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Development of a Remote Patient Monitoring System for Maternal Health in Ondo State, Nigeria

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ABSTRACT: Maternal mortality remains a major issue affecting women of reproductive age across Nigeria. The World Health Organization (WHO) reported that 1047 women died per 100,000 due to pregnancy and childbirth complications in Nigeria. From the foregoing, Nigeria contributes to about 19% of global maternal death, still births and neonatal deaths. Hence, Nigeria is ranked the third nation with high maternal and child death with South Sudan and Chad taking the lead respectively. There are however variations in the levels of maternal mortality in the Northern and Southern Nigeria. Maternal mortality is more pronounced in the North than the Southern part of Nigeria. In the south western part of Nigeria, Ondo state had the worst maternal and child care indices in 2008. The Ondo state government put a lot of efforts towards reducing maternal mortality in the state. These efforts include the launching of the safe motherhood (abiye) project in 2009. Despite the efforts geared towards the reduction of maternal mortality in Ondo state, the maternal mortality ratio still remains abysmally high. Hence, this study develops a system for remotely monitoring the health of pregnant women in the state. The system was tested using sixty pregnant women in fourteen Local Government Areas of Ondo state, Nigeria, with accuracy, precision and recall as the performance metrics. The system recorded an accuracy of 95.24%, a precicion of 96.67% and a recall of 98.31%.

KEYWORDS: maternal mortality, maternal mortality ratio, remote patient monitoring, pregnancy, Nigeria.

1 INTRODUCTION

Maternal mortality is a significant measure of the human, economic and social development of a nation because it reveals the overall health status of women, their access to quality healthcare, and the responsiveness of the healthcare system to their needs. Maternal mortality is defined as the death of pregnant women during pregnancy or within 42 days of termination of pregnancy, irrespective of the duration and site of the pregnancy from any cause related to or aggravated by the pregnancy or its management but not from accidental or incidental causes [1]. Maternal mortality, or deaths related to pregnancy and childbirth can be caused by direct or indirect complications [2]. Direct maternal deaths are primarily caused by obstetric complications like severe bleeding (hemorrhage), infections, maternal suicide, omissions or incorrect treatment and hypertensive disorders. The indirect complications have been linked to pre-existing conditions such as HIV/AIDS, anemia, and heart disease. Nevertheless, the rate of maternal deaths varies significantly across diverse countries in the globe usually with low-income countries experiencing higher mortality rates particularly Sub-Saharan Africa and Southern Asia [3]. Typical examples of countries in the global south that experience a high mortality rate exceeding 1000 deaths per 100,000 live births as stipulated by the United Nations Sustainable Development Goals include Central African Republic, Sierra Leone, Somalia, South Sudan, Chad and Nigeria [4].

Nigeria is the most populous country in Africa with a population of over 200 million, and the seventh most populous country in the world with women constituting 49.95% of the entire population [5]. Unfortunately, the incidence of maternal death in Nigeria is one of the worst in the world with a global rate of about 19% and over 50,000 maternal deaths annually [6]. Specifically, the number of maternal deaths in Nigeria per 100,000 live births stands at 1047 as at the time of this study. This

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extremely high Maternal Mortality Ratio (MMR) is only surpassed by South Sudan and Chad with MMRs of 1223 and 1063 respectively [7]. These high MMRs negate the Sustainable Development Goal (SDG) of less than 70 maternal deaths per 100,000 live births by 2030. The detrimental effect of high MMR in Nigeria is apparent on the low level of socioeconomic development of the nation as women and children play pivotal roles in the socio-economic development of any nation.

There are disparities in the MMR in the Northern and Southern parts of Nigeria. Maternal mortality is more pronounced in the North than the Southern part of Nigeria. According to Babajide et al. [8], the North Eastern part of Nigeria has a consistently high MMR while the South Western part of Nigeria experienced a considerably rise in MMR between 2008 and 2018 with Ondo state having the worst maternal outcomes in the region [9]. This is evident in the National Demographic Health Survey of 2008 which ranked Ondo state as the state with the worst maternal and child care indices in the Southwestern region of Nigeria [9]. Nevertheless, the government of Ondo state as at that time put in a lot of efforts towards reducing maternal mortality in the state. These efforts include the provision of various initiatives, programmes and policies on reproductive and maternal health. One of such initiatives is the safe motherhood (Abiye) project launched in 2009. One of the objectives of the program was to monitor every pregnant woman in the state and provide them with qualitative and effective healthcare irrespective of their geographical location. In addition, the initiative was set up to provide sustainable equity-based healthcare services in order to provide universal access to the healthcare system in the state. These goals were achieved through the use of mobile phones, renovated health centers and improved means of transportation to health facilities [10]. Unfortunately, this programme was halted in 2017, thereby, intensifying the maternal mortality ratio in Ondo state. In order to ameliorate this problem, this research aims to develop a Remote Patient Monitoring (RPM) System for Maternal Health in Ondo state with a view to reducing maternal mortality in the state.

2 THEORETICAL FRAMEWORK

This research relies on two theoretical frameworks which include the health belief theory and the theory of planned behaviour.

2.1 HEALTH BELIEF THEORY

The theory of health belief is a psychological framework propounded by Irwin M. Rosenstock, Godfrey M. Hochbaum, S. Stephen Kegeles, and Howard Leventhal in the 1950's. It is used to describe and predict people's behaviours, attitudes and beliefs on their health [11]. The theory emphasizes the need to understand and promote engagement in health-protective behaviours. The health belief theory also opines that the willingness of individuals to transform their health-related behaviours stems from the perceptions that they have about their health. Hence, the theory predicts that an individual is likely to adopt a specific health behaviour based on their perceptions of the severity and susceptibility of a disease, the perceived benefits of adopting the behaviour as well as the barriers of the behaviour. This theory is found to be related to this study because the health belief theory has been used by healthcare providers to create programmes and interventions to prevent health problems, encourage treatment and support health related behavioural change. Hence, this theory will be of great benefit in encouraging pregnant women in Ondo state to adopt the remote patient monitoring system to reduce MMR in the state.

2.2 THEORY OF PLANNED BEHAVIOUR

The theory of planned behaviour (TPB) is a cognitive theory, propounded by Azjen [12]. The theory opines that an individual's decision to engage in a specific behaviour, particularly in the context of health can be predicated by his intention to engage in that behaviour. Intentions in this context refer to the efforts as well as the motivating factors that influence peoples' behaviours towards the action. These intentions are however determined by the individual's personal attitudes, subjective norms and perceived behavioural control.This theory is related to this research because it will assist in designing a system that aligns with the patients' motivations which will ultimately results in improved health outcome.

3 A REVIEW OF MATERNAL HEALTH IN ONDO STATE, NIGERIA

Ondo state is located in the South Western zone of Nigeria. It lies between Longitudes 4"30" and 6" East of the Greenwich Meridian, 5"45" and 8" 15" North of the Equator [13]. Ondo state has a land mass of 14,788.723 square kilometers which is occupied by eighteen (18) Local Government Areas. Ondo state is blessed with natural resources which include crude oil, quartz sand, clay, granite, limestone, talc, kaoline, coal, columbite, rock, tin and bitumen. The people of Ondo state are mostly subsistence farmers, fishermen and traders.

In the south western part of Nigeria, Ondo state had the worst maternal and child care indices in 2008. Hence, the National Demographic Health Survey ranked Ondo state as the state with the worst maternal and child care indices in the Southwestern region of Nigeria with its MMR far above the average 545 per 100,000 live births and the tenth highest in the World [14]. Nevertheless, the Ondo state government put a lot of efforts towards reducing maternal mortality in the state. The administration of Dr. Olusegun Mimiko (Governor of Ondo State from 2009 to 2017) initiated the Abiye (Safe Motherhood) programme in 2009 at Ifedore Local Government Area. The objective of the programme was to address the challenge of infant and maternal mortality by monitoring every pregnant woman and providing them with sustainable, accessible, qualitative and effective healthcare. Diverse methods were used to achieve this objective. These strategies include the use of health rangers which basically consisted of specially trained Community Health Extension Workers (CHEW) to counsel pregnant women on family planning and birth preparedness, provision of mobile phones to pregnant women to maintain free contact with their health rangers and healthcare providers, provision of appropriate means of transportation from the patients' location to the point of care as well as the provision of the Mother and Child hospital model [9]. By 2016, there was a massive reduction in the MMR of Ondo state to 112 per 100,000 live births [15]. This represented 84.9% reduction in the MMR. Unfortunately, this programme was halted in 2017, thereby, intensifying the maternal mortality ratio in Ondo State [16]. By 2020, the MMR of Ondo state had risen to 341 per 100,000 live births surpassing only Ogun and Lagos States with MMRs of 364 and 356 respectively in the South Western Part of Nigeria [17]. By 2021, the Ondo state government mapped out strategies to collaborate with traditional birth attendants in a bid to reduce maternal mortality in the state [18]. In spite of this, the state of maternal healthcare in Ondo state still requires urgent attention. In order to ameliorate this problem, this research aims to develop a Remote Patient Monitoring System (RPMS) for Maternal Health in Ondo state with a view to improving maternal health in the state.

4 REMOTE PATIENT MONITORING

Patient monitoring according to Iroju and Ojerinde [19] is the telehealth practice of obtaining and transmitting regulated observation or measurement of a patient's physiological function with digital devices for decision making and therapeutic interventions. Hence, Remote Patient Monitoring (RPM) can be viewed as a form of telehealth that allows healthcare providers to remotely examine the health of their patients through the use of mobile medical devices and digital technology irrespective of their geographical locations. From the foregoing, Remote Patient Monitoring (RPM) can simply be viewed as the observation or measurement of a patient's physiological function such as Electrocardiogram (ECG), heart rate, oxygen saturation, glucose levels and fetal movement in pregnant women at a distance with the aim of helping medical practitioners to make insightful decisions and prioritize healthcare efficiently. RPM targets diverse patients who are required to be monitored continuously. Typical examples of these categories of patients include patients diagnosed with chronic illnesses, patients with mobility issues, or other disabilities, post-surgery patients, neonates, elderly patients and pregnant women.

RPM includes five basic steps which include the collection of patients' information, transmission of patients' information, evaluation of patients' information, notification and intervention. The collection of patients' information involves the process of acquiring patients' physiological data through sensor based peripheral devices such as blood pressure cuff, pulse oximeter and glucometer which can either be worn by the patients or might not have direct contact with the patients. Examples of wearable devices used in RPM include wristbands, wristwatches or patches, blood pressure cuff, glucometer and pulse oximeter. Contactless patients' information acquisition methods in RPM include the use of smart phones and cameras. In the transmission phase, the data collected are conveyed to healthcare practitioners through different means of communication such as Wireless Area Network (WAN) and cloud-based platforms where they are reviewed and evaluated by algorithms or healthcare providers who provide clinical review, care management and patient education. In the case of emergencies, the patient is notified through a mobile device or an intermediary healthcare provider who takes the necessary intervention.

4.1 BENEFITS OF REMOTE PATIENT MONITORING ON MATERNAL HEALTH

The benefits of RPM are highlighted below:

- Reduces the barrier associated with unequal health access: In developing countries like Nigeria, unequal access to healthcare is a major challenge facing individuals most especially those residing in rural areas or have mobility challenges. This uneven access to healthcare is manifested in diverse ways which include high incidence of diseases, poor health outcomes and high rate of mortality. RPM breaks this barrier of uneven distribution of healthcare services by ensuring that every individual has access to quality healthcare in the comfort of their homes irrespective of the distance that exist between them and the hospitals or clinics, this no doubt overcomes the barriers of distance and transportation usually associated with unequal access to healthcare most especially in the rural areas. RPM also reduces the barrier associated

with limited access to specialist care during pregnancy because the limited specialists available can attend to as many patients as possible remotely.

- Timely interventions: Pregnant women are usually considered vulnerable individuals that require special care in a timely manner. Unfortunately, any delay in their healthcare has severe consequences which can ultimately lead to their untimely death. RPM facilitates the continuous collection and real time tracking of the vital signs and health related data of these individuals right from their homes for onward transmission to healthcare providers. This can then be used by the healthcare practitioners to easily identify early indicators of pregnancy complications as well as detect early signs of deterioration, abnormalities and complications and thus respond timely with the appropriate treatments and interventions. This no doubt facilitates quick medical interventions and disease management.
- Improved patient safety and health outcomes: RPM provides the opportunities for the improvement of maternal safety and health outcomes because of the timely intervention of healthcare providers involved in the care process.
- Active participation of patients in their care: RPM systems are usually designed to contain features like vital signs collection, appointment scheduling, medication reminders and access to medical records which patients interact with. With these features, pregnant women are also encouraged to be actively involved in their own care.

5 RESEARCH METHODOLOGY

We designed the models of the RPM system with the use-case and activity diagrams of the Unified Modelling Language (UML). The system was implemented in Hyper Text Mark-up Language (HTML) for its structure, Cascading Style Sheet (CSS) for styling and java script for interactivity. The database used was MongoDB and Express js was used for the server side development.

6 SYSTEM DESIGN

The use case model represents the functional requirements of the system from the users' perspectives. It identifies the functions of the system; the users otherwise called the actors who interact with the system and the system boundaries. Fig. 1 shows the use-case model for the RPM system.

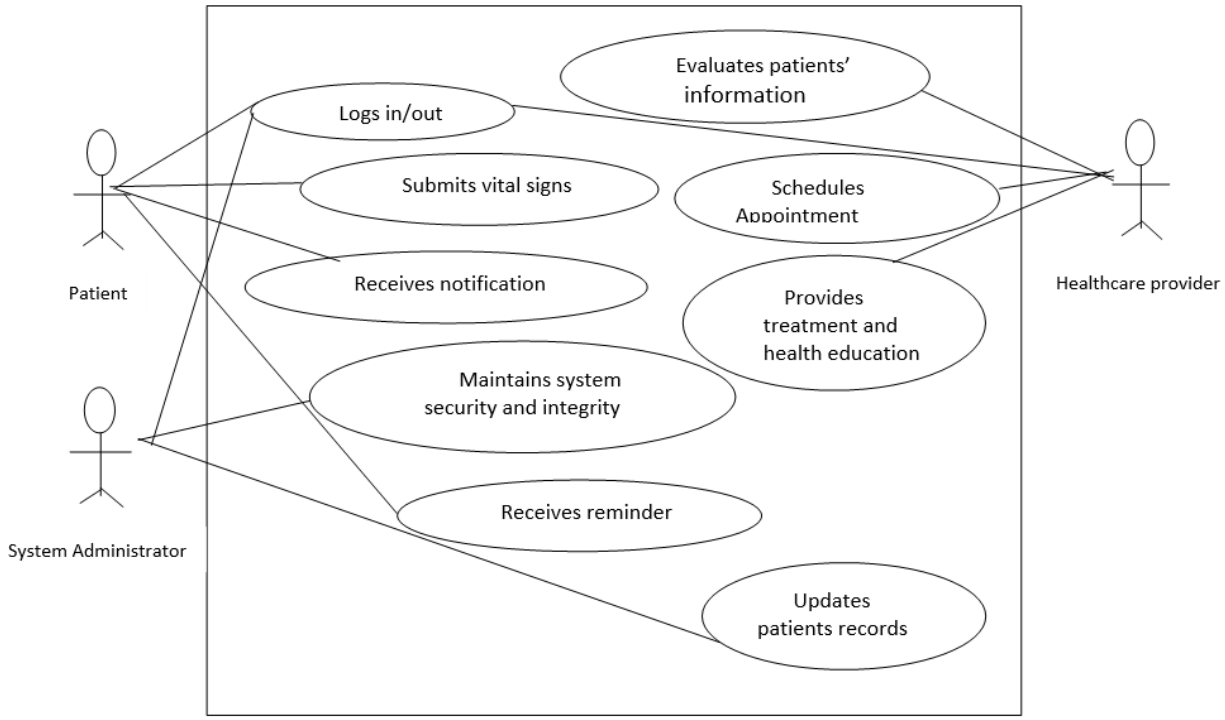

Fig. 1. The Use Case of the Remote Patient Monitoring System

The use-case diagram includes the healthcare providers, the patients who in this case are the expectant mothers and the system administrators. The system is designed for the patients, system administrator and the healthcare providers to log in by providing their login details such as their user names and password. Once this authentication is successful, the RPM devices such as Blood pressure monitors, Finetest Glucometer, pulse oximeter, and Heavy-duty digital scale can be used to obtain the vital signs of the patients which are then submitted and transmitted to the healthcare providers via data transmission technologies. The healthcare provider receives the information via his mobile device and then diagnose, treat and provide the necessary health education to the patients if the vital sign is above the normal threshold. The patient in turns receives the notification of his diagnosis and treatment also on his mobile device. If the patient needs further attention, the healthcare provider schedules an appointment. The system administrator updates the patients records as well as maintains the integrity and security of the system. The corresponding activity diagram of the model above is depicted in Fig. 2.

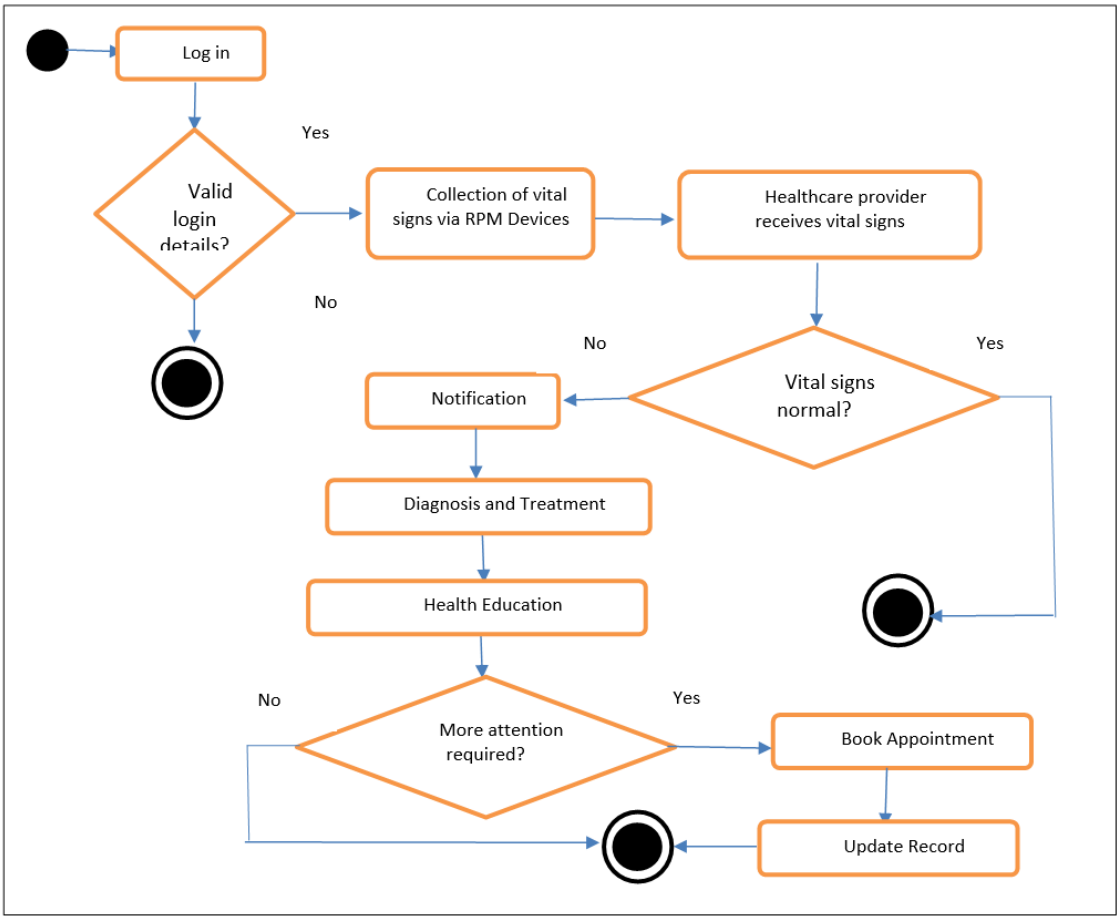

Fig. 2. The Activity Diagram of the Remote Patient Monitoring System

7 SYSTEM IMPLEMENTATION

This section describes the hardware and software requirements of the system.

7.1 HARDWARE REQUIREMENTS

For the system to be effectively implemented, the following hardware devices are required.

- Remote patient monitoring devices such as thermometer, blood pressure cuff and glucometer
- Mobile devices such as smart phones, labtops or tablets
- Router and hub
- Medical Display Monitor

7.2 SOFTWARE REQUIREMENTS

For the system to be effectively implemented, the following software are required.

- Real Time Operating system
- Communication protocols to ensure efficient transmission of data from patients to healthcare providers
- Database systems
- Cloud software for ensuring secured storage of large amount of patients' data from Internet of Things devices
- Push notifications for sending notifications to patients

The system was implemented in Hyper Text Mark-up Language (HTML) for its structure, Cascading Style Sheet (CSS) for styling and java script for interactivity. The database used was MongoDB and Express js was used for the server side development.

Fig. 3 shows the login page of the RPM system. Fig. 4 shows the page that defines the users' roles. For instance, the page provides the patient with the information that they can take their vital signs with their RPM devices and transmit to the healthcare providers. Fig. 5 shows the dash board where the patient vital signs are obtained and viewed by the healthcare providers. Fig. 6 shows the page where the healthcare providers provide treatment plan to the patients.

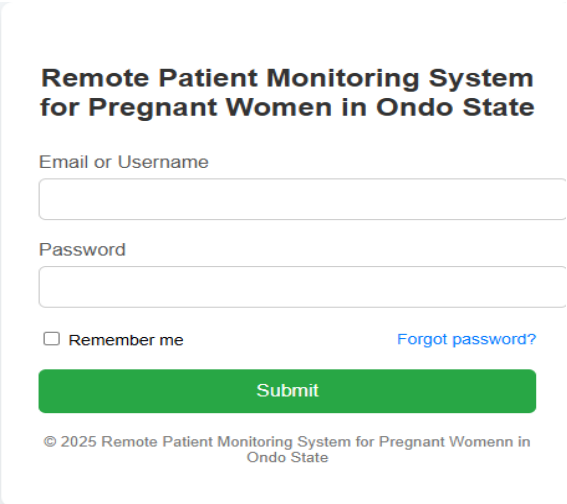

Fig. 3. The Login Page of the Remote Patient Monitoring System

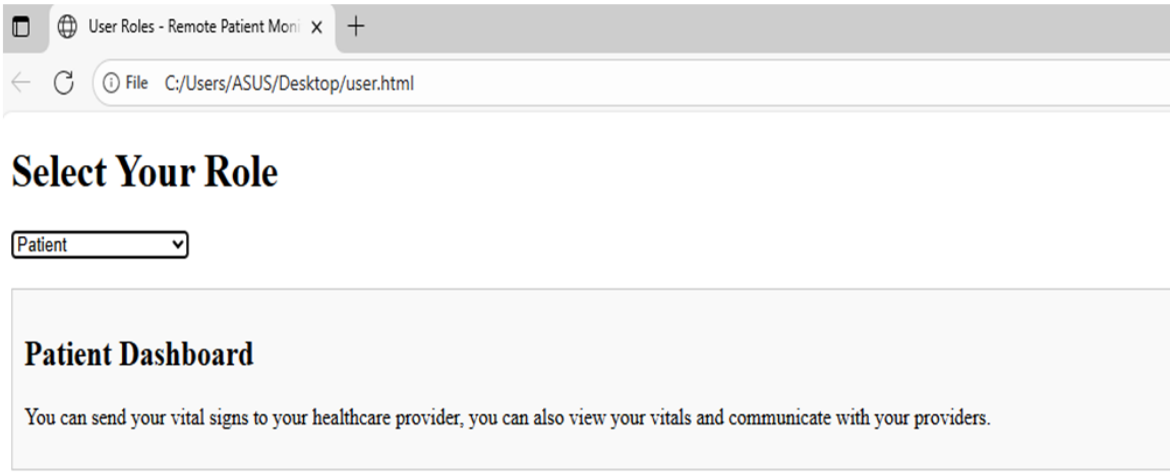

Fig. 4. The Page of the Remote Patient Monitoring System Showing the Users' Role

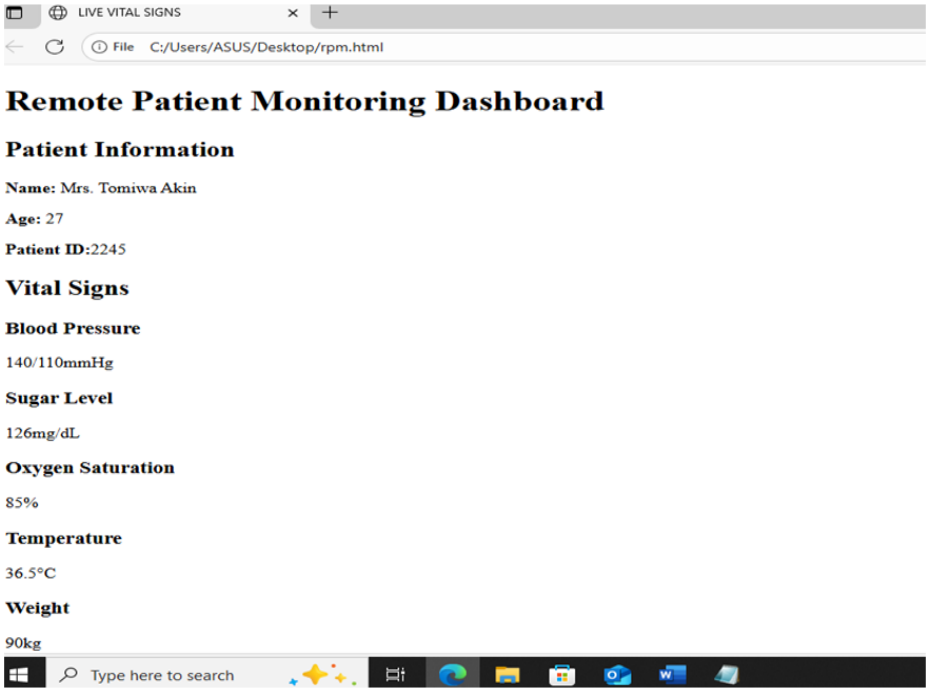

Fig. 5. The Page of the Remote Patient Monitoring System Showing a Patient's Data

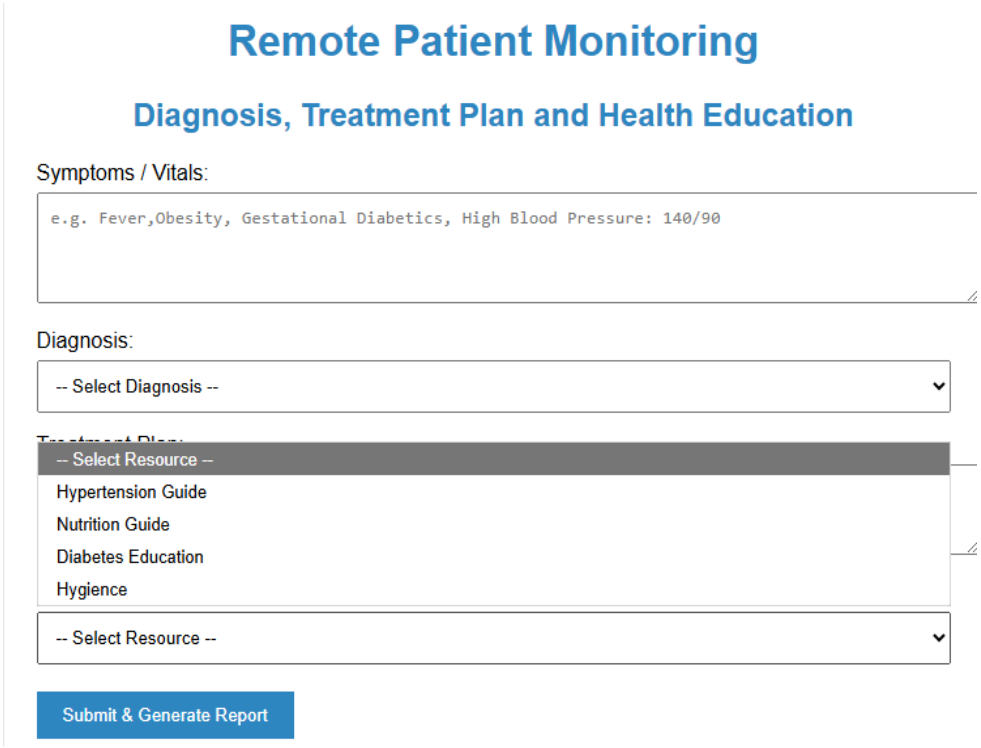

Fig. 6. The Page of the Remote Patient Monitoring System Showing a Treatment Plan

7.3 SYSTEM TESTING

Sixty pregnant women in their second trimester aged 18-45 years were monitored remotely in the system testing phase. They were subjected to both remote patient monitoring and the conventional method at the same time within fourteen premises in seven local government areas in Ondo state Nigeria.

The performance of the RPM system was tested using accuracy, precision and recall. Accuracy is used to describe the degree of correctness of a system. It is denoted as shown in equation (1).

$$A = {}^{TP+TN}/_{TP+TN+FP+FN} \quad (1)$$

Precision is a performance metrics that describes the closeness of agreements between independent test results obtained under certain conditions. It is measured as shown in equation (2)

$$\boldsymbol{P = {}^{TP}/_{TP+FP}} \quad (2)$$

Recall measures the ratio of correctly found correspondences over the total number of expected correspondences. It is given as shown in equation (3):

$$R = {}^{TP}/_{TP+FN} \quad (3)$$

where TP, FN, FP and TN are True Positives, False Negatives, False Positives and True Negatives respectively.

These parameters were obtained from the cases reported by the RPM system and those reported by the conventional method. Concisely, TP indicates that the RPM system correctly reports a normal as reported by the conventional method, FN indicates that the RPM system fails to detect a real normal sign. In the same vein, FP incorrectly flags an abnormal case as normal while TN correctly detects abnormal case when compared to the results obtained from the physicians. Table 1 shows the confusion matrix which reveal TP, FN, FP and TN of the system.

Table 1. The confusion matrix revealing the TP, FN, FP and TN

N=60	Normal	Abnormal
Actual (Normal)	TP: 58	FP: 2
Actual (Abnormal)	FN:1	TN:2

Fig.7 shows the graph depicting the accuracy, precision and recall of the RPM system. From Fig. 7, the RPM system records an accuracy of 95.24%, a precision of 96.67% and a recall of 98.31%.

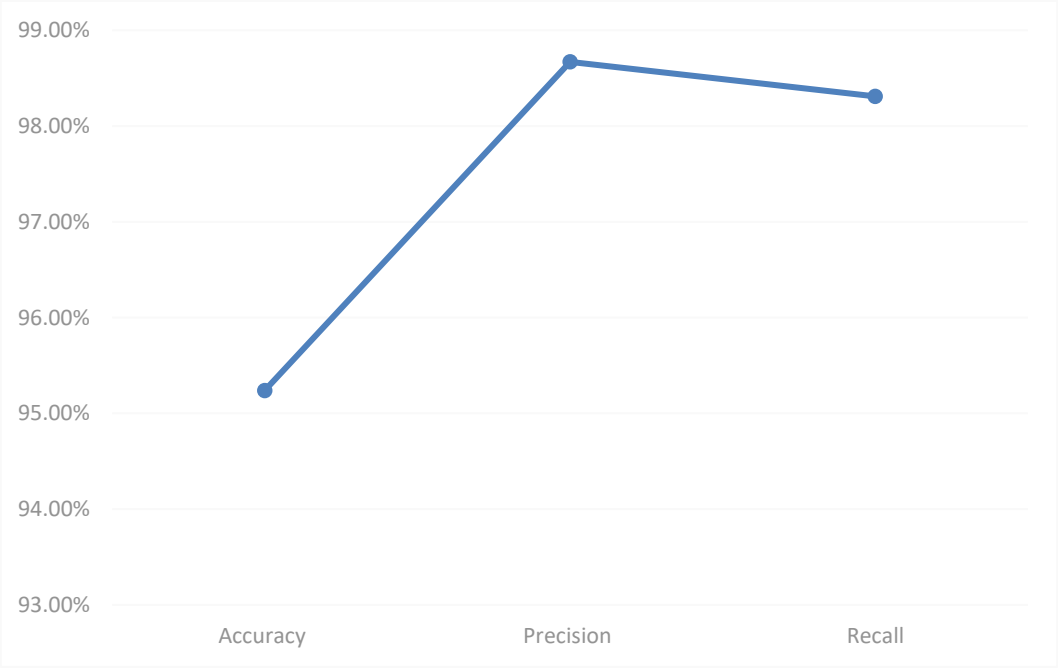

Fig. 7. A Graph Depicting the Accuracy, Precision and Recall

8 CONCLUSION

The research developed a system that enable healthcare providers to remotely monitor pregnant' women's health to avoid emergency during pregnancy, delivery and post-partum. The system allows the vital signs of patients to be collected with their RPM devices and transmitted to the healthcare providers who view them and diagnose, treat and provide health education to the patients based on the vital signs. The study concludes that RPM systems should be effectively deployed in all hospitals and healthcare centers in Ondo state, Nigeria in order to effectively combat the menace of high maternal mortality and morbidity plaguing the state.

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