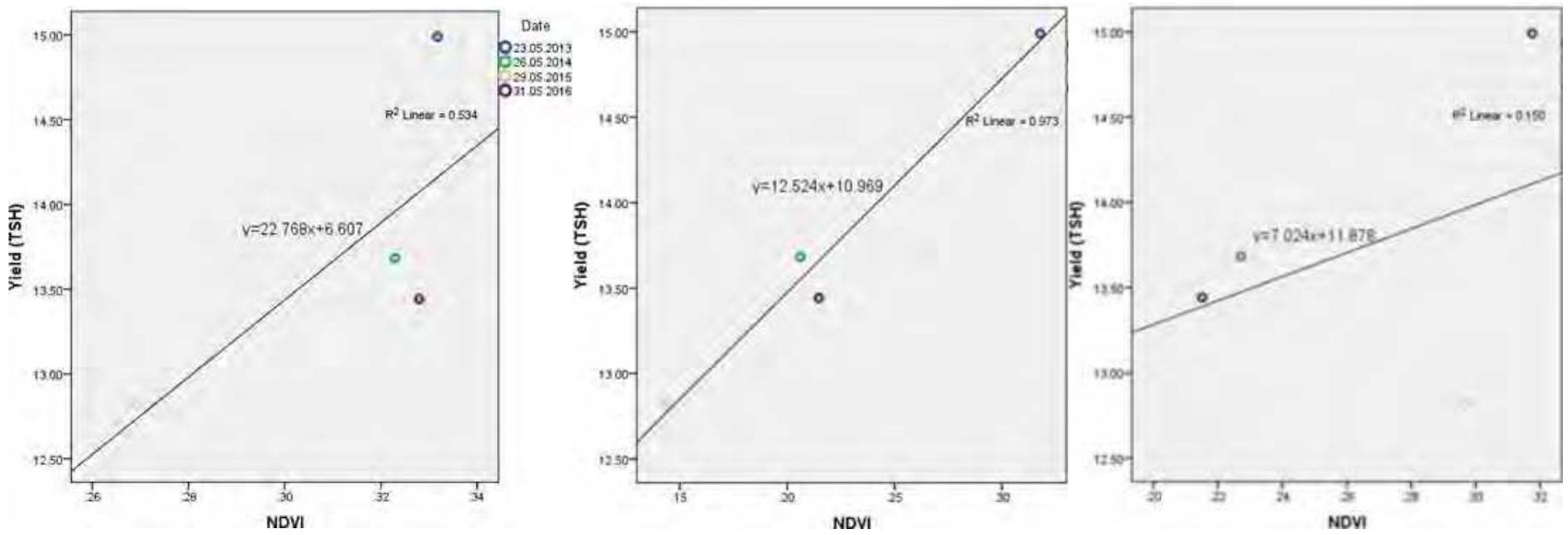


2015 2016

Figure 9: Correlation between averaged NDVI and crop yield values for the whole of farmer companies at LUSIP, Siphofaneni 2015 and 2016.

5.2.4 Average NDVI and crop yield correlation for each month in across the years for the whole project area

Averaged NDVI and yield values correlation was found for the three respective months across the four years of study, and was found to be 0.534, 0.973 and 0.15 for the months of May, August and November respectively (Figure 10).



May August November

Figure 10: Correlation between averaged NDVI and crop yield values for the whole LUSIP project across the years per month

6. Discussion

6.1 Relationship between NDVI and sugarcane crop yield in Eswatini

The results of the study indicate that for the three respective months across the four years of study, there were very weak correlations at individual farmers level of analysis. When the relationship between sugarcane actual yield data and NDVI values were considered at sugarcane farmer company level for each of the respective individual months, a weak correlation was found. The was in line with other studies such as Caudill (2000) who reported no relationship between NDVI and sugarcane crop yield at farm level in South Africa.

Mulianga *et al.* (2013) and Gunnula *et al.* (2011) averaged the yield values and NDVI values for each company across the years of study, and the reported a slight improvement on correlation. The same approach was explored in this study, whereby the crop yield and NDVI values for each month and each farmer company was averaged. A slight improvement was noted in the correlation, even though it was not significant. These findings are in agreement with Bastidas (2007) and Jurecka and Zdenek (2016) in Czech Republic who averaged the yield and NDVI values for each farmer company and concluded that the strength of the correlation increases when considered at a larger scale. Likewise, Bastidas-Obando and Carbonell-Gonzalez (2007) who found no relationship between average NDVI and farmers' yield in Colombia.

Averaging the crop yield values and NDVI values across the whole LUSIP project scale area by each month yielded the strongest correlation. For the month of May, R^2 was found to be 0.534, 0.973 for August, and 0.150 for November. Results were notably in line with previous studies such as Hadsarang and Sukmang (2000), Uemo *et al.* (2005), and Rudorff and Batista (1990), which all depicted that two months before harvest is the best period for sugarcane crop yield estimation. Dlamini (2012) also reported that the maximum NDVI is reached about two months before harvest begins. Begue *et al.* (2010) also reported a correlation of 0.98 two months before harvest period.

Lastly, when averaging the crop yield values and NDVI values across the LUSIP project area across the years, a significant improvement in the correlation was noted, but this was not as strong as when the averaging was done by month. The correlation ranged from 0.128 to 0.409 marking a notable improvement in the relationship.

6.2 Appropriateness of Landsat imagery for sugarcane crop yield estimation in Eswatini

The results showed that NDVI derived from Landsat imagery yielded stronger correlation in the month of August compared to the months of May and November. Moreover, this correlation improved greatly when considering large scale areas, compared to localised field level coverage. At individual farm level, the correlation was found to be very weak. Therefore, it was concluded that Landsat data is appropriate for sugarcane crop yield estimation in Swaziland at a large scale instead of farm levels.

7. Conclusion

Remote sensing has potential to be used to estimate crop yield in Eswatini. The study reveals that there was a weak relationship between NDVI and sugarcane crop yield level scale, but yield a very strong correlation at project area scale. Moreover, August imagery was found to be the best for crop yield estimation as it gave the strongest correlation compared to May and November imagery.

Post Conference Report

The conference brought together over 40 ICT professionals from the industry, Ministry of ICT, academia and students. Twenty Eight (28) papers were presented by the delegates that had come from various countries across the globe including Japan, Norway, Nigeria, Uganda, Kenya and South Africa.

Its opening ceremony was officiated by the Acting Vice Chancellor, Prof. Zwane and the Dean of the Faculty of Science and Engineering, Prof. Sandile Motsa. Prof. Wallace Chigona delivered his keynote address, and his address was followed by two plenary sessions and two parallel sessions.

Prof. Atsushi Ito and Prof. Christian Omlin delivered keynote addresses for the second and third days respectively. And each keynote address was followed by two plenary sessions and two parallel sessions. In the last days of the conference, the Acting Vice Chancellor presented gifts to the keynote speakers at a cocktail/gala night, and the delegates enjoyed a picnic and a game drive at the Hlane Game.

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In the closing remarks, Dr. Andile Metfula, the Head of Computer Science Department conveyed his gratitude to all delegates, particularly to the Technical Program Committee Chair (Prof. Agbinya), the Vice Chair (Prof. Adeyeye Oshin), the Keynote Speakers, the Paper Reviewers, the Session Chairs, the Delegates, the University Management, the Faculty Dean in his capacity as the Conference General Chair. He extended his thanks to the Local Organizing Committee headed by Dr. Fashoto for their efforts and expressed his satisfaction with the interactive nature of the discussions, while congratulating the delegates on the extensive networking that had taken place. He also announced that the next PACT conference will be taking place in Namibia.

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