IST-Africa 2022 Conference Proceedings
Miriam Cunningham and Paul Cunningham (Eds)
IST-Africa Institute and IIMC, 2022
ISBN: 978-1-905824-69-4

A Remote Blood Pressure Data Collection and Monitoring System for Expectant Mothers

Moses THIGA[1], Pamela KIMETO[2], Mvurya MGALA[3], Emmanuel KWEYU[4], Steve WANYEE[5], Tooroti MWIRIGI[6]
[1,2]Kabarak University, P.O. Box Private Bag, Kabarak, 20157, Kenya
Email: [1]mthiga@kabarak.ac.ke, [2]p_kimeto@kabarak.ac.ke
[3]Technical University of Mombasa, Kenya, Email mmgala@tum.ac.ke
[4]Strathmore University, Kenya, Email: ekweyu@strathmore.edu
[5]Intellisoft Consulting Ltd, Kenya, Email: swanyee@intellisoftkenya.com
[6]Emed Solutions Ltd, Kenya, Email: torootimwirigi@gmail.com

Abstract: Pre-enclampsia, a condition evidenced by persistent high blood pressure during pregnancy, can lead to the loss of both the mother and child, and often times persists beyond the delivery of the baby. Its early detection through regular blood pressure measurements can inform timely and life saving interventions for both the mother and baby. This study developed a system for remote blood pressure data collection and monitoring incorporating (i) a smartwatch with Photolethysmography (PPG) and Electrocardiogram (ECG) sensors, (ii) a mobile application for receiving the readings through bluetooth and (iii) a mobile application for use by caregivers, namely; ante natal clinic nurses, community health extension workers, community health workers and next of kin, to monitor the blood pressure readings for mothers assigned to them. The system demonstrates significant potential in the early detection of pre-eclampsia, which will in turn inform timely interventions to prevent fatal complications for both mother and baby.

Keywords: hypertension, pre-eclampsia, maternal, ambulatory blood pressure monitoring, photolethysmography sensors, electrocardiogram sensors

1. Introduction

Preeclampsia is a pregnancy complication characterized by persistent high blood pressure. It usually begins after 20 weeks of pregnancy in women whose blood pressure (BP) has been normal. The condition is often diagnosed when a mother goes to a healthcare facility for routine check where BP measurement is taken. Its first sign is a BP reading exceeding 140/90 in two or more occasions, at least four hours apart at 20 or more weeks gestation.

Pre-eclampsia affects about 8.2 % of pregnant mothers and if left untreated, progresses to eclampsia that is often fatal to both mother and baby [1]. In addition, it also impacts on the fetal growth and development leading to low birth weight, which is a predisposing factor for neonatal death [2] Its early prediction and management can therefore reduce both maternal and infant morbidity and mortality.

Pre-eclampsia remains a significant public health problem for both the developed and developing countries contributing to both maternal morbidity and mortality globally [3, 4]. However, the impact of the disease is felt more severely in developing countries [5] where unlike other causes of mortality, medical intervention may be ineffective due to late presentation [6].

In Low and Middle Income Countries most pregnant mothers depend on BP readings taken during antenatal clinic visits, which are 4-5 for the entire pregnancy. Early detection of preeclampsia is often missed during these visits because the BP measurement is often taken once unless otherwise indicated during the visit. In addition, regular data on the mother's BP readings in out of clinic settings is not available as there are no initiatives to take these measurements as well as the lack of personal BP machines and systems for this purpose.

This is in spite of the increased availability of smartwatches and other devices in the market for Blood pressure readings such as the Omron Smart watch [7, 8], and Bpro by MedTach Inc [9]. These devices are not only able to take readings and generate alarms but are also capable of transmitting this data to other devices such as mobile phones for use in further analysis using techniques such as machine learning.

2. Objectives of the Study

The objective of this study was therefore to develop a system integrating smart watches and and a mobile application for the remote collection of Blood Pressure data from expectant mothers and monitoring by caregivers in order to inform timely interventions.

3. Literature Review

A systematic review of 184 mobile applications on Dutch app stores for blood pressure monitoring established that while a great number of applications for blood pressure monitoring were available for use, their quality was low. This was attributed to low involvement of medical experts in their development with only 3.8% (7/184) of the apps mentioning the involvement of medical experts in their development. In addition, none of the apps were formally evaluated and results published. The study therefore recommended the involvement of medical experts in the development process of these applications in order to improve their quality and eventual adoption [10]

A study conducted by Musyoka (2020) on a sample of 50 pregnant mothers integrated the F1 smart armband and a mobile application for BP data collection and sharing it health care providers and family caregivers. The Internet of Things (IoT) system can inform antenatal practice in the future without the challenge of proximity and data loss challenges in monitoring pre-eclampsia among expectant mothers. The real-time data was sent to the caregivers' smartphone, as well as an alert [11]. The solution has shown a great potential for adoption in healthcare systems in developing countries, given its simplicity and affordability [12].

A 2020 study by Thiga, Kimeto & Kiptoo demonstrated that it is possible to integrate an application that has provision for the mother to input their activity when an abnormal BP is detected in a mother. This data would then be used to make machine learning predictions on when a mother was likely to experience abnormal blood pressure levels in the future. The study further recommended the use of a combination of blood pressure sensors given the challenges occasioned by the use of Photolethysmography (PPG) heart rate sensors on persons with dark skin pigment as well as the need to automate the readings in order to improve on the regularity of the data collection [13].

A systematic review published by the Korean Society of Hypertension in January 2021 reveals that the use of photoplethysmography-based algorithms paired with a smartwatches is increasingly gaining acceptance and utilization in the detection and management of Hypertension. The study however notes that there are still considerable discrepancies in the readings from these new and the more conventional approaches for measuring blood pressure. Scanty evidence in their effectiveness in managing hypertensive patients was also a concern noted in the study. It was therefore recommended that more collaborative work between researchers and industry be undertaken in order to evaluate the effectiveness and usability of these emergent approaches for hypertension management in the general population [14].

4. Methodology

The overall process to be adopted for the study was that developed by the Kenya Ministry of Health for the development of mHealth solutions presented in *Figure 2*. The implementation process provided for stakeholder involvement in the identification of priority issues and areas of intervention as well as their subsequent involvement in the development and system testing activities.

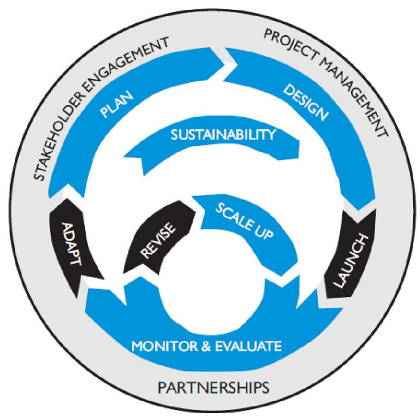


Figure 2: Ministry of Health MHealth development process [15]

4.1 Stakeholder Engagement

Stakeholder engagement was required for validating the challenges and designing a suitable solution. This engagement was undertaken using the Collaborative Requirements Development Methodology (CRDM) depicted in *Figure 3*.

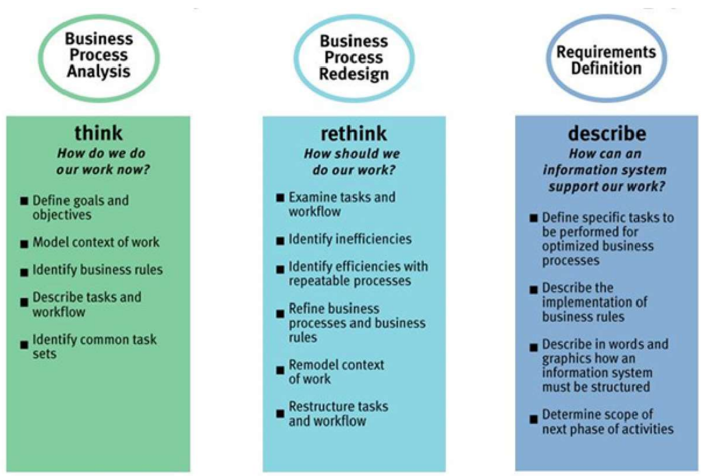


Figure 3: Collaborative Requirements Development Methodology [16]

In this regard four engagements were held with various stakeholders as follows;

Date	Group	Objective
30th November 2020	Nakuru Level 5 Hospital Maternal Health Team	Establish challenges in the maternal healthcare process from a care perspective.
8th January 2021	County Health Management Team	Establish challenges in the maternal healthcare process from a management perspective.
23rd July 2021	County Health Management Team	System Prototype Testing and requirements elicitation
30th July 2021	Nakuru Level 5 Hospital Maternal Health Team	System Prototype Testing and requirements elicitation

4.2 System Development

The system developed comprises of the following components as depicted in F*igure 4*.

i. A Smartwatch for the measurement of blood pressure
ii. A mobile application for
   a) The collection of demographic, blood pressure and activity data from expectant mothers.
   b) Preliminary analysis of blood pressure data to identify readings outside normal ranges.

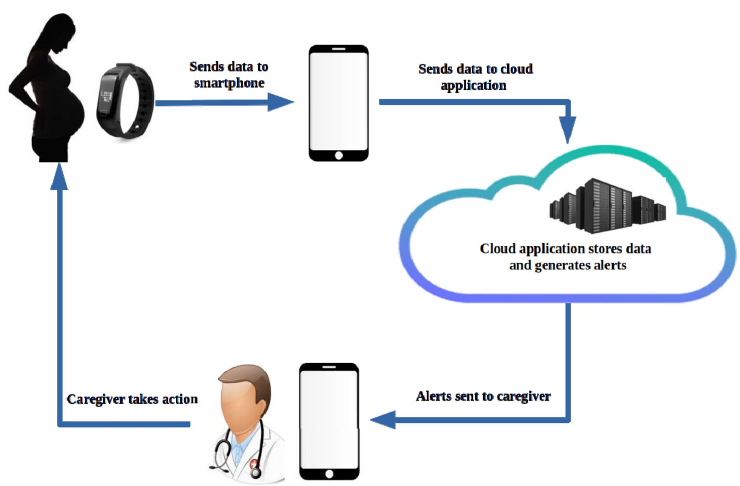


Figure 4: System model integrating a smartwatch, mobile application and cloud application for blood pressure measurement and analysis [17]

The system development adopted the rapid prototyping system development approach. The approach is suitable for the development of systems where extensive stakeholder engagement is required and for scenarios where system requirements have a tendency to evolve or emerge as the development process continues.

The mobile applications were developed using the Android programming language using a variety of Android Integrated Development Environments (IDE's) such as Android Studio and Eclipse. The web application development was undertaken using the Laravel PHP development framework.

5. Results

5.1 Stakeholder Engagement

Prior to the development of the solution, two stakeholder engagements were undertaken. Their key objectives and findings are as follows;

1. Maternal Health clinic at the Nakuru Level 5 Hospital - This engagement was held by the study team on 30th November 2020. The objectives of the engagement were to establish, from a point of care perspective, the challenges faced in the antenatal care process as well as to identify potential solution approaches. It was established that the manual approach to collecting maternal health data as well as the spaced out antenatal clinic visits presented a challenge in the early detection and management of pre-eclampsia.
2. County Health Management Team (CHMT) Meeting - This engagement was held on 8th January 2021. The objectives of the engagement were to establish, from a management perspective, the challenges faced in the antenatal care process as well as to identify potential solution approaches. It was established that pre-eclampsia was a leading cause of maternal mortality in Nakuru County but the county was limited in its ability to identify mothers at risk in good time for intervention.

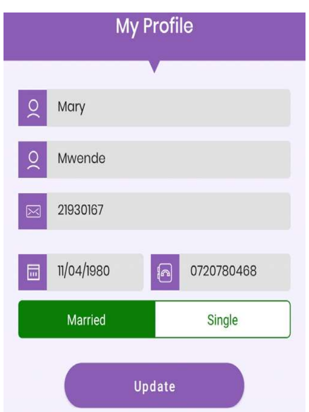
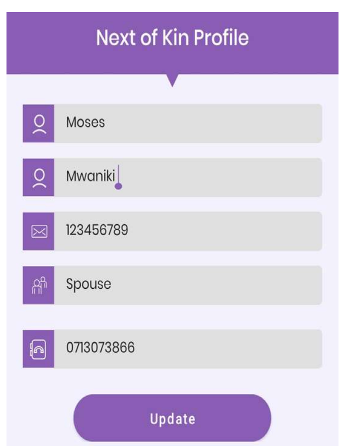
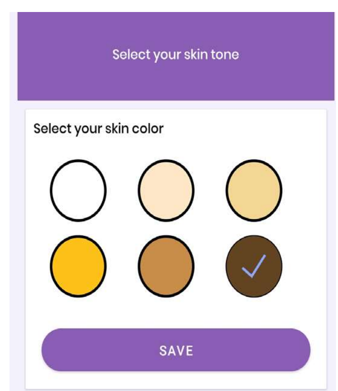
5.2 System development

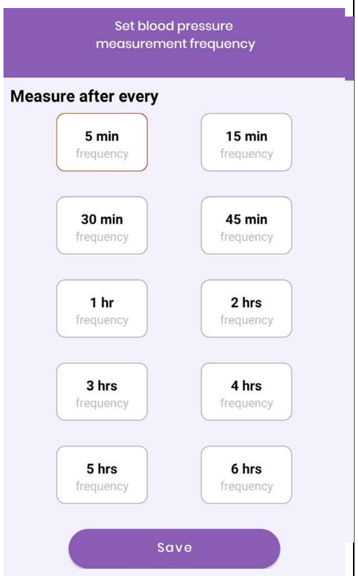
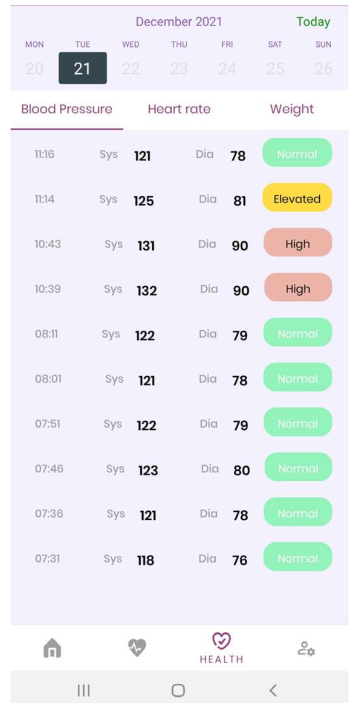
5.2.1 Stage 1 - Smartwatch identification

A suitable smartwatch (*GE-W74 supplied by Gold-East Ltd, https://www.gold-east.net/Products/info/id/10.html*) with bluetooth connectivity, a Photolethysmography (PPG) heart rate sensor and an Electrocardiogram (ECG) sensor was identified and procured.

5.2.2 Stage 2 - Development of a BP Data collection application for Mothers

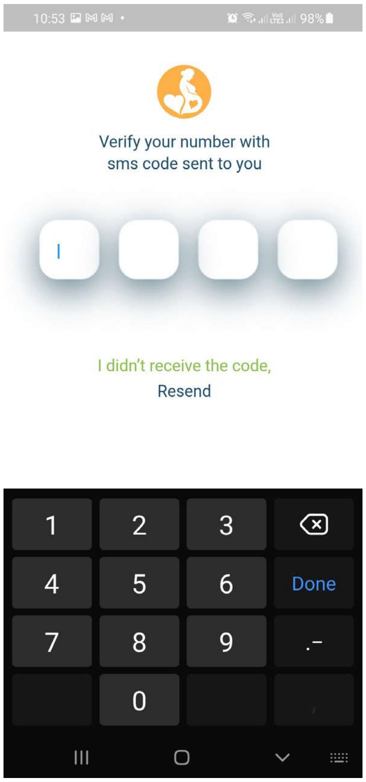
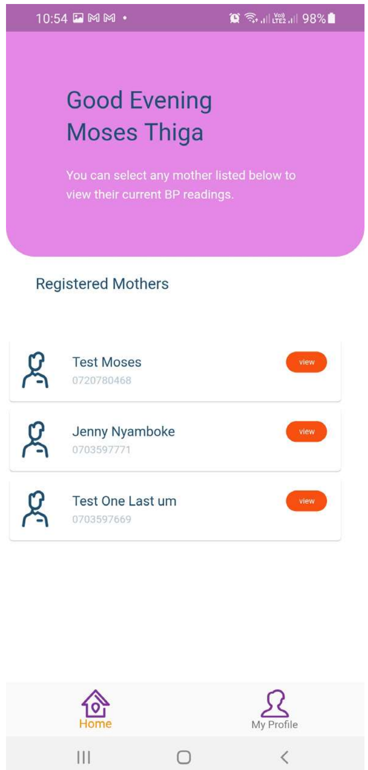
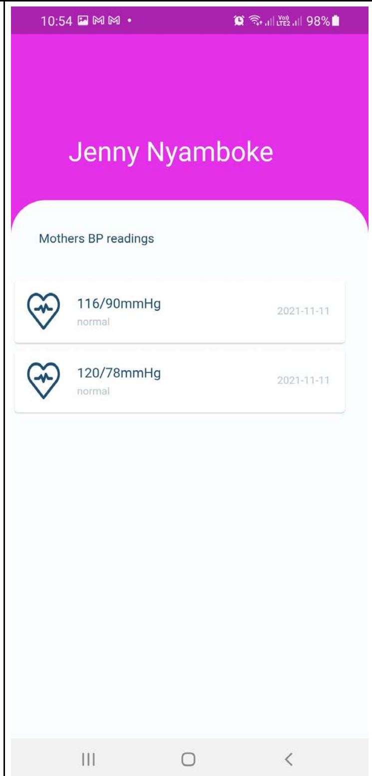
An Android application for the collection of blood pressure data using a smartwatch from the mothers was developed. The key steps followed in the application are as follows

<table>
<tr><th>Step 1 - Signup</th><th>Step 2 – Provide next of Kin details</th><th>Step 3 – Set Skin colour</th></tr>
<tr>
<td>
</td>
<td>
</td>
<td>
</td>
</tr>
</table>

<table>
<tr><th>Step 4 - Set reading interval</th><th>Step 5 - Take readings</th><th>Step 6 – View readings history</th></tr>
<tr><td>
</td><td></td><td>
</td></tr>
</table>

5.2.3 Stage 3 – Development of a BP data viewing application for caregivers

An Android application for the viewing of blood pressure data by Community Health Extension workers, Community Health Volunteers and Next of Kin was developed. The key steps followed in the application are as follows;

<table>
<tr><th>Step 1 - Signup</th><th>Step 2 - View Mothers List</th><th>Step 3 - View Readings</th></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
</table>

5.2.4 Stage 4 – Prototype Testing

Two engagements were held on the 23rd and 30th July 2021 with the CHMT and Nursing teams respectively to test the BP data collection system prototype. The prototype was found to be applicable in BP data collection from mothers. It was also established that there was need to involve community health extension workers and volunteers in the system use given the need to monitor mothers in out of clinic settings.

5.2.5 Stage 5 – Smartwatch Accuracy Testing

The smartwatch was tested between 21st and 22nd March 2022 to determine its accuracy in blood pressure reading with 20 participants. Its readings were compared with blood pressure readings from digital blood pressure machine and sphygmomanometer which is considered as the gold standard for the measurement of blood pressure. The participants were randomly sampled from among strudents in the School of Medicine and Health Sciences at Kabarak University.

A total of 60 blood pressure readings were collected from the 20 participants using the smartwatch, the digital BP machine and sphygmomanometer.

- The mean systolic and diastolic BP reading on the smartwatch was 118.0 (±3.84) and 76.15 (±3.47) respectively.
- The mean systolic and diastolic BP reading on the digital BP machine was 115.45 (±14.378) and 65.25 (±12.47) respectively.
- The mean systolic and diastolic BP reading on sphygmomanometer was 119.37 (±7.67) and 74.70 (±6.424) respectively.

One way ANOVA was done to determine the difference in systolic and diastolic BP readings between the smartwatch, the digital BP machine and sphygmomanometer. There was a significant difference in mean diastolic BP reading between the smartwatch and Digital BP machine ((α=0.05, p≤0.003). The smartwatch had mean diastolic BP of 118.0 (±3.84) compared to digital BP machine 115.45 (±14.378). There was no significant difference between the readings of the smartwartch and the sphygmomanometer.

6. Discussion

The solution developed demonstrated the ability to collect Blood Pressure data from expectant mothers in out of clinic settings and to further provide for monitoring of these readings by caregivers.

The solution developed demonstrated the following key improvements on previous efforts in the area of out of clinic blood pressure data collection and monitoring

1. Combination of sensors - The smartwatches selected for the blood pressure collection use a combination of Photolethysmography (PPG) and Electrocardiogram (ECG) sensors.
2. User customizations for data collection
   i. Reading frequency settings – The Mothers BP data collection application allows for customization of data collection intervals from 5 minute to 6 hour intervals.
   ii. Skin colour settings – The Mothers BP data collection application allows for customization of skin colour settings from light to dark skins to allow the Photolethysmography (PPG) heart rate sensor to work on all skin tones.
3. Involvement of community health workers and volunteers - The solution has an application for use by community health workers and volunteers. This inclusion allows them to receive realtime alerts on unusual BP readings from the system for the mothers assigned to them. This information enables them to intervene in a timely manner when there is danger.

7. Business Benefits

The key benefits of this solution are as follows;

1. Continuous monitoring of BP in out of clinic settings – The combination of the smart watch and application enables a mother to monitor their own blood pressure without the need to visit a clinic. This is convenient and also allows them to better manage their health.
2. Access of the BP data by caregivers and next of Kin – The availability of BP data by caregivers and next of kin allows them to be able to assist an expectant mother in the event that a very high or low blood pressure is detected.

8. Conclusions

The key achievements from this study are the successful integration of a smart watch and mobile application for BP readings collection and the development of a caregiver application that allows them to access BP data for an expectant mother.

The key step that follows from this study is the piloting of the solution with expectant mothers, nurses and community health volunteers. This will help to establish how the system performs in an actual use scenario.

A key recommendation from the study is the need to identify GSM watches for BP reading transmission in areas with poor Internet coverage and for mothers who cannot afford smart watches.

Acknowledgements

This work has been made possible with funding from the Kenya National Research Fund, the Artificial Intelligence for Development (AI4D) Program of the International Development Research Centre (IDRC) through the Knowledge for all Foundation (K4A) and the Kabarak University Research Fund.

References

[1] Macdonald-Wallis, C., Silverwood, R.J., Stavola, B.L, de, Inskip, H., Cooper, C., Godfrey, K.M., Crozier, S., Fraser, A., Nelson, S.M., Lawlor, L.A., and Tilling, K. (2015) Antenatal blood pressure for prediction of pre-eclampsia, preterm birth, and small for gestational age babies: development and validation in two general population cohorts. *British Medical Journal.* https://doi.org/10.1136/bmj.h5948.

[2] Sufriyana, H., Wu, Y.-W., & Su, E. C.-Y. (2020). Artificial intelligence-assisted prediction of preeclampsia: Development and external validation of a nationwide health insurance dataset of the BPJS Kesehatan in Indonesia. *EBioMedicine*, *54*, 102710. https://doi.org/10.1016/j.ebiom.2020.102710

[3] McClure, E. M., Saleem, S., Pasha, O., & Goldenberg, R. L. (2009). Stillbirth in developing countries: A review of causes, risk factors and prevention strategies. *Journal of Maternal-Fetal & Neonatal Medicine, 22*(3), 183-190. Doi: 10.1080/14767050802559129

[4] Shah, A., Fawole, B., M'Imunya, J. M., Amokrane, F., Nafiou, I., Wolomby, J., Wolomby, J. (2009). Cesarean delivery outcomes from the WHO global survey on maternal and perinatal health in Africa. *International Journal of Gynecology & Obstetrics, 107*(3), 191-197. doi:10.1016/j.ijgo.2009.08.013

[5] Prakash, J., Niwas, S. S., Parekh, A., Pandey, L. K., Sharatchandra, L., Arora, P., & Mahapatra, A. K. (2010). Acute kidney injury in late pregnancy in developing countries. *Renal Failure, 32*(3), 309-313. doi:10.3109/08860221003606265

[6] Jido, T. A., & Yakasai, I. A. (2013). Pre-eclampsia: A review of the evidence. *Annals of African Medicine, 12*(2), 75-85. Doi: 10.4103/1596-3519.112395

[7] Omron (2019) Omron Heart Guide. https://omronhealthcare.com/products/heartguide-wearable-blood-pressure-monitor-bp8000m/. Accessed 24th February 2019.

[8] Aktiia (2018) Re inventing Blood Pressure Monitoring. https://aktiia.com. Accessed 24th February 2019.

[9] Medtach Inc (2018) ABPM Made Simple. *https://www.medtach.com/bpro.html* Accessed 24th February 2019.

[10] Jamaladin, H., van de Belt, T. H., Luijpers, L. C., de Graaff, F. R., Bredie, S. J., Roeleveld, N., & van Gelder, M. M. (2018). Mobile Apps for Blood Pressure Monitoring: Systematic Search in App Stores and Content Analysis. *JMIR mHealth and uHealth*, *6*(11), e187. https://doi.org/10.2196/mhealth.9888.

[11] Musyoka, F. M (2020). *Performance Evaluation of Internet of Things Prototype for Preeclampsia Monitoring in Antenatal Care*. International Journal of Engineering and Advanced Technology (IJEAT). ISSN: 2249-8958, Volume-10 Issue-2, December 2020.

[12] Musyoka, F. M., Thiga, M. M., & Muketha, G. M. (2019). A 24-hour ambulatory blood pressure monitoring system for preeclampsia management in antenatal care. *Informatics in Medicine Unlocked*, *16*, 100199. https://doi.org/10.1016/j.imu.2019.10019

[13] Thiga, M,. Kimeto, P., and Kiptoo, D (2020) *Collecting Blood Pressure and Activity Data Using an Integrated Mobile and Smartwatch Application*. Proceedings of the Kabarak University International Research Conference on Computing and Information Systems. 5th - 9th October 2020 Nakuru, Kenya.

[14] Lee, H.Y., Lee, DJ., Seo, J. *et al. Smartphone / smartwatch-based cuffless blood pressure measurement : a position paper from the Korean Society of Hypertension*. *Clin Hypertens* 27, 4 (2021). https://doi.org/10.1186/s40885-020-00158-8

[15] Ministry of Health, Kenya (2017) Kenya Standards and Guidelines for mHealth Systems.

[16] Taylor, C., Luchitsky, A., Lubinski, D., Peloso, L., & Wilson, K. (2012). *Common Requirements for Maternal Health Information Systems*. Retrieved from https://www.path.org/resources/common-requirements-for-maternal-health-information-systems-produced-with-the-collaborative-requirements-development-methodology/

[17] Mueni, F., Thiga, M., and Muchiri, G.M., (2018) A Blood Pressure Monitoring Prototype for Preeclampsia Management in Antenatal Care in Kenya. Proceedings of the Kabarak University International Conference on Health Sciences. October 22nd - 26th 2018.