Design of an IoT Based Monitoring System for Expectant Rural Women in Developing Countries

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***Abstract*—Maternal and child deaths due to pregnancy-related complications are still a huge concern and more prevalent in developing countries. Early detection of complications can help avoid many of the reported cases. Due to long distances to nearby health facilities, lack of knowledge, and poverty, the majority of expectant mothers in rural developing nations are still adamant about prioritizing their health during this very sensitive period. This study aimed at designing and prototyping a system intended to help improve maternal health in rural areas of developing nations. This can be achieved by providing a relatively easy way to monitor the health of expectant mothers remotely and provide vital information in the form of periodic tips with automatic alerts and tracking in case of missed clinical appointments. Therefore, an architecture for context awareness and an IoT-based system is proposed to improve pregnancy monitoring in Africa and thus reduce fatalities and complications. The system uses a pulse sensor, temperature sensor, and GPS module to collect data with an Arduino as the microcontroller. The collected data is sent to the cloud using the GSM module. The cloud data is stored, processed, analysed, and then sent to the health worker. In case of any health complication or an appointment is missed, the health officials are alerted in real-time. This system will ensure a timely response in an emergency, thus leading to better health and contributing to sustainable development goals.**

Keywords—IoT, Health Monitoring System, Health Information System, Pregnancy Monitoring, IoT in Healthcare

I. INTRODUCTION

According to WHO, in 2017, a worldwide estimation of 295,000 women died from pregnancy and childbirth-related complications. The most significant percentage (about 94%) of these deaths were from low-income areas, with sub-Saharan Africa alone accounting for more than two-thirds of these deaths. WHO further stretches that most of these deaths could be prevented if proper care is administered, especially during pregnancy [1].

The average gestation period is 280 days, approximately 40 weeks. During this period, a woman is required to take most care of their health for the good of themselves and the unborn child's life as their bodies become extra sensitive and the chances of developing several complications increase. Doctors recommend that a pregnant woman carry out routine check-ups during which various parameters, for example, body weight, temperature, blood pressure, heart rate, and foetal movements, are recorded and analysed to determine the health of both the mother and unborn child. This reduces the chances of pregnancy-related complications that could endanger the lives of the mother and child [2].

These complications can be due to the pressure that comes with carrying a pregnancy, such as high blood pressure, bleeding, weight gain, and others, which may significantly impact the internal organs of the expectant mother. It is also recommended that expectant mothers limit long-distance movements to avoid increasing the risk of these complications [3].

The Internet of things (IoT) enables device interconnection where physical and virtual things are connected and centralized data. IoT has proved to be very significant in the health care sector, especially now that the circumstances have changed due to the COVID19 pandemic, and social distancing is encouraged worldwide. Remote patient monitoring systems involve using various sensors within the medical equipment to continuously check different patients' parameters and have proved effective [4]. The topic of IoT and maternal health still have the potential for further exploitation to improve the current systems that have gaps and limitations. They are expensive, not easily accessible by people in developing nations, they also do not send health tips to users, and most lack alert and tracking capabilities.

Therefore, this study reviewed the existing systems in selected facilities in East Africa, proposes an architecture for integrating IoT into existing systems for African health facilities, and designs a prototype for such a system. Data on existing solutions, perceptions, and challenges were collected from mothers, health officials and system managers in selected facilities across east Africa using questionnaires, interviews, and document reviews. The proposed architecture and system will go a long way toward enhancing the integration of IoT into pregnancy monitoring and, thus, more context-aware solutions leading to better service provision and ultimately reducing deaths and complications during pregnancies.

The system employs sensors, the body temperature sensor, the pulse sensor, and the GPS module. These sensors collect data from the pregnant mother, which is instantly sent to the cloud using the GSM module. The data is stored, processed, analysed, and sent to the health worker from the cloud in real-time, who in turn responds accordingly. This system also provides alerts and information periodically to the expectant mother to keep her informed about her health and as a reminder of when her next visit will be. The system used open-source technologies to ensure reduced costs. For example, the Arduino for hardware development and Arduino IDE also used the Things speak cloud platform for data storage, procession, and analysis.

The rest of the paper is organized as follows; the next section gives a brief literature review. Section III provides the research methodology. The system design and data analysis are presented in Section IV. In Section V, the system results are presented, and lastly, recommendations, conclusions, and future works are given.

II. LITERATURE REVIEW

This section reviews related literature concerning IoT in health care, pregnancy, and pregnancy monitoring, how it is currently done in remote communities, the challenges faced, and how they can be catered for. It also discusses the existing commercial solutions and the existing open prototypes.

A. IoT in HealthCare

As an aspect of IoT, Ubiquity enables the interconnection of devices equipped with sensors and microcomputers to communicate together. Like many industries, the healthcare industry is still benefiting from the IoT concept. For example, the hospital patient monitoring systems can communicate, take action, and upload information to the cloud [5]. This has brought so many benefits to the health care sector in terms of improved patients health, increased health workers' productivity, and reduced operational costs as IoT enables remote monitoring, which means fewer or no hospital visits and reduced costs [5]. The evolution of new technologies, for example, the 5G, AI, and Big Data will positively impact the growth of IoT in health care. They can provide ultra-low latency speeds and mobility and provide real-time decisions from AI algorithm data analysis, hence minimizing errors and improving treatment outcomes [5]. IoT is expected to revolutionize healthcare. According to Brandessence market research, the market is expected to exceed ten billion USD by 2024 [5].

B. Pregnancy Monitoring

Pregnancy is that period when a woman is expecting a baby. It is counted from the first day of the woman's last menstrual period [2]. The average length of the pregnancy or the human gestation is estimated to be 40 weeks or 280 days [2]. During pregnancy, a woman is likely to develop certain health problems which can affect the mother, the baby, or both. It is, therefore, important for every woman to undergo health care during pregnancy to reduce the risks of pregnancy-related complications [6]. Pregnancy complications range from person to person, depending on different factors. Some can be mild, and others severe and life-threatening. They range from physical to mental. Some complications are brought about by pregnancy, while others are made worse when pregnant and may harm the mother and the growing foetus [6]. When managed and monitored, most of these complications tend to go away. Therefore, it is recommended that every pregnant woman visits a health care provider to monitor their health during pregnancy [6]. The most common pregnancy complications include Anaemia, a complication connected to low red blood cells, Urinary Tract Infections, hypertension, and mental health conditions like depression and stress [6]. Such conditions can be preliminarily diagnosed. All these and other pregnancy-related complications can be fatal and life-threatening and need immediate attention.

Pregnancy monitoring also referred to as prenatal or antenatal care, is medical care given to women during pregnancy [7]. It is recommended that every healthy pregnant woman with no underlying medical issues carry out at least four visits at given intervals throughout their pregnancy lifetime [8]. During these visits, the health personnel discuss the expectant mother's health and that of the growing foetus and usually carries out various exams, including; physical exams, Blood pressure monitoring, urine sample tests, blood sample tests, foetal monitoring.

In most developing nations, especially in rural communities, pregnancy monitoring is done following mainly these approaches; the Traditional approach [9] and The Focused antenatal care (FANC) [10].

C. Existing Commercial Solutions to monitor pregnancy in developing nations

There are a number of commercial pregnancy monitoring systems used in Africa in place. Here, we discuss some of these: Maternal health Mobile Apps are one of the main ways used in sub-Saharan Africa to reduce the maternal mortality rate is using mobile apps. Developers across Africa have come up with mobile applications to help expectant mothers monitor their health. Here are some mobile apps used to save mothers' lives across Africa.

MumSpring is a Nigerian eCommerce start-up recently launched. It is a tracker app that provides reminders for expectant mothers on their upcoming examinations, provides prenatal care information on each stage of pregnancy, and connects the mother to a nearby health provider [11].

Zero Mothers Die is a western African initiative to save the lives of expectant mothers and their unborn children. Expectant mothers are given mobile phones where pregnancy and childbirth educational information is sent via audio messages. In addition, expectant mothers have access to health workers' numbers to contact in case of emergencies [12, 13]. They also developed a mobile application, zero mothers die, that provides the same information and connects health workers and expectant mothers [13].

Gifted Mom is a mobile developed to help expectant mothers monitor their health via text messages in Cameroon. Mothers are reminded to attend antenatal care and the importance of receiving this care to reduce maternal mortality [12].

M-Mama's Ambulance Taxi: a program by Vodafone company launched in 2013, is a cost-effective ambulance to reduce maternal mortality in rural Tanzania. It uses a network of locally owned taxi drivers to form one unit 'of taxi ambulances. The 'taxi ambulances' operate so that an expectant mother calls a toll-free number of the health centre. The call handler assesses her condition to determine whether there is a need for attention. If needed, a nearest 'taxi ambulances' driver is contacted to take this mother to the nearest health centre. The driver is then paid via a mobile transfer system [14, 15].

RapidSMS Rwanda: an initiative was originating from Rwanda aimed at saving lives of expectant mothers and children below two years through improved access to antenatal and postnatal care and a real-time emergency response system. Information is shared via SMS. Community workers are equipped with mobile devices to collect data and use it on maternal and neonatal indicators in real-time. The indicators are recorded and sent reminders to the expectant mothers via SMS. RED Alerts' emergency system is also used [16, 15].

Mum & Baby: another initiative by Vodafone foundation used in South Africa to help vulnerable expectant mothers by sending free health information by SMS to mothers and caregivers. This program works so that users enter their details upon signing up. The messages are personalized depending on each person's details. It also offers a site with articles, videos and tutorials about childbirth, immunization and nutrition [15], [17].

D. *Existing Open Prototypes to Monitor Pregnancies*

This part outlines the state-of-the-art frameworks used in pregnancy monitoring based on IoT. A significant number of IoT-based frameworks designed to monitor pregnancy exist. Many of these studies are carried out in developed countries and do not favour the poor population in developing countries. For example, Sarhaddi *et al*. presented a paper on an IoT-based system that monitors maternal health during and after pregnancy [18]. Various data collection methods were used to track a mother's health during pregnancy, including stress, sleep, and physical activity. This study was carried out in southwestern Finland and did not cater to the poor communities of developing countries.

Most studies are carried out to investigate the feasibility of using IoT and sensor networks to monitor pregnancy. For example, Bjelica *et al*. designed a caring model for pregnant women based on the IT ecosystem integrating various e-health ecosystem services [19]. They designed mobile applications and web applications employed in real-time environments to help health care workers and expectant mothers. This model was designed to prove that pregnancy monitoring can indeed be done using IoT technologies but does not focus on any given health parameter at any given time and therefore does not aim to improve maternal health.

Other studies focus on a specific health condition and ignore others which could be even more fatal. For example, Tsai *et al*. designed a prospective observational study in Taiwan. They examined the cross-sectional and longitudinal relationship between sleep and how its effects on the quality of health of pregnant women [20]. This study focused on only sleep and ignored the other health factors equally as if not more important during pregnancy.

Allahem, *et al*. designed a framework to monitor high-risk pregnant women with high premature birth risks to reduce premature births [21]. They used body sensors to collect uterine contractions and inform patients if the threshold was reached through mobile applications.

Some wearable devices that continuously collect parameters from expectant mothers have been proposed. Lopez et al. proposed a model for monitoring hypertension during pregnancy. A wristband to monitor heart rate and sleep quality was leveraged and evaluated for three months in the health care centre, and the users were satisfied with it [22]. Gayathri *et al*. developed a system to monitor pregnancy for women at home after operations. A heart rate sensor, MEMS sensors and Wi-Fi communication module were used with Arduino [23].

Suman *et al.* proposed a pregnancy monitoring architecture to monitor pregnancy and provide real-time and adaptive data. Mobile devices and different sensors were used [24]. Shruth. *et al.* proposed a monitoring system for foetal health. A system that employed various sensors, for example, heart rate, body temperature and ECG sensors that a distant specialist for consultation could view, was proposed [25].

Aswar *et al.* designed and implemented a system to reduce medical emergency response time and constantly monitor patients' heart rate and BP. The system generates an alarm sound in abnormal readings and alerts the doctor [26].

E. *Summary*

The above studies and most others have contributed to improving maternal health monitoring using IoT have restrictions. The majority of them were carried out on populations from developed nations and therefore do not necessarily cater to the less privileged populations of the developing countries. Other frameworks are limited to specific health parameters and ignore others altogether, yet it is essential to focus on most health parameters to attain excellent and improved maternal health.

III. PROPOSED SOLUTION

In this section, the proposed IoT-based pregnancy monitoring system is presented.

A. *System Architecture*

Fig. 1 gives the system architecture. The main components of the architecture include the sensing unit, the microcontroller connected to things speak, an open-source IoT platform via a GSM module, and a user alert unit. The sensing unit is the temperature sensor, the pulse sensor, and the GPS module connected to a microcontroller. These sensors collect data for the different parameters and track mothers' locations. The GSM modem connected to the system then transfers the data to ThingsSpeak for storage, analysis and procession. The use of GSM was informed that it is the only means of connectivity available in rural African regions. The processed data is sent to the health workers' mobile and back to the mother's side, displayed on the LCD.

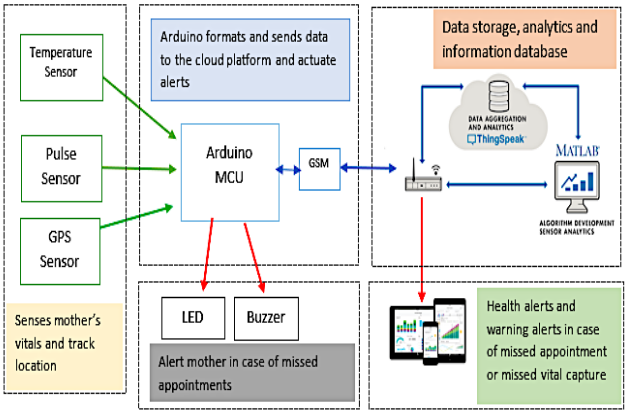

Fig. 1 The System Architecture.

B. *System Block Diagram*

Fig. 2 gives the embedded system block diagram showing different system components. The MAX30205 sensor was used to sense the body temperature, MAX30100 to sense the body pulse and the BN-220 GPS sensor for detecting the real-time location. The ATmega328 was the selected microcontroller. The GSM module chosen was a SIM900A with an LCD being used for display.

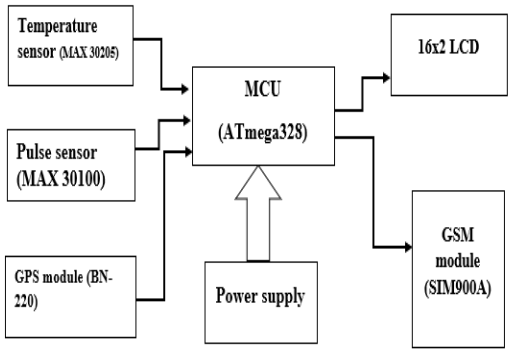

Fig. 2. The System Block Diagram.

C. System Components

The system is made up of both hardware and software components. The hardware components have been grouped into categories based on their functions.

- The sensing Module

This is the data collection part of the system, which comprises different sensors that take the parameters from the mother's side, and send them to the cloud for analysis and processing.

i) Temperature Sensor:

We chose to include a temperature sensor to measure the body temperature level of an expectant mother, this is placed on the hand of the user, and the reading is taken. When this reading exceeds the threshold, which is 390C, the alert is triggered. We used the CJMCU 30205 body temperature sensor in this system, a form of the MAX 30205 family that gives an accurate body temperature reading with an over-temperature shutdown output.

ii) GPS module;

The Global Positioning System (GPS) is a system that navigates based on the satellite. It works anywhere at any time at zero charges. The GPS module in the system enables the real-time location of the expectant mother in case of an emergency. In this system, we used the BN-220 GPS. It is an affordable, lightweight, dual Mode.

iii) Pulse sensor:

The pulse sensor is a device that monitors the change in volume of the blood vessels occurring when the heart pumps blood. They use the photoelectric pulse wave method to measure the heart rate. The MAX30100 pulse oximeter heart Rate sensor was used in this system. This sensor has the following specifications 3.3V power supply, Optical sensor:

- System control module

The Arduino UNO microcontroller controls the whole system. Arduino UNO is a low-cost, open-source and easy to use a board with an ATmega328 microcontroller.

- Communication module

The collected data from the sensors is sent to a remote database via GSM communication. GSM is an open digital mobile communication technology used widely in IoT applications due to its affordability. In this system, we used the GSM SIM900A modem to communicate and send collected data from the sensors to the remote database

- The Cloud platform:

The cloud platform used in this system is the ThingSpeak IoT cloud platform. ThingSpeak is an IoT cloud platform that allows sensor data to be sent to the cloud, analysed and visualized using MATLAB. In this system, sensor data was sent using the GSM module to Thing speak, sent data is visualized, and an alert system is sent to the health care provider via email if the set rules are met. When the expectant mother's end data exceeds threshold temperature values set at 39 degrees Celsius, an automatic email is sent to the health care provider via email to implicate the mother's condition.

IV. Research Methodology

A mixed research design approach involving qualitative and quantitative research was used to understand the existing pregnancy monitoring systems better and yield complete evidence for integrating IoT in pregnancy monitoring in developing countries.

Data was collected from three selected rural health facilities in Rwanda, Kenya and Uganda during the period of June to July 2021. Questionnaires, Interview schedules, and document analysis guides were used as the main tools for collecting data. The selection of these tools was guided by the nature of the data to be collected, the time available, and the study's objectives. For quantitative data collection, questionnaires were sent to 50 mothers from each of the health facilities who were randomly selected from a list of women treated in the facilities in the past year. Health facility managers and system administrators were interviewed. Different documents used in the clinics were also analysed.

The qualitative data generated from the interviews and observations were transcribed and grouped. It was then analysed based on the research questions and developed themes. Content and thematic analysis were used to analyse the data and make inferences by objectively and systematically identifying characteristics of responses. For qualitative data, online google data analysis and visualization tools were used.

The prototyping software development method was applied in developing the embedded system. The system was designed and simulated using Proteus before implementation on a real board. Arduino IDE was used to write the code for the system prototype.

V. Data Analysis

In this section, the results of data collected on pregnancy monitoring systems in Africa are presented

A. Respondents' characteristics

Out of the 150 questionnaires, a total of 92 responses were received. 85.5% of the respondents had been pregnant before, with 65.3% of those saying they have had multiple pregnancies. 91.9% of the respondents indicated they did not have any underlying health conditions.

B. Conception Awareness

Most of the respondents indicated that they noticed they were pregnant during the first trimester. Only a few noticed this when it was late. However, most women only visited the health care providers during their second trimester. Fig. 3 shows a plot of the period taken to visit health care providers from conception.

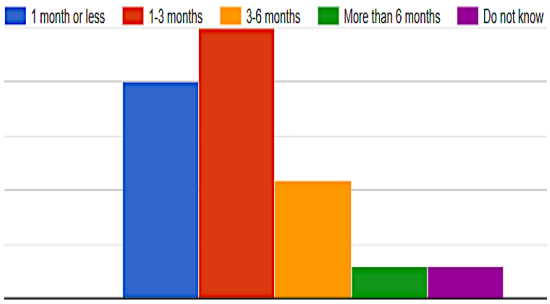

Fig. 3. The period is taken to visit the healthcare providers.

Some of the reasons for late visits include lack of adequate financial resources and health facilities being far from where the respondents stay. The respondents also indicated they did not have a way to monitor their health, with 27.2% developing complications during pregnancies. They, however, indicated they could communicate to the health care providers using mobile phones from time to time.

C. *Areas for improvement*

The respondents indicated that they would love to have the following to ensure safe pregnancies. They would love to monitor their pregnancies from home. They would love to get alerts and reminders for appointments. They want to get health information during pregnancy and would also love to be easily tracked in case of emergencies. Fig. 4 gives the suggested areas of improvement by the respondents.

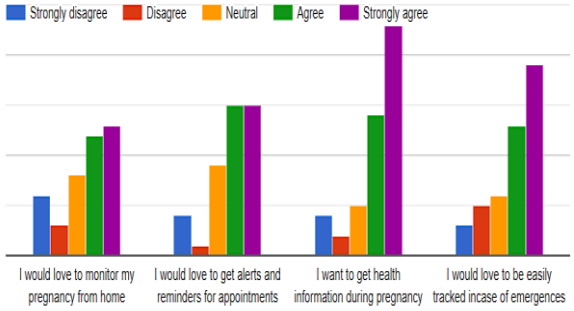

Fig. 4 Suggested Areas of Improvement

D. *Existing Systems*

From the interviews, observation, and analysis of documents, the researchers analysed the system currently in place. It was found that manual paper records are used to capture details of pregnant women during visits. This makes it challenging to trace missed appointments and the patients' health history if documents are lost. Nurses in health facilities in one country are usually required to collect health information and make phone calls to remind the women about their appointments. We were, however, noted that this is not done.

It was also noted that there were no ways to trace those who missed appointments easily. Also, in cases of emergencies, delays in responses were witnessed, leading to complications and deaths.

VI. SYSTEM DESIGN

This section presents the system results and the embedded system-level design analysis.

A. *The system PDLs*

The Program Design Language (PDL) was used to design and document the system's methods and procedures as presented. It was written in plain language without technical terms like pseudocodes but primary keywords.

```
BEGIN
  Initialize Variables
  DOFOREVER
    Display Welcome Message
    CALL HEALTH_CHECK
    CALL APPOINTMENT
    Change to Sleep Mode
ENDDO
END

BEGIN/APPOINTMENT
  IF switch on THEN
    Read Timestamp
    Display Timestamp
    Calculate Next visit
    Display Days to next visit
    IF 1 week or day left THEN
      Turn on red LED
      Display Reminder Message
    ELSE
      Turn on Green LED
      Display Reminder Message
    ENDIF
END/APPOINTMENT

BEGIN/HEALTH_CHECK
  IF switch on THEN
    Read Temperature
    Display Temperature
    Read Pulse Rate
    Display Pulse Rate
    IF reading normal THEN
      Turn on Green LED
      Display Normal Message
      CALL SEND_DATA
    ELSE
      Turn on Red LED
      Display Health Alert
      Read GPS Location
      CALL SEND_DATA
      Send Emergency Alert
    ENDIF
END/HEATH_CHECK

BEGIN/SEND_DATA
  Connect to IoT Platform
  IF connected THEN
    Send Data to IoT Platform
    Display Send Notification
  ELSE
    Display Connection Error
  ENDIF
END/SEND_DATA
```

Fig. 5 The system PDL.

B. *Simulation Setup*

Fig. 6 shows the simulation setup for the system on the proteus design suit. Given that the specific selected OEM component libraries were not available for simulation on proteus. Alternatives were chosen to show the flow working of the system.

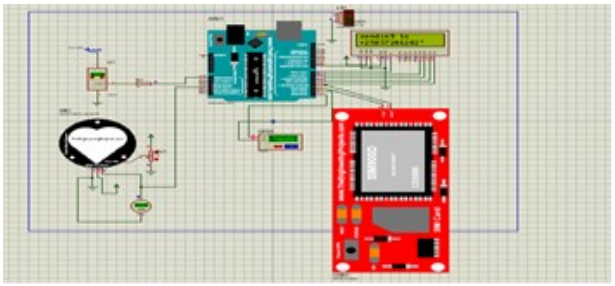

Fig. 6 Proteus simulation setup

C. *System Prototype*

Fig. 7 shows an image of the initial system prototype. Different components of the system were connected and tested in a lab environment.

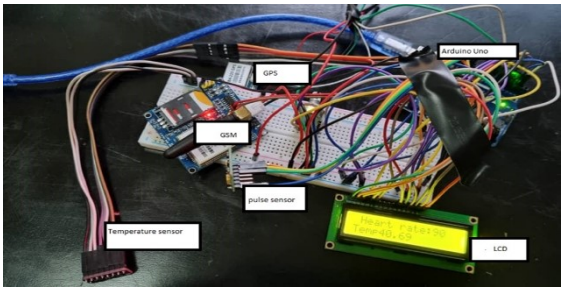

Fig. 7. System Prototype

D. *System Implementation Steps*

After testing and verifying the functionality of the porotypes, the real system will be developed, and PCB printed and packaged. The administrators will be able to set initial

parameters before giving them to the pregnant women to use when they visit the hospitals

VII. Results and Analysis

After the system data was collected, it was sent via GSM module SIM900A to ThingSpeak. Data from 129 entries were collected and sent to the cloud, and the following outputs were obtained over time. Fig. 8 shows the created cloud platform dashboard. It shows the number of entries that have been sent so far and when.

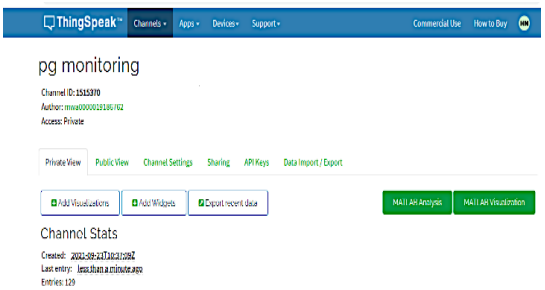

Fig. 8. Pregnancy Monitoring System Dashboard.

Fig. 9 shows the data entries made over a while graph. The graph is a visualization in ThingSpeak that indicates the temperature and heart rate status as viewed continuously over a given period. The data from sensors sent to the cloud from different entries are different, which explains the up/ down lines in the graphs

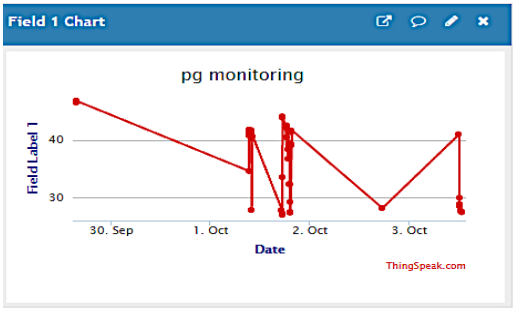

Fig. 9. A graph of received data in the cloud over time

The cloud platform was set to send a health alert automatically to the health care provider via email whenever the vitals go beyond recommended levels. This shows the mother's health condition, and the health worker should react accordingly. Fig. 10 shows the health alerts that were generated.

Fig. 10. Health alert

To evaluate the advantages of our solution over the existing solution, a comparison was made with the reviewed solutions. Table I gives the results of the comparisons.

TABLE I. Comparison to other Solutions

Solution	Real-time monitoring	Monitor temperature and pulse rate	Deployable to rural areas	Tracking and notification ability
Traditional approach	NO	NO	YES	NO
Focused Antenatal care	NO	NO	YES	NO
Health mobile Apps	NO	NO	NO	YES
SMS based solutions	NO	NO	YES	YES
Reviewed IoT solutions	YES	YES	NO	NO
Our Solution	YES	YES	YES	YES

From the analysis, our solution outperforms the existing solutions in the following ways:

- Has the capability to monitor the conditions of the women in real-time.
- Focus on temperature and pulse rate, which are major indicators of the health condition of pregnant women
- It can be deployed to rural Africa, where connectivity is a challenge given that 2G/3G is readily available.
- Provided the option of tracking and notification to relevant authorities from time to time.

VIII. Conclusions and Future Work

From the study, it is evident that it is crucial to monitor the health status of pregnant women. Different solutions have been developed to make this a reality. However, existing solutions are not portable to the African settings and thus the need for customized solutions. The emerging technology of IoT is an area that can be exploited to make this a reality. The simulation and the prototype results show the effectiveness of such a system in monitoring pregnant women. If implemented, this will lead to a reduction in deaths and complications during pregnancies.

Future works will involve the system's deployment in different rural health facilities for further testing and validation. Additional health conditions will also be explored, which will involve using various other sensors. For example, the ECG sensor in case of abnormal pulse sensor reading, the blood pressure sensor and the sensor to measure blood sugar will also be explored for a more effective solution.

For seamless integration of the system, a five-layer IoT integration architecture that involves the data collection layer, transportation layer, Data integration layer, application layer, and a business layer will be used.

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