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IoT BASED POSTOPERATIVE PATIENT MONITORING VITAL SIGNS USING WIRELESS BODY SENSOR IN BURUNDI: A CASE STUDY OF VAN NORMAN CLINIQUE

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**IoMT BASED POSTOPERATIVE PATIENT MONITORING VITAL
SIGNS USING WIRELESS BODY SENSOR IN BURUNDI: A CASE
STUDY OF VAN NORMAN CLINIQUE**

Jesus de la Paix Irakomeye

**A Project Report Submitted in Partial Fulfillment of the Requirements of the Award
the Degree of Master of Science in Embedded and Mobile Systems of The Nelson
Mandela African Institution of Science and Technology**

Arusha, Tanzania

October, 2022

ABSTRACT

The Internet of Things (IoT) in healthcare plays a vital role to increase the efficacy in health care monitoring. Vital signals are crucial part of monitoring a patient's health status in the hospital for early diagnosis of delayed recovery, assess wellbeing of the patient and prevent misdiagnosis. During the postoperative period, vital signs must be checked more frequently than they would be for other patients. Patients are placed in a high dependency unit, and vital signs have to be checked every 4 hours, or 6 hours depending on the severity of the procedure done. A comprehensive and integrated health-care paradigm is provided, allowing for remote health monitoring of postoperative patients to diary collect vital sign parameters and send to the caretakers using Internet of Medical Thing. This enables a nurse, doctor, junior doctor, or consultant to screen patients remotely and take action when there is a need. Wireless body sensors play a vital role in healthcare, this project uses them to monitor remotely a patient in the hospital, connecting to the ESP32 microcontroller with WiFi integrated on it to display remotely the vital signs on a mobile phone, local computer also in the cloud. The objective of this project was to develop a smart IoMT-based monitoring system that can detect and monitor postoperative patient vital signs such as body temperature, heart rate, oxygen saturation, and respiration rate in real time, as well as send live data to the doctor in charge via mobile application and analyze data using ThingSpeak.

DECLARATION

I, Jesus de la Paix Irakomeye, do hereby declare to the Senate of The Nelson Mandela African Institution of Science and Technology that this project report is my original work and that it has neither been submitted nor being concurrently submitted for a degree award in any other institution.

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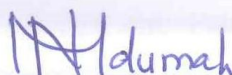
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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by The Nelson Mandela African Institution of Science and Technology, a project report titled ***“IoMT Based Postoperative Patient Monitoring Vital Signs Using Wireless Body Sensor in East Africa Region”*** in partial fulfillment of the requirements for the degree of Master of Science in Embedded and Mobile Systems of The Nelson Mandela African Institution of Science and Technology.

Dr. Neema Mduma



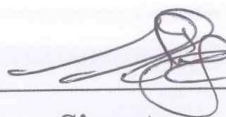
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May God bless you.

DEDICATION

In memory of my late Father, Rev. Gregoire Ndayongeje.

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LIST OF ABBREVIATIONS AND SYMBOLS

IoMT	Internet of Medical Things
EAC	East Africa Community
HEACH	Digital Regional East African Community Health
GSM	Global System for Mobile Communication
ECG	Electrocardiogram
LCD	Liquid Crystal Display
PCB	Printed Circuit Board
IDE	Integrated Development Environment
SMS	Short Message Service

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

The latest advances and trends in technology have revolutionized the healthcare system, the introduction of IoT in healthcare systems has become more in demand because of its precision and efficiency with the use of wireless sensors and biosensors in health monitoring. The Internet of Medical Things (IoMT) is having an equally significant effect on the global pharmaceutical and medical communities. Internet-connected devices are now commonly used in hospitals and doctors' offices, from blood pressure monitors to MRI scanners. More and more medical organizations are turning to the Internet of Medical Things to lower healthcare costs, simplify operations, and improve accuracy. This changes the traditional model of healthcare for both healthcare providers and patients. IoMT plays a crucial role in the care and monitoring of telemedicine to make medical equipment more efficient and the speed and accessibility of medical services. It can be used to collect health data from remote patients using sensors and wearable devices connected to an Internet-based health monitoring system (Singh, 2019).

The Internet of Medical Things (IoMT) is a collection of medical devices and software that can connect to healthcare information technology systems using networking (Selvanayakam *et al.*, 2020; Singh, 2019). In a hospital when a patient's body vital signs have to be continually monitored, It is often carried out by a doctor or other paramedical staff member who continuously monitors the vital signs and records them, it is a time-consuming process (Nayyar *et al.*, 2019).

Vital signs are critical in diagnosing and monitoring different medical issues at an early stage because they demonstrate the quality of the body's basic functions, showing the overall state of a person's physical health (Alecú *et al.*, 2017; Valsalan *et al.*, 2020).

By connecting post-operative patients to their physicians and allowing the transfer of medical data over a secure network it can reduce unnecessary hospital visits this means that we do not prevent interaction of the doctor and the patient but we enable the doctor to monitor the vital signs anytime, minimize the pressure on health care systems (Hassanalieragh *et al.*, 2015). The postoperative patient will be connected to wireless body sensors and wireless body sensors are

connected to the microcontroller. The microcontroller receives information from sensors connected to the body to visualize on a mobile phone and in the cloud (Al Shorman *et al.*, 2020; Priyanka & Reji, 2019). Medical services are becoming unmatched and less extreme by effectively obtaining, recording, examining, and exchanging current data in real-time.

However, any distant smart device, such as laptops or smartphones connected to the same network, can visualize and monitor a postoperative patient's vital statistics. It substitutes the procedure of having a health expert check the patient's vital signs at regular intervals with a continuous automated flow of information (Engineering, 2018). As a result, it enhances the quality of care while also lowering the cost of care by removing the requirement for a caregiver to actively participate in data gathering and analysis.

New diagnostic and therapeutic technologies have begun to be included in hospitals. The vital parameters are the fundamental parameters assessed by the admission of a patient. This is a fast and efficient technique to monitor the patient's pathophysiological status (Singh, 2019). It shows whether or not the patient requires immediate assistance.

This project aimed to offer a new smart post-operative patient health tracking system that utilizes sensors to watch patient vital data and uses the internet to inform physicians remotely so that they may aid in case of any difficulties as soon as possible, therefore reducing death rates (Senthamilarasi *et al.*, 2018).

The IoMT based patient monitoring vital signs using wireless body sensors will focus on offering better healthcare services to a patient and use sensors to track patient health at home, a doctor or family member will be able to monitor the patient's condition via the internet and Global System for Mobile Communications (GSM) using Short Messages Services (SMS) alert in case there are issues.

1.1.1 Digital Health in East Africa Community

Currently, the EAC region has a variety of digital health implementations amongst the Partner States (Burundi, Kenya, Rwanda, South Sudan, Tanzania, and Uganda) addressing access to health services and improving health outcomes for citizens. Significant progress are being made, yet there are many opportunities to act regionally, and for the EAC to lead and coordinate across partners states, development partners, and private companies to improve health

outcomes by implementing sustainable digital technologies that expand the ways patients seek quality care (East African Health Research Commission, 2018).

The Digital Regional East African Community Health (REACH) initiative is seizing that opportunity. The Initiative lays the groundwork for concerted action. It builds on collaborative momentum and understanding to develop a regional digital health strategy that allows the EAC Partner States to work together: apply ICT across the entire health sector for the improvement of health outcomes and benefit of patients and the general population, across East Africa (African, 2021).

1.2 Statement of the Problem

Most of the hospitals has a low-resource setting with limited personnel such as rural district hospitals and each post-operative patient in a critical stage is located in his room or are in the same room. Healthcare workers practically do not have sufficient time because of the overburden with patients. So it is not possible to make regular visits to every patient's bed many times after surgery (Aravind H, 2020). Also, each time a health professional passes to check the state of a patient they have to pay money which is expensive for the patient (Joyia *et al.*, 2017).

Postoperative recovery, on the other hand, is not that straightforward. There may be a variety of complications that arise for the patients, causing them discomfort or even resulting in the operation a failure. With this in mind, it is critical to develop strategies to care for patients in a way that ensures a successful post-op time (Aravind H, 2020). Therefore, this study developed a postoperative patient monitoring vital signs system that will help health care providers to monitor the patient remotely.

1.3 Rationale of the Study

Measuring vital signs parameters has been a major challenge in hospitals especially in the postoperative unit center which affects the working routine of doctors and nurses. They have to pass by all rooms with patient record vital signs parameters with paper and pen. The existing mechanism is not saved reliable because those papers that are used to record vital signs parameters can be stolen or destroyed at any moment. Therefore, there is a need to develop a low-cost system that can be deployed in all possible hospitals.

1.4 Research Objectives

1.4.1 General Objective

The main objective of this project was to develop an IoMT based postoperative patient monitoring vital signs using a wireless body sensor.

1.4.2 Specific Objectives

- (i) Identify the requirements of developing a postoperative patient vital sign monitoring system.
- (ii) Design and develop IoMT based postoperative patient vital signs monitoring system.
- (iii) Implementation and Validation of the developed system in postoperative patient vital signs monitoring system.

1.5 Research Questions

- (i) What are the requirements for developing postoperative patient monitoring system?
- (ii) How to design and develop IoMT based postoperative patient monitoring vital signs system?
- (iii) How to implement and validate the developed system in postoperative patient monitoring vital signs system?

1.6 Significance of the Study

The developed project is an important contribution to the healthcare system and the community. The increase of awareness in healthcare monitoring will contribute to reducing the risk of complications of the post-operative patient, increase access to care and decrease healthcare delivery costs. The adoption of these monitoring systems has the potential to reduce medical costs for the country in the long term. Furthermore, the vital signs parameters of the post-operative patient will be monitored and information will be provided to the doctor in charge remotely to undertake action when there is a problem. Early detection of any health complication can assist the nurses or doctors in taking required emergency measures, perhaps saving the patient's life.

1.7 Delineation of the Study

The study aimed to develop an IoMT based postoperative patient monitoring vital signs using a wireless body sensor to provide features to measure and monitor vital signs parameters, keep records of vital signs to be reviewed to analyze the evolution of the patient. The system automated the working routine of measuring the vital signs parameters without using paper and pen also without moving one room to another measure and keeping a record of the vital signs parameters. However, during the development of this study, we faced challenges and limitations due to the COVID-19 during data collection and most of the devices were not available and we were forced to purchase them from out of the country, and took a long time to be shipped.

CHAPTER TWO

LITERATURE REVIEW

2.1 Vital Signs

The term "vital signs" refers to a set of four to six of the most significant medical indicators that indicate the state of the body's vital processes. These measurements are taken to help assess a person's overall physical health, detect probable illnesses, and track healing progress (Hobbs, 2016).

The vital signs parameters are the most closely monitored physiological characteristics; generate a large quantity of data and seek a close follow-up to determine a patient's health status. Continuous vital signs monitoring necessitates the use of various equipment and systems, which, when used appropriately, have a beneficial influence on the activities involved by permitting the continuous collection of data. Providing information on patients' general health status, as well as assist to individuals' well-being by avoiding and decreasing deadly hazards (Bowyer & Royse, 2016).

2.1.1 Type of Vital Signs

Vital signs are measures of the most fundamental functioning of the body (Liddle, 2013). Body temperature, pulse rate, respiration rate (breathing rate), blood pressure (Although blood pressure is frequently monitored together with the vital signs, it is not considered a vital sign.), and oxygen saturation are the four primary vital signs that medical professionals and health care providers frequently check.

The detection and monitoring of medical issues can be aided by vital signs. In a hospital setting, at home, during a medical emergency, or anywhere else, vital signs can be monitored (Liddle, 2013).

2.1.2 Normal Parameters of Vital Signs of Healthy Adults

Table 1: Vital signs parameters

Vital signs	Healthy range
Blood pressure (BP)	120/80 mmHg
Pulse or Heart rate (HR)	60-100 beats per minute
Body temperature (T)	36.5°C to 37.5° Celsius
Respiration rate (RR)	10 to 16 Breaths per minute
Blood oxygen saturation SpO ₂	98%-100%

2.2 Post-Operative Vital Signs Collection

Traditionally, postoperative patient monitoring has consisted of the collection of routine and controlled vital signs, supplemented with observations of various elements of a patient's recovery.

One of the key challenges that healthcare professionals confront is the current usage of traditional methods such as pen and paper in vital sign data recording, collection, and storage. These practices have an impact on healthcare workers' daily tasks in terms of delays in recording, storing, and transmitting vital sign parameters data, which has an impact on the entire patient's treatment.

Normally, the nurse measures vital signs 2 times a day means morning and evening for people who are not in intensive unit care. Vital signs are taken periodically to evaluate physiological stability in patients who have undergone surgery requiring intravenous or inhalation anesthetic.

The main disadvantage of traditional vital sign records is that it takes a long time to write vital sign parameter measurements on paper and then measure them with various instruments and devices. Furthermore, data written on paper or forms can be lost or destroyed in some way. As a result, keeping essential patient information on paper is neither good nor secure where comes to the developed system.

2.3 Related Works

The patient monitoring system has become one of the most important developments in the medical sector and nowadays health sensors play an important part in hospital systems (Islam *et al.*, 2020). Studies show that the wireless network and its use in the area of healthcare are becoming more and more popular (Panchatcharam & Vivekanandan, 2019).

The study conducted by Liddle (2013) highlights the postoperative nursing care concepts. These have remained relatively stable over time, but nurses must ensure that they are up to speed on guidelines, rules, and evidence-based practice. Aravind (2020) proposes a simple gadget designed specifically for surgical and post-operative patients that will be capable of wirelessly transmitting data from a patient's vital signs to a distant device. This device uses a tiny diagnostic device with a restricted number of cables and tubes to monitor important parameters. However, the implementation of this system becomes expensive due to the high price of its devices. Therefore, Nayyar *et al.* (2019) propose a BioSenHealth functioning prototype for monitoring real-time vital sign of patients in terms of body oxygen level, pulse rate/heart rate, and body temperature. However, this strategy was shown to be unsuitable for real-time data visualization to assist health staff in monitoring the physiological stability of the patient. Therefore, Al Shorman *et al.* (2020) introduce IoMT-based remote health monitoring for diabetes patients to identify practical methods to improve healthcare living facilities. However, this system's focus was only on the glucose monitoring and has challenges of processing and storing big data. Moreover, Singh (2019) presented a fitness-based IoT that gathered all of a patient's clinical information, such as heart rate, blood pressure, and ECG, and could transmit signals to the patient's health practitioner about his/her comprehensive scientific statistics, providing a quick and reliable healthcare picture. However, Further, Senthamilarasi *et al.* (2018) used a heart sensor and DHT sensor to monitor a patient heart condition, it is particularly beneficial for chronically ill, aged, and even bedridden patients in the house to have his room temperature so that both patient and doctor can have real-time contact. However, the developed system was not cost-effective and was not suitable to be implemented in a hospital. A similar study was conducted by Joyia *et al.* (2017) who provided a summary of internet of things (IoT) services and technology used in healthcare. Based on the research conducted by several IoT researchers, they explore the application and advantages of the internet of things (IoT).

2.3.1 Comparison with the Existing Systems

The comparison with the existing system was done regarding their approach, services, technologies used and the limitation of the existing system as shown in Table 2.

Table 2: Comparison with the existing system

Author	Approach	Sensors	Services and Technologies	Limitation
Alecu <i>et al.</i> (2017)	developed a system that monitors vital signs for a human or non-human	heartbeat and body temperature sensors	a portable device that Monitors vital signs system and uploads data to the cloud	The system doesn't use mobile and GSM technology they are limited on two parameters which are body temp and heart rate
Senthamilarasi <i>et al.</i> (2018)	proposed a system of patient health monitoring	heartbeat and EEG sensors	It is frequently used in emergencies because it can be regularly watched, recorded, and data saved in a database.	The system doesn't use the mobile app and cloud also they are limited on 3 parameters, body temperature, ECG, and heart rate
Gupta (2018)	Developed remote monitoring vital signs	heartbeat, temperature, and humidity sensors	Wi-Fi and Bluetooth connectivity are used at home for chronically unwell, elderly, and even bedridden people.	The system doesn't use the mobile app, cloud, or GSM. It is limited to 2 parameters, heartbeat and body temperature

Author	Approach	Sensors	Services and Technologies	Limitation
Al Shorman <i>et al.</i> (2020)	Proposed IoMT monitoring the vital signs of diabetic patients	Glucose, heartbeat, and blood pressure sensors	Home real-time monitoring using Wi-Fi module	The system doesn't use mobile app and GSM. It is limited to 2 parameters, heartbeat and blood pressure.
Aravind (2020)	Proposed a simple diagnostic and monitoring equipment for postoperative patients	Heart rate, blood pressure, and body temperature sensors	Develop a wearable device for intensive care unit patients	The system is expensive and doesn't use the mobile app.
Palanisamy <i>et al.</i> (2019)	propose a patient Monitoring System that can be operated wirelessly	heartbeat, body temperature sensors	Monitoring health condition of the patient using wireless technology	The system doesn't use the mobile app, cloud, or GSM. It is limited to 2 parameters which are heartbeat and body temperature.

To address the various challenges presented by the existing systems regarding the cost and some missing functionality, SMS notification, mobile based remote monitoring and cloud monitoring of the existing system, the present study demonstrates the need of developing an IoMT based postoperative patient monitoring vital signs using wireless body sensor in Burundi. The developed low-cost system can be used in many hospitals to monitor vital signs parameters. The system will continuously monitor vital signs parameters and provide updates of the vital signs parameters in real time, hence, will significantly improve the healthcare system in Burundi.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

3.1.1 Case Study

The study was carried out in Burundi, one country of the East Africa Community. Particularly in two hospitals of Burundi, Clinic Van Norman, and Hospital de Kibuye. The developed system was implemented and tested in Clinic Van Norman in Bujumbura-Burundi.

3.1.2 Data Collection

There are several different qualitative and quantitative data collection methods. The gathered information through a mixed approach was useful in developing a low-cost system. In this project, interviews, group discussions, and surveys were used to collect information to answer project questions.

The use of interview methods with the different medical doctors, nurses, physicians helped to get clear information about vital signs monitoring in post-operative service. Discussing with medical experts helped to understand the requirements of the developed system.

Also, the use of surveys and group discussions was very suitable. The discussion was done with nurses who work in intensive unit care and post-operation service. The discussion focused on their working routine and how the developed system can be improved, what to add or remove, ideas that were useful in the development of the working system.

3.1.3 List of Participants

The selection was done based on the need and wish to contribute to the project research and the role of each participant. In total 15 participants were voluntarily involved in different stage of the project research, 2 Doctors, 5 nurses, 4 doctor specialist and 4 nurses' specialist.

Table 3: List of participants

Participants	Title	Unit	Participation methods	Place
A	Doctors	Intensive unit care	Google meet interviews	Hospital 1
B	Nurses	Surgery, post-operation	Phone interview,	Hospital 1
C	Doctors Specialist	Surgery, Post-operation	Phone interview google meet interview, Gmail	Hospital 2
D	Specialist Nurses	Intensive unit care	Discussion, interview	Hospital 2
E	Specialist Nurses	Intensive unit care	Discussion and interview	Hospital 3
F	Doctors Specialist	Surgery, Post-operation	Discussion and interview	Hospital 3
G	Nurses	Surgery, Post-operation	Discussion and interview	Hospital 3

3.2 Methods

3.2.1 Software Development Model Used

Agile system development methodology was used to develop this system due to its effectiveness. This methodology was selected due to its advantages compared to other system development.

Agile scrum methodology responds to the changing requirement of the project, gives high visibility of the daily project, has better productivity and control of the project means allow changes to be made at any point during the project, gives better quality means the ability to find problems, creates solution quickly and supports a continuous improvement at each stage of the project.

3.2.2 System Design

The developed post-operative monitoring system was divided into three units: sensing, processing, and alerting.

(i) Sensing unit

This unit has Max 30101, DS18B20, and ECG (*electrocardiogram*) sensor for the heart rate, blood pressure, oxygen saturation, measuring the temperature of the body, and checking the respiration rate of the patient. The max 30101 is used to detect the heart rate, and oxygen saturation of the body if they don't exceed the normal healthy range parameters, it operates on a single 1.8V power supply and can be a wearable device. The DS18B20 is a body temperature sensor used to monitor the healthy range parameters of the body if it doesn't exceed normal parameters. It can work in the condition of -55°C to $+55^{\circ}\text{C}$ within a voltage range of -0.5V ~ $+6.0\text{V}$. The electrode on the ECG is used to detect the patient's respiratory rate.

(ii) Processing unit

The major purpose of this system is to process all data received from the sensing operation in real-time. ESP WROOM 32 was used as the open-source microcontroller board. The ESP has Wi-Fi and Bluetooth integrated into it to ensure that a wide range of applications can be targeted. Wi-Fi is used to provide internet connectivity from a Wi-Fi router for real-time data monitoring through the cloud and on a mobile phone. It operates with a frequency range of 2.4GHZ to 2.5GHZ with 802.11n up to 150Mbps and has a power supply of 3.0V~3.6V and recommended operating temperature range -40°C ~ $+85^{\circ}\text{C}$.

(iii) Alerting unit

This unit has a buzzer and a GSM Module. The GSM module is used to send an SMS notification to nurses, doctors, and physicians to show them which vital signs parameters are abnormal. A buzzer was used to produce an alarm to alert nurses, doctors, or physicians.

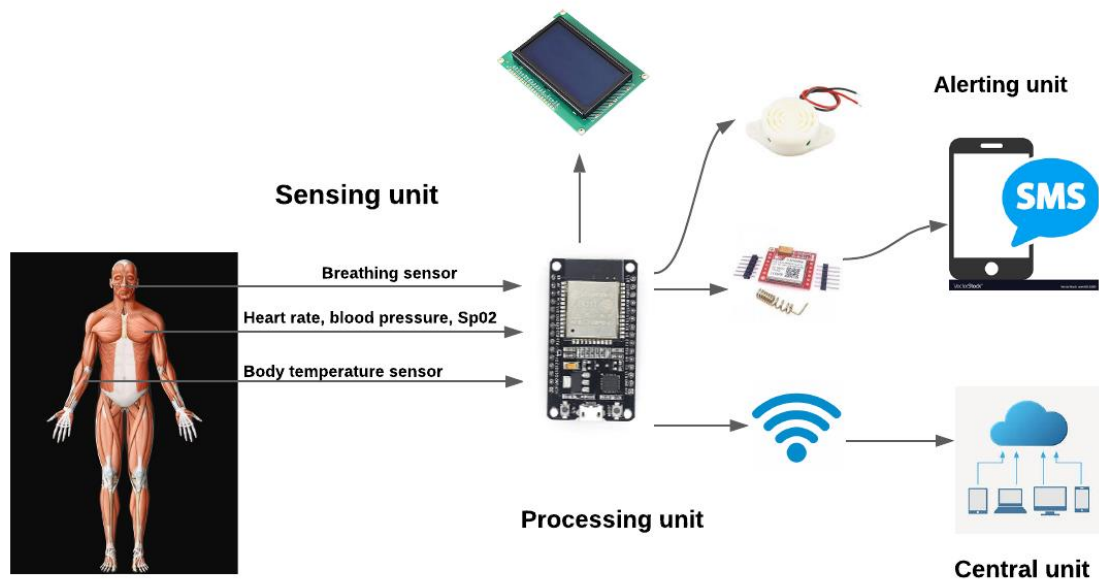


Figure 1: System architecture

Figure 1 depicts the developed system architecture, which is described as a conceptual model showing how the system would be deployed. The system was deployed in a patient room at the hospital and the sensor was on the patient's body.

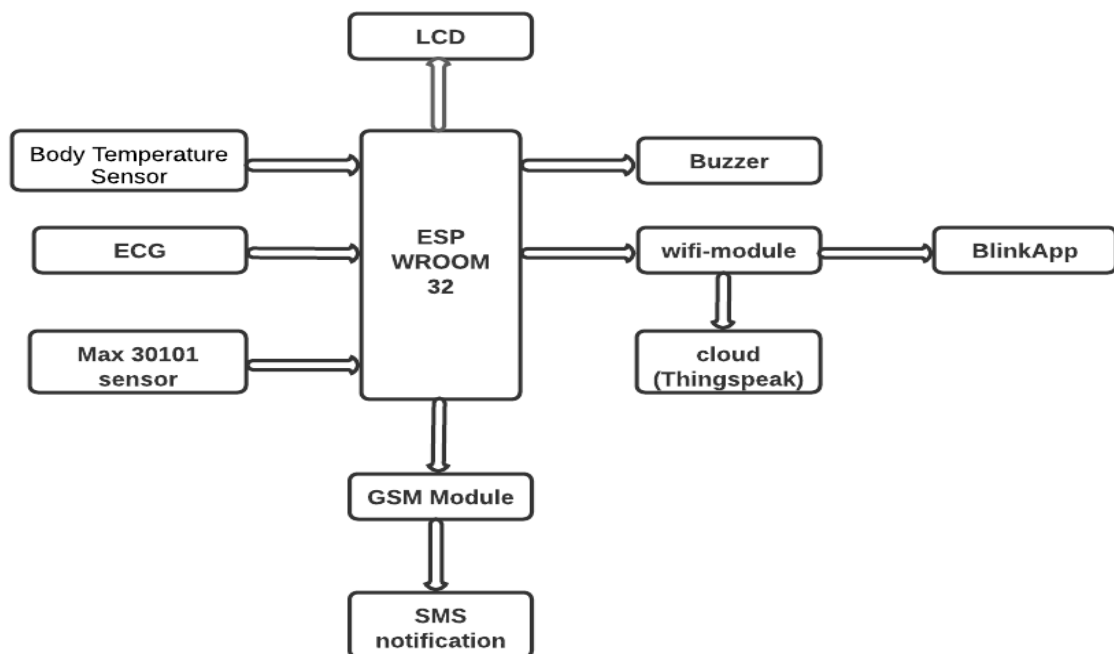


Figure 2: Block diagram of the system

3.2.3 Description of electronics components

(i) Microcontroller

ESP-WROOM32 ESP32 is a microcontroller series with low-cost power systems on a chip. The ESP32 is an advanced version of the ESP8266 series. The ESP32 series was created and developed by Expressive Systems. The ESP32 has a dual-core and ultra-low power co-processor, a low-cost Wi-Fi microchip embodying both a full TCP/TP stack and microcontroller potentiality. ESP WROOM is suitable for IoT-based applications compared to Arduino modules which do have not a built-in Wi-Fi capability (Islam *et al.*, 2020).



Figure 3: ESP WROOM 32 (Islam *et al.*, 2020)

(ii) GSM Module

In the communication section, a GSM module of the type GSM SIM800L is chosen to carry out the work. It has a Dual-Band 900-1800 MHz frequency range and is only intended for use outside of Europe and the United States. It has a proven performance, an industrial-grade interface standard, and an incorporated TCP/IP protocol, making it presentable and appropriate for an electronics project. It is supposed to be able to interface with any low-power microcontroller because it requires very little power during operation.



Figure 4: GSM module

(iii) MAX30100

The MAX30100 is a sensor that combines a heart rate monitor and pulse oximetry. Two LEDs, a photodetector, better optics, and low-noise analog signal processing are used to detect the pulse oximetry and heart rate signals. It will be used to measure heart rate, and oxygen saturation (Kadhim *et al.*, 2020).



Figure 5: Max 30100 (Kadhim *et al.*, 2020)

(iv) ECG sensor

An ECG is a digital recording of the electrical signal's activity, it is put on the chest surface to allow the heart to move. At various periods during the respiratory cycle, the lead axes change, and any sufficiently exact measurement of the mean cardiac electrical axis reveals fluctuations that are connected to respiration (Wan *et al.*, 2018).



Figure 6: ECG sensor (Wan *et al.*, 2018)

(v) DS18B20 Temperature sensor

The DS18B20 temperature sensor is a digital temperature sensor used to measure temperature in the range of -55°C to 125°C with 5% accuracy. The resolution of this sensor ranges from 9 bits to 12bits. Any microcontroller that uses a digital pin and this sensor works great together.

Using a one-wire bus protocol, which requires just one data line, this sensor can communicate with the central microcontroller (Valsalan *et al.*, 2020).



Figure 7: DS18B20 temperature sensor (Valsalan *et al.*, 2020)

(vi) Liquid Crystal Display

LCD 3.2-inch is a TFT LCD Display Screen Module Resistive Touch Panel 320x240 with SD Card Slot for Mega 2560. This 3.2-inch display works at 3.3V (Mohamad *et al.*, 2020).



Figure 8: LCD display (Mohamad *et al.*, 2020)

(vii) Piezoelectric Buzzer Module

Buzzer It's a type of audio signaling device that can be mechanical, electromechanical, or piezoelectric in nature. It's an alarm circuit that requires the user to be concerned about something. It can be utilized by simply connecting it to a DC power supply with a voltage range of 4 to 9 volts (Koshti *et al.*, 2016).



Figure 9: Buzzer (Koshti *et al.*, 2016)

3.2.4 System Implementation

(i) Configuration of the system

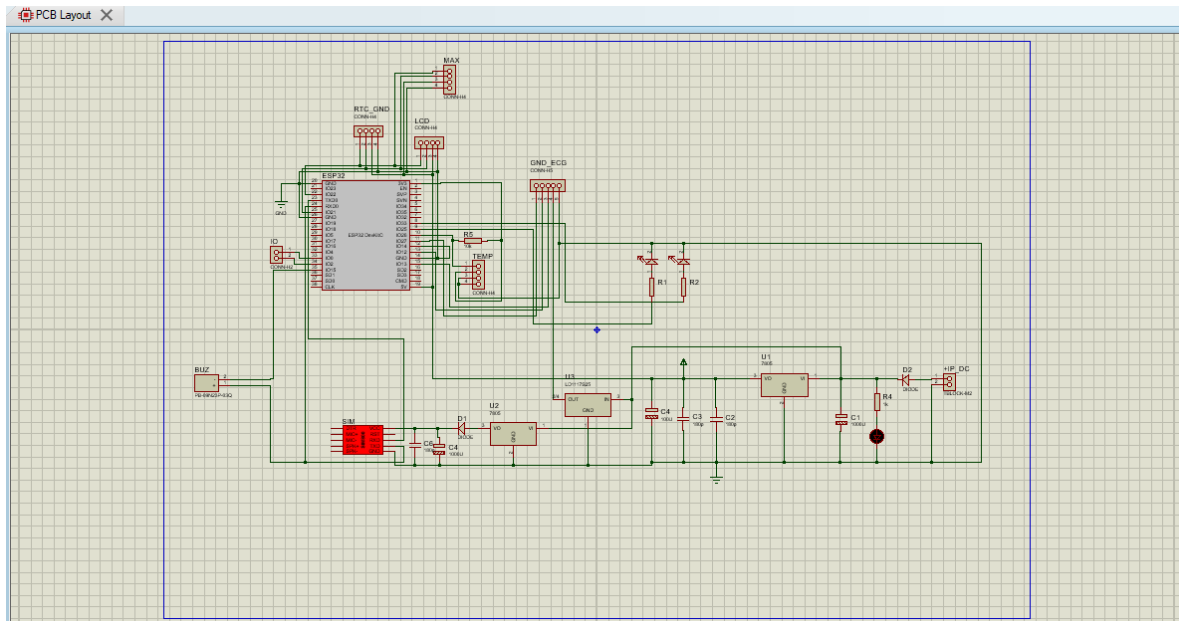


Figure 10: Schematic diagram

(ii) Programming languages used and software

The developed system will be done using the C programming language with the Arduino IDE's help the C programming language is a high-level, procedural, and a general-purpose computer programming language. It is the most widely used and popular language due to its powerful features. Arduino IDE is an open-source software used to write, edit code and upload it to the board, it uses C++ and C programming languages and can be used for any Arduino board. All of the sensors' libraries were imported, and the output was visible in the Arduino IDE's serial monitor.

To deliver real-time information regarding data acquired by sensors, the ThingSpeak platform was deployed. ThingSpeak is a cloud-based and open source and analytics platform for aggregating, analyzing, and displaying data in live streams (Fig. 11).

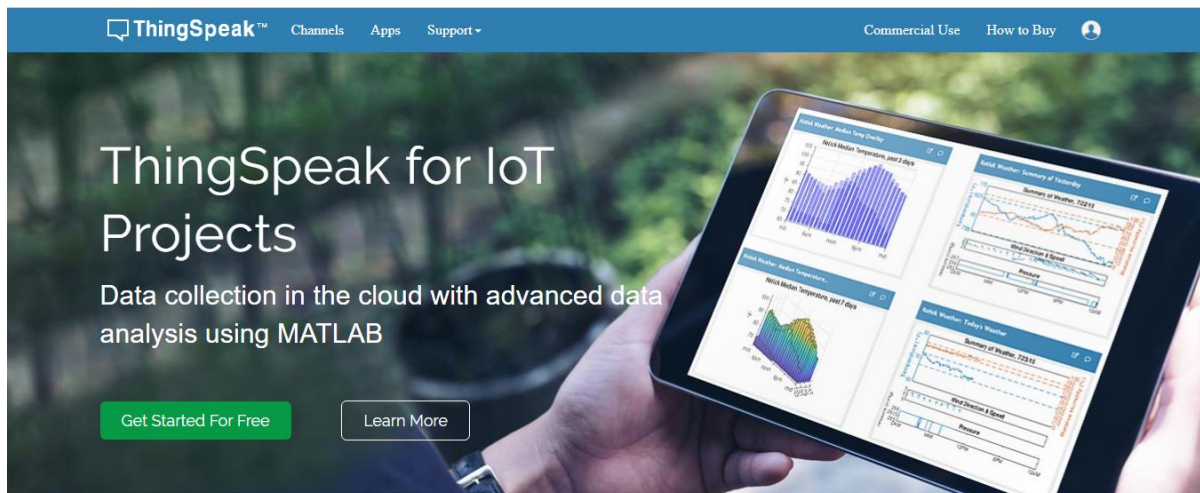


Figure 11: ThingSpeak IoT cloud

Blynk was used as a mobile app to keep track of the data collected by the sensors. Blynk is an iOS and Android app that allows you to control Arduino, Raspberry Pi, and other web-connected devices (Fig. 12). It's a digital dashboard where we may drag and drop widgets to design a project's graphic interface.

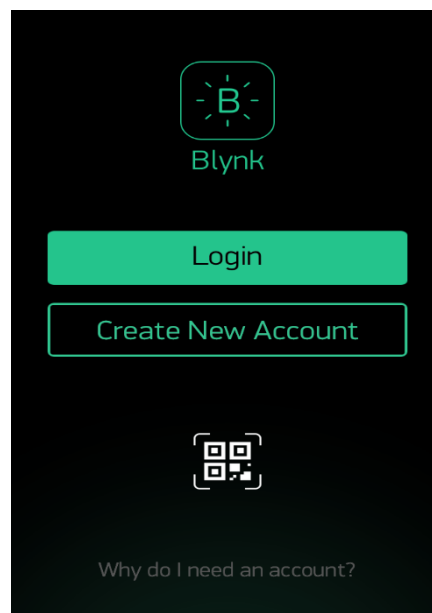


Figure 12: BlynkApp cloud

(iii) The functionality of the developed system

Figure 13 shows the flowchart of the developed system. A flowchart is a diagram that shows how a process, system, or computer algorithm works. Activities and connections are

represented by various types of boxes and rows, respectively. The flowchart below depicts a step-by-step system functioning from beginning to end.

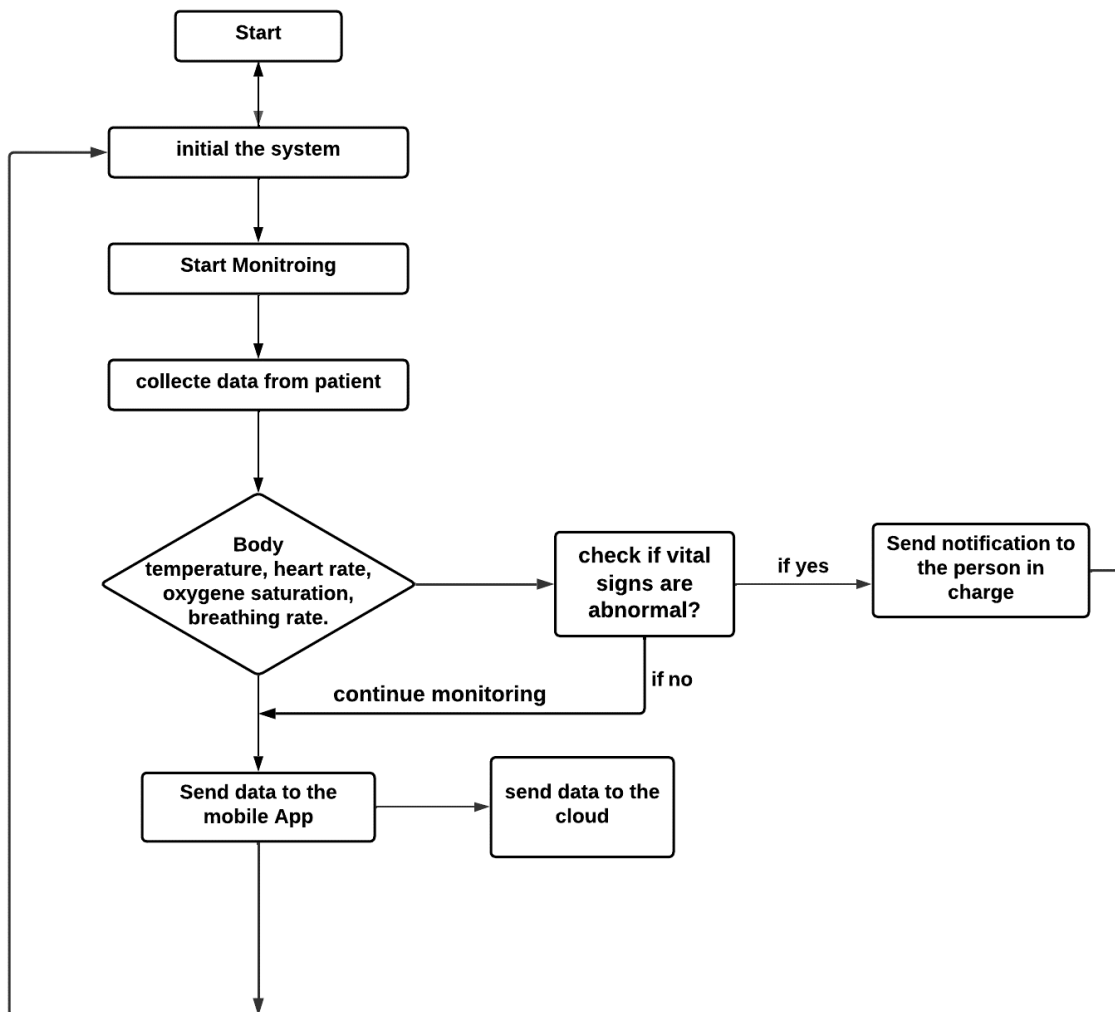


Figure 13: Flowchart of the developed System

The flowchart explains the working flow of the system. After turning on the system, the sensors will start monitoring the vital signs parameters at every stage. In this project, the ECG was used to measure the respiration rate, the Max30100 was used to measure heart rate, oxygen saturation, and DS18B20 was used to measure body temperature. Sensors continuously monitored the vital signs parameters and detect whether there is an abnormal condition or a normal condition. If there is no emergency condition detected, the patient is in normal condition. If there is any abnormal condition detected the system will activate the alarm and send an SMS notification will be sent to the person in charge, it can be a doctor, a nurse, all will be able to see which vital signs have exceeded the normal parameters, all personnel will be able to see the emergency condition of the patient locally or remotely.

3.2.5 System Testing

System testing is a process that is applied to a complete integrated system. Before testing the entire system in the field, prior hardware testing was done to determine if the system meets the user's requirements and field testing was done after for verification and validation of the developed system.

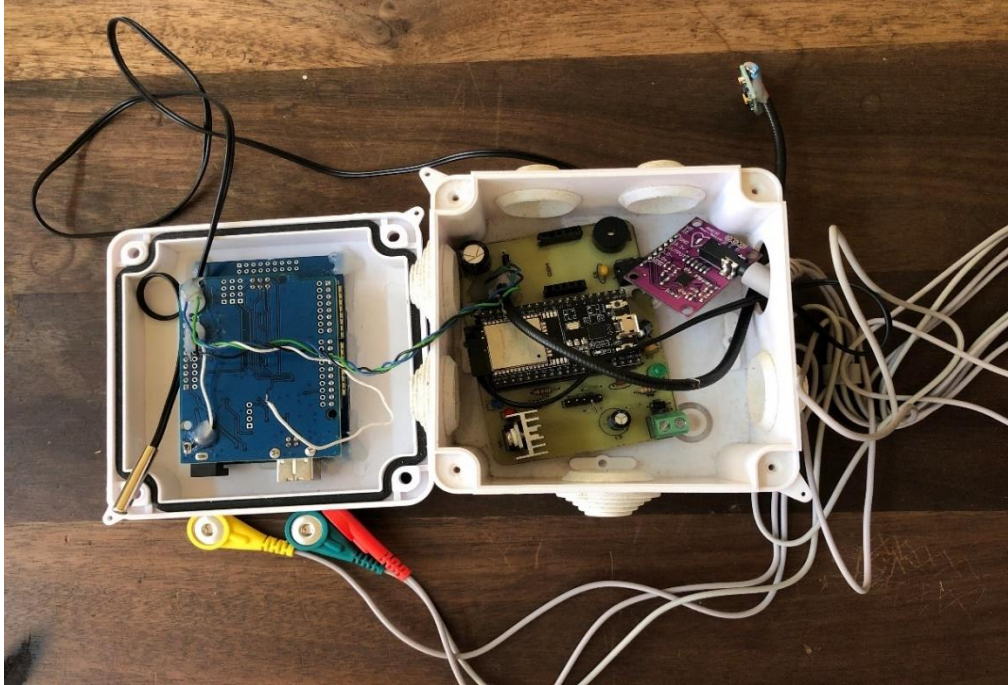


Figure 14: Connection of hardware components

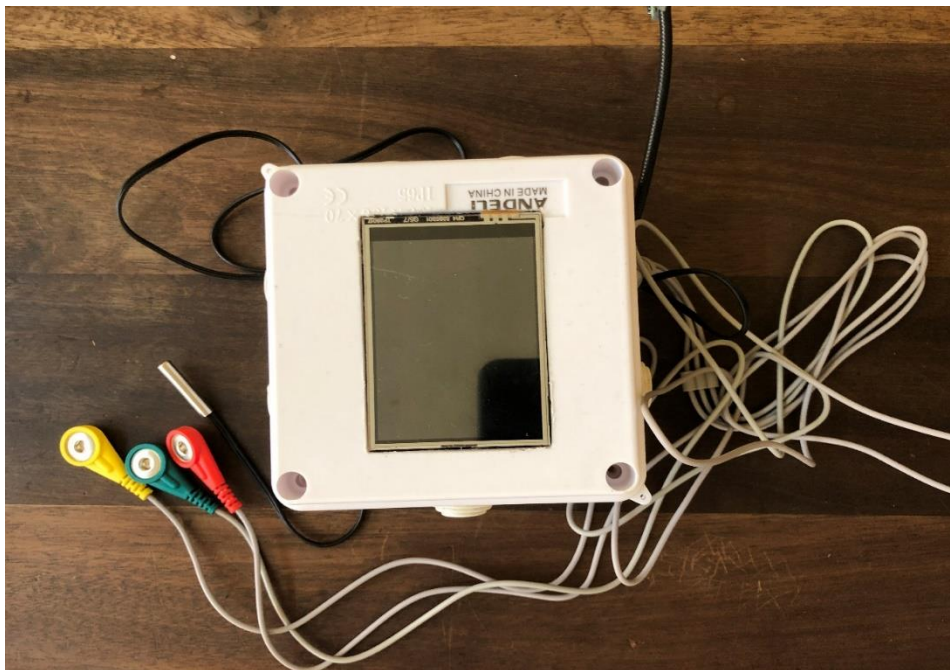


Figure 15: Prototype development

(i) Unit testing

Unit testing is a type of test that is performed on a section of code to ensure that it is functional. This is accomplished on a functional level.

(ii) Integration testing

Any sort of software testing that aims to check the interfaces between components against a program design is known as integration testing. Its primary purpose is to expose interface module issues.

(iii) System testing and performance

System testing ensures that a fully integrated system fits its specifications. Acceptance testing was done to verify the readiness of the application if it satisfies all requirements. Figure 17 shows how system performance was done to determine the effectiveness and response time of the systems.

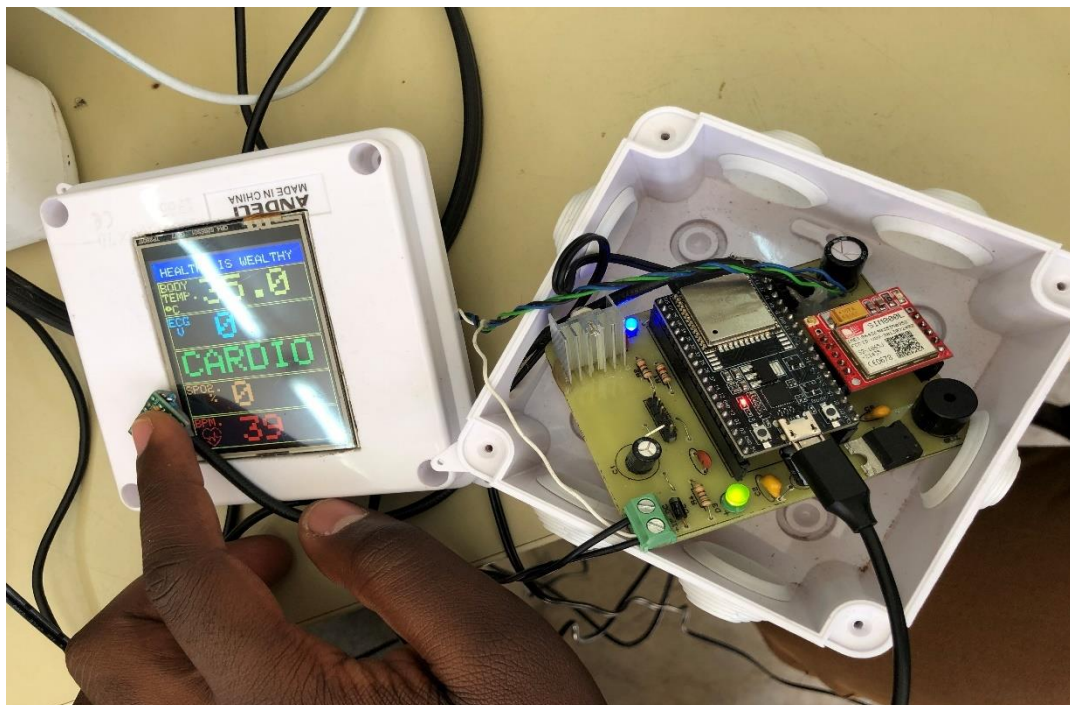


Figure 16: Lab testing system

Then data transmission testing from sensors was done to verify if data can be sent to the cloud and to the mobile application to determine if it is working. Figure 18 below shows how data transmission was tested to display data in the mobile phone application.

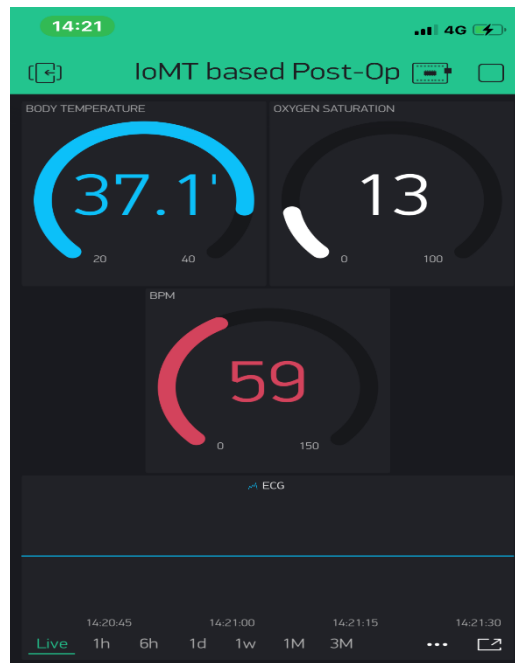


Figure 17: Data processing in mobile app

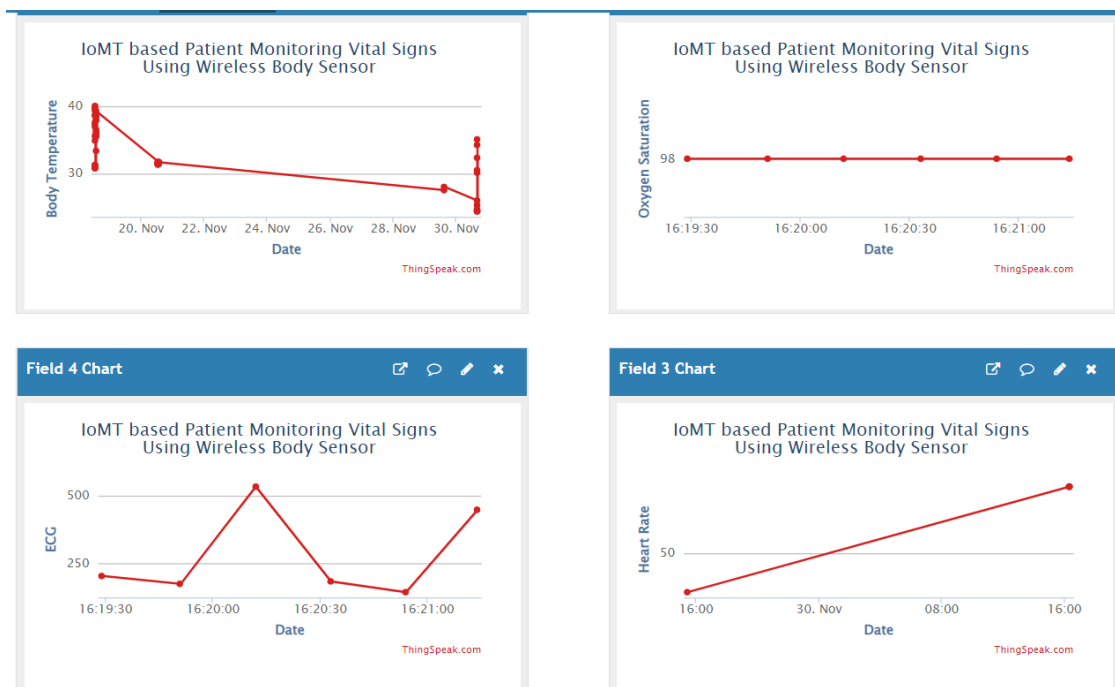


Figure 18: Data processing in the cloud

(iv) Field-testing approach

The approach of field testing was carried out in the hospital using a complete prototype. Before conducting a test, a discussion was made with a health care professional to explain to them how the prototype is working which devices are used, which technology is used also if applied to the patient body there will be no effect.

The goal of the field-testing approach was to confirm that the system could be deployed successfully in the hospital and function as planned. The system was mounted in the patient room on his bed as shown in Fig. 19.



Figure 19: System installation

The vital signs parameters were measured and visualized in real-time and the sensor was applied to this hand as you can see in Fig. 20, Fig. 21, and Fig. 22



Figure 20: Body temperature measurement



Figure 21: Heart rate and Spo2 measurement



Figure 22: ECG measurement

During testing, we were assisted by healthcare professionals to verify if the vital signs parameters measured are correct without error and to validate the working efficiency of the prototype. A successful system implementation would require healthcare professionals' assistance to ensure that there is any mistake in the placement of the sensors, this means healthcare professionals are the one who shows where to place the sensors on the patient body in order to record the correct parameters to avoid errors.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 System Design Result

The schematic diagram in Fig. 10 was used as a guide to implementing the system on PCB. Electronic components are mechanically supported and electrically connected via printed circuit boards. Printed Circuit Boards are constructed of copper sheets bonded to a non-conductive substrate and carved with conductive channels, tracks, and signal traces. After that, the board is loaded with electrical components, and etchings are made on the surface to allow electricity to flow from component to component via copper as you can see in Fig. 23.

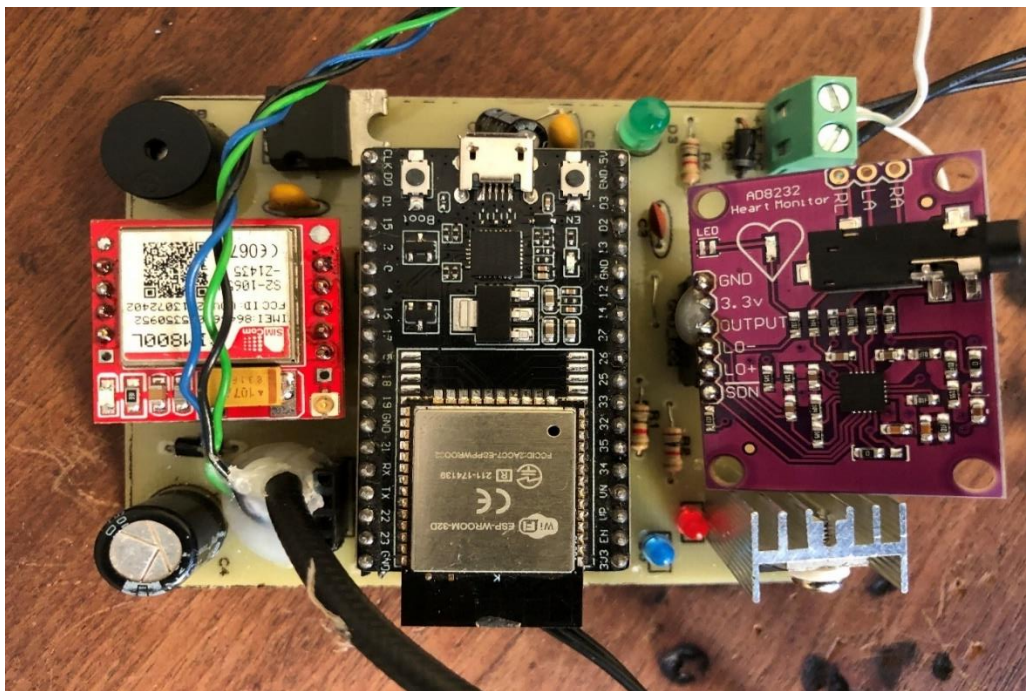


Figure 23: System PCB

4.2 Results from Data Collection

Assessment of Burundi hospital was very inevitable to understand how doctors and nurses monitor postoperative patient vital signs and how they know that there is a complication so that they can react accordingly. The focus was to examine the experience of nurses and doctors working in postoperative unit care. Figure 24 demonstrates the number of participants in this study, 66.7% of participants were doctors, 16.7% were enrolled, nurse and nurse attendants.

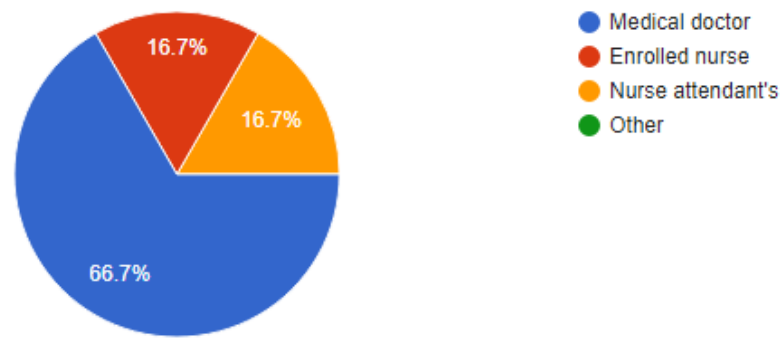


Figure 24: Participant occupation role

4.2.1 Number of Times to Measure Vital Signs in Postoperative Unit Care

A normal day in postoperative patient unit care in any hospital starts with nurses attending all patients and monitoring the vital signs parameters. The vital signs parameters are often measured by hand in the most hospital.

Results showed that 50% of respondents said that they applied continuous monitoring for all patients, 16.7% said that they monitor patients every 15 min for 1hour usually takes 24 hours, 16.7% said that they monitor patients every 2 hours and 16.7% said that it depends on the gravity of the surgery, some patient requires continuous monitoring while others don't, but obviously after every 4 hours as shown in Fig. 25.

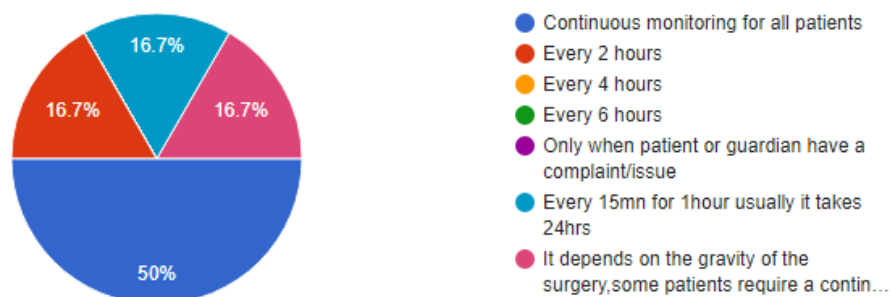


Figure 25: Vital signs measurement

4.2.2 Challenges Faced in the Postoperative Room

Due to the placements of the systems, the size of the monitors, and the number of systems in place, the current systems do not assist healthcare practitioners in vital sign monitoring. Instead of employing technological systems and gadgets, healthcare professionals do some measurements manually, they document vital signs using papers and, writing vital signs

parameters measurements on paper which takes a lot of time. The biggest challenge of using paper when data is written on paper or forms is that it is possible to lose information or corrupt in some way. As a result, keeping essential patient information on paper is neither good nor secure.

There are other challenges faced by healthcare professionals when measuring vital signs. Those challenges are:

- (i) Patients are observed for less time on continuous monitoring machines because there isn't enough equipment to monitor all patients.
- (ii) Storing the medical record of the patient.
- (iii) Many patients are in the same room with insufficient monitoring machines.
- (iv) The insufficient number of nurses.

4.3 System Testing and Performance Results

Based on system design each unit was tested during system testing and performance. In the sensing unit, each sensor was tested to analyze its performance regarding measurement and monitoring. The lab testing results were efficiently reviewed and met the requirements, and a real-time data visualization of body temperature, ECG, heart rate and oxygen saturation were made possible. As presented in Figs. 26, 27, 28, 29 and 30 the real-time visualization of data from sensors was enabled.



Figure 26: Mobile visualization of data from Sensors

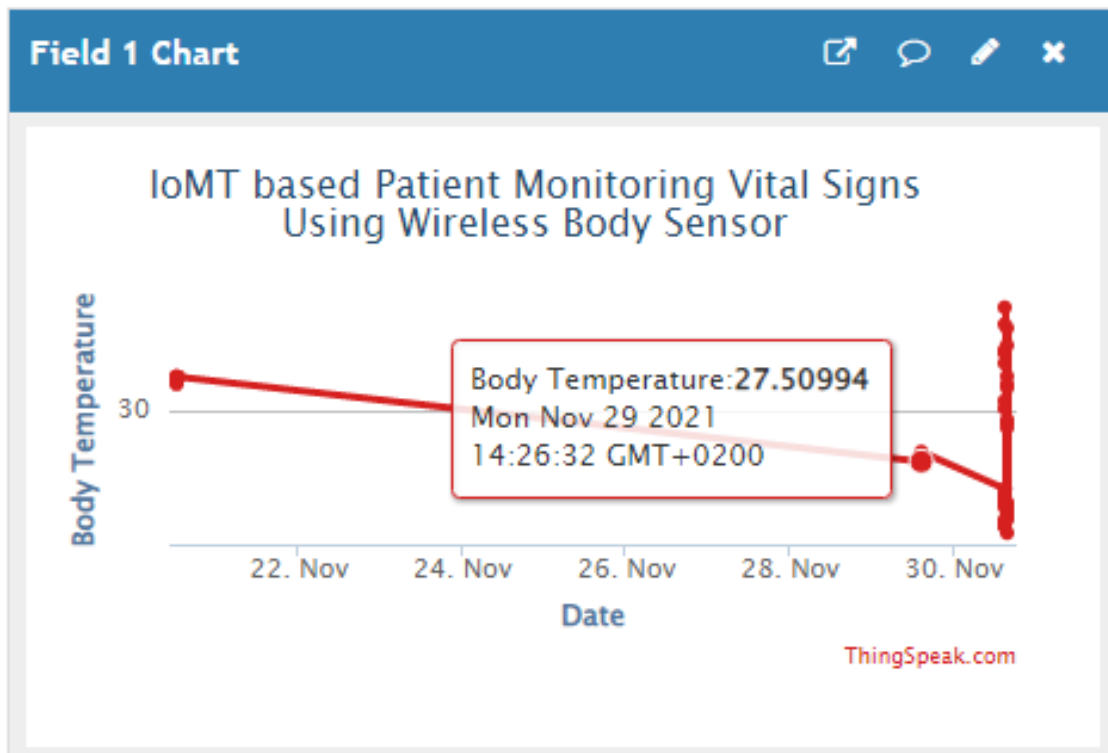


Figure 27: Data visualization from the DS18B20

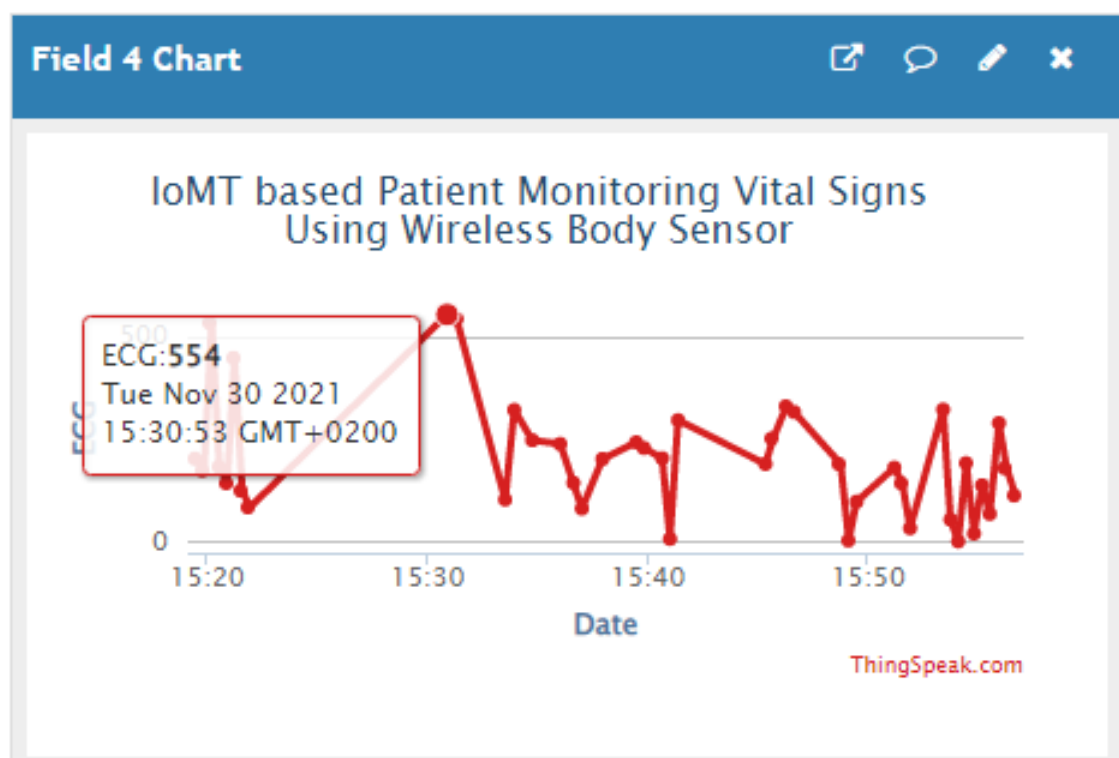


Figure 28: Data visualization from the ECG

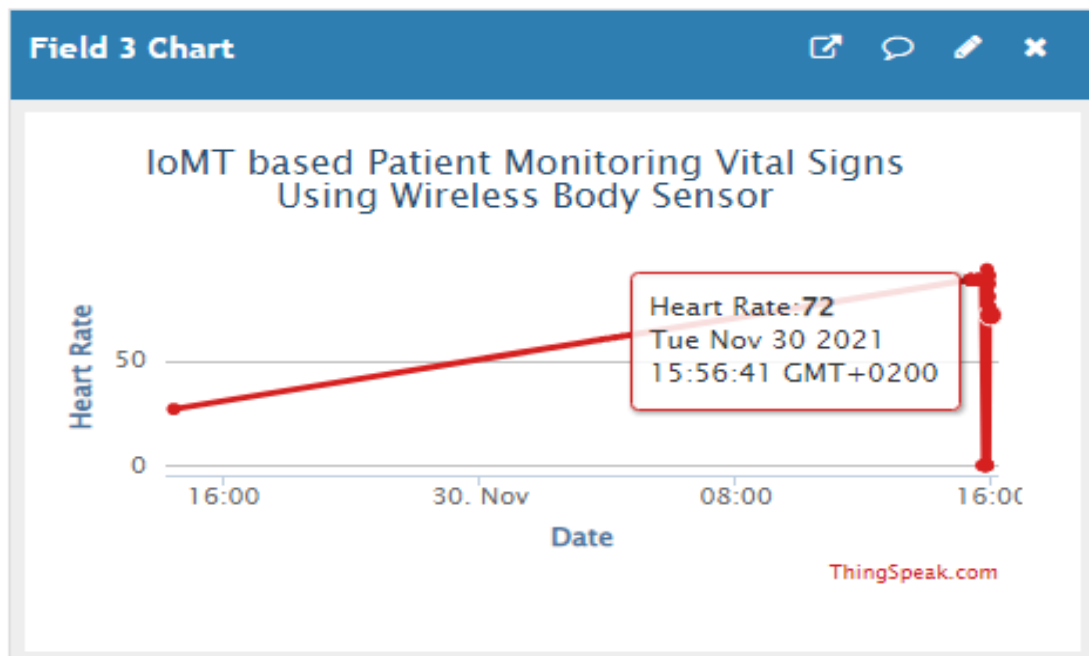


Figure 29: Data visualization from the MAX30100

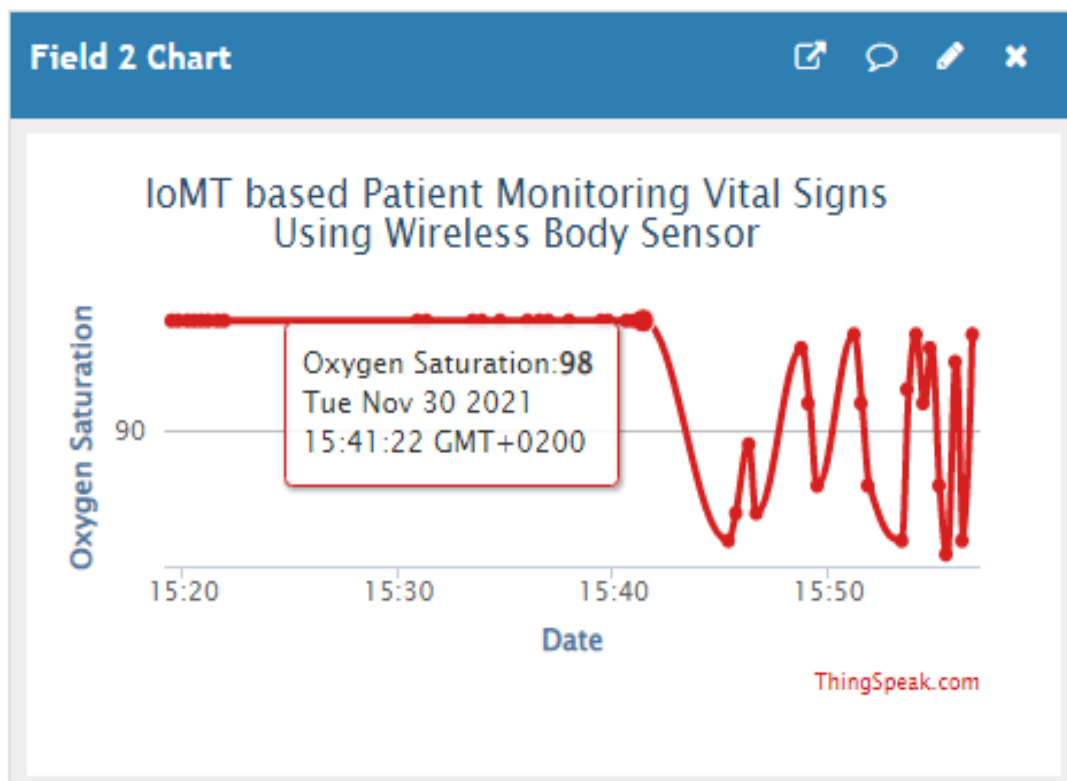


Figure 30: Data visualization from the MAX30100

When the normal parameters of vital signs are exceeded, an SMS message is delivered to the nurse as shown in Fig. 31.



Figure 31: SMS notification

4.4 Field-Testing Results

During the field-testing phase, the system was mounted in the patient's bed. From the evaluation of the system, it was observed that the detection of abnormal vital signs depends on the state the patient means when there is a complication after the surgery. However, the system did not detect any abnormal parameters of vital signs because no patient was presenting any complications after the surgery. The normal vital signs parameters were detected continuously, as shown in Fig. 32, data from the sensor was continuously sent to the mobile phone and the cloud, patient's condition monitored in real-time was displayed using a Liquid Display (LCD) device.



Figure 32: Visualization of data on LCD

Figures 32, 33, 34, 35, 36, and 37 show visualization of live data sent on the mobile app and ThingSpeak cloud platform. The detected parameters show different values of vital signs measured during the testing process.



Figure 33: Visualization of data on mobile phone

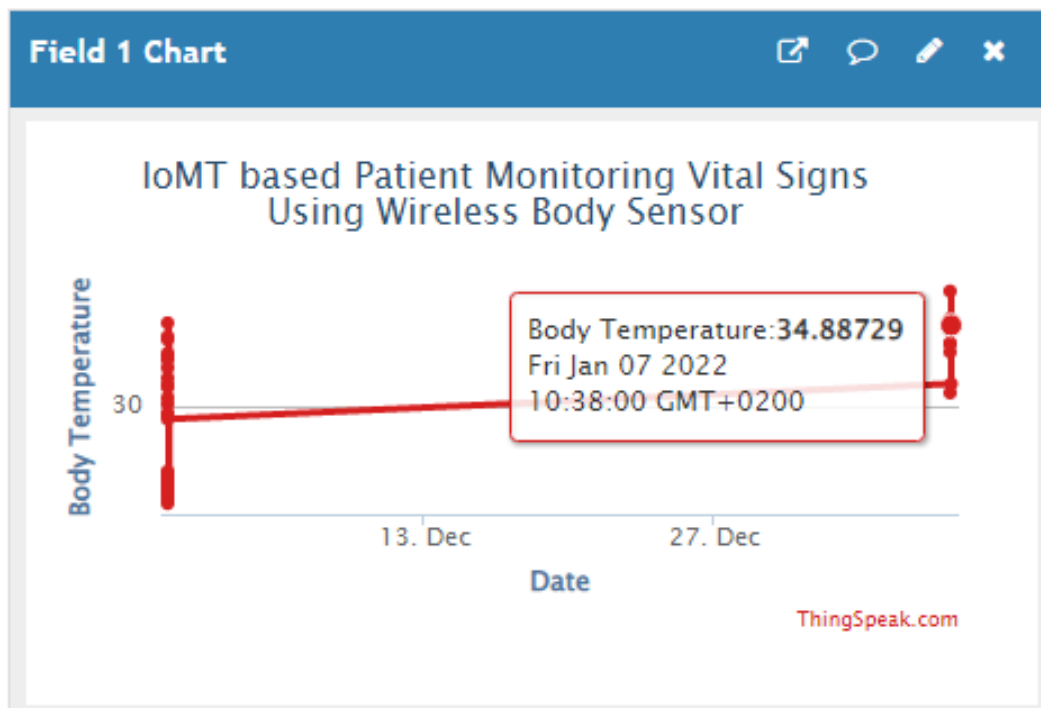


Figure 34: Data visualization from a DS18B20

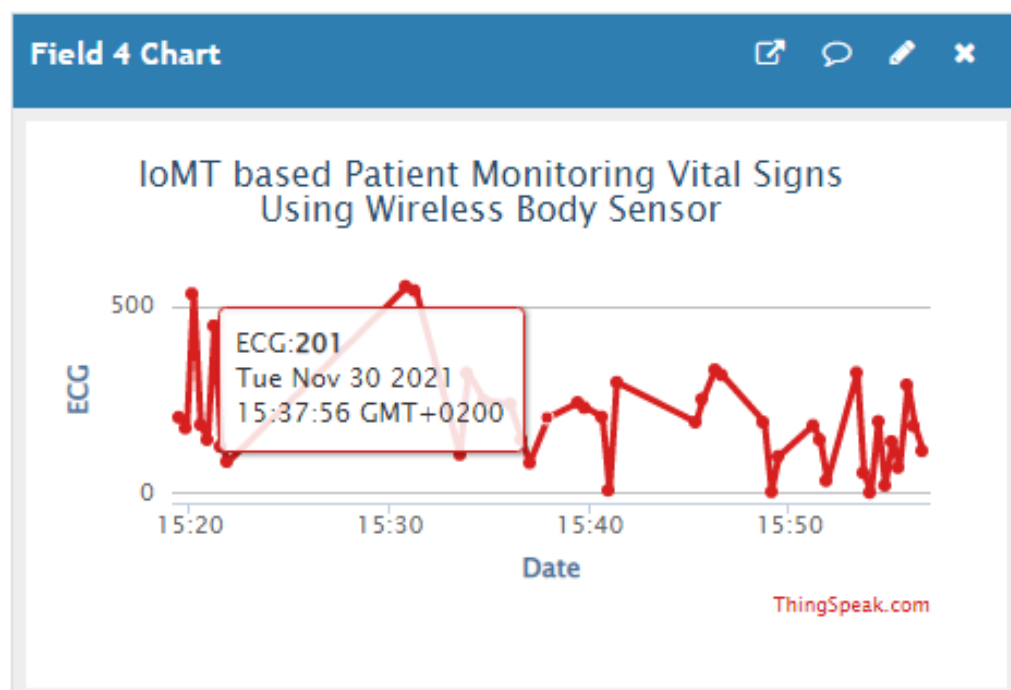


Figure 35: Data visualization from the ECG

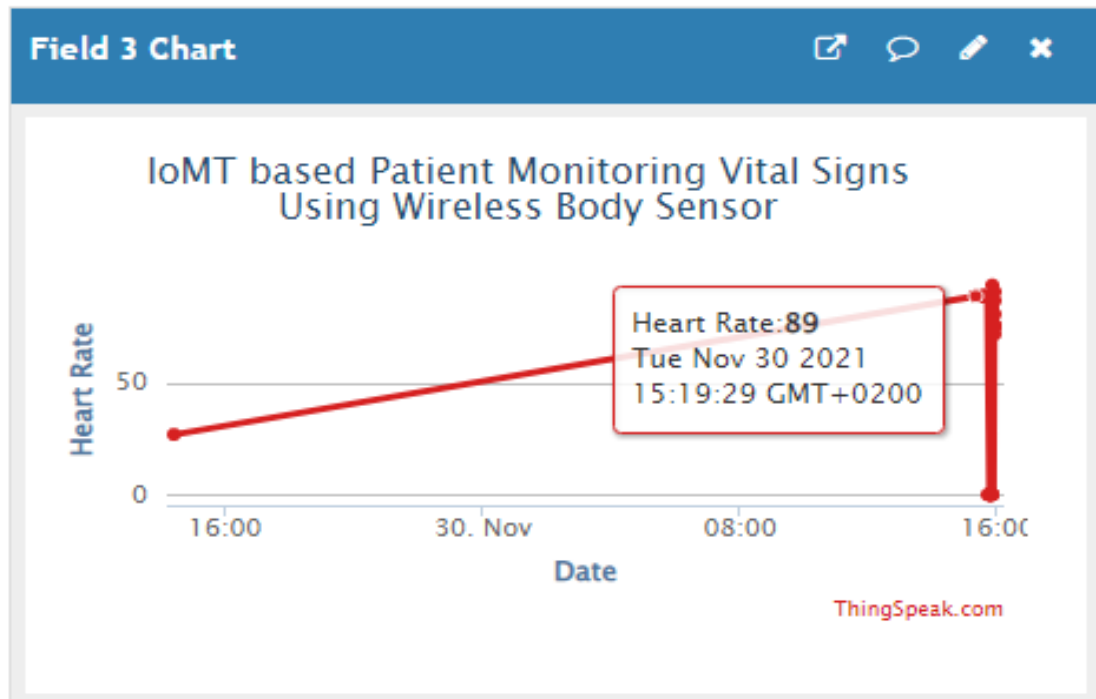


Figure 36: Data visualization from the MAX30100

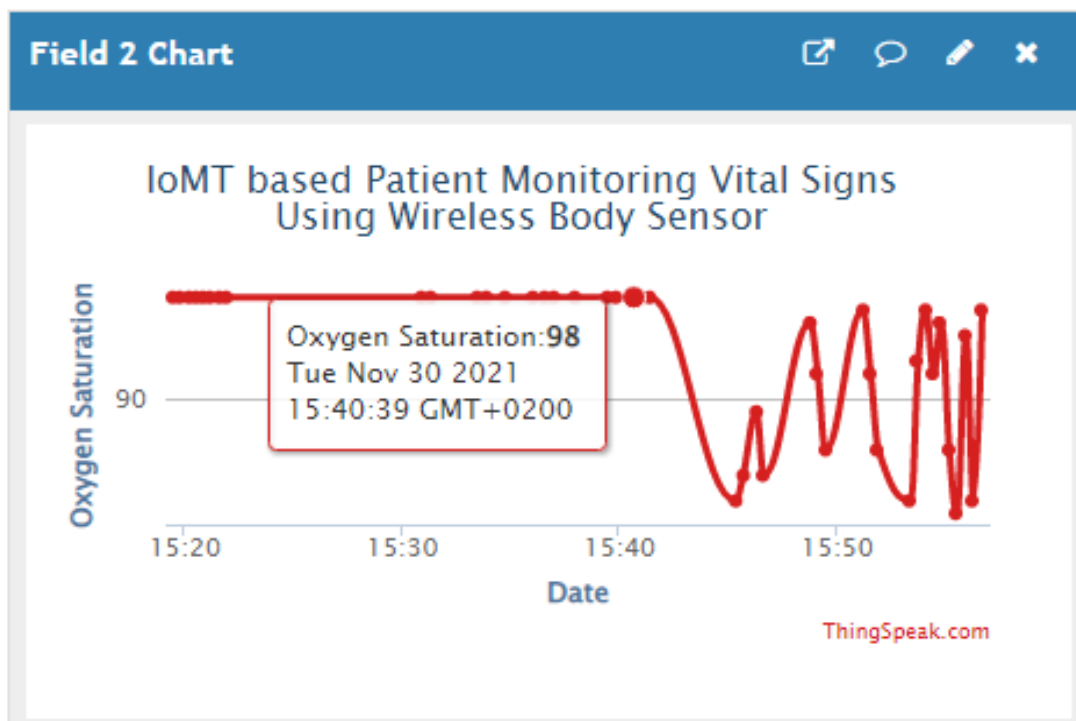


Figure 37: Data visualization from the MAX30100

4.4.1 Attributes of the developed system

Table 4: Developed system attributes

Attributes	Description
Low cost	The developed system is cost-effective and can be deployed in any hospital
Real-time monitoring, updates, and vital signs detection	The updates of the vital signs' status were timely provided
Fast alert method	Alerting the nurse and doctors is very fast, they are informed of the abnormal condition early before there is a complication

4.5 Discussion

From the lab experiments and the field experiments, we can testify that the vital signs parameters can be measured and monitored in real-time. Compare to the other existing system, the system is fast and easy to use, the combination of mobile applications and cloud monitoring will help healthcare professionals to improve their work which also helps healthcare professionals in their decision making. The use of electronic devices to record patients' vital signs in real-time makes more accurate and more efficient diagnoses and treatments this improve effective result compared to the old one of using paper record.

Body temperature, heart rate, oxygen saturation, and respiration rate were all measured using the DS18B20 sensor, Max30100 sensor, and ECG. In the mobile app and cloud, data from sensors was updated every 5 min. Figures 32, 33, 34, 35, 36 and 37 represent the visualization of data in real-time and instantly updates from the sensors, in case there is a detection of abnormal parameters that occurs from a critical condition of a patient leads to the alert as a text message notification that was sent to the nurses to inform them that there is a problem with a patient in postoperative unit care that needs assistance as shown in Fig. 31.

Based on the observation, results, and evaluation the system is a real-time monitoring and can be easily implemented. The system is affordable, accurate, efficient, and effectiveness. The healthcare professionals can visualize data from sensors using IoMT technology.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Different physiological markers that represent the overall status of the patient's health condition are referred to as vital signs. IoT and digital technologies are being used to improve vital sign monitoring and healthcare in general. The study aims to contribute to the reduction of patient health complications by using wireless sensor measures and monitoring. The developed system proved that the system can provide vital signs parameters in real-time.

Findings showed that the existing system in Burundi and most of the EAC countries are still using the old methods to record vital signs parameters on the papers. In case the patient is unwell and in critical condition, the use of the traditional methods observation rounds in post-operative and false alarm has led to missing early detection of patient health condition. The continuous vital signs parameters are measured and monitored with the automated and connected monitoring system that determines the patient that needs more attention and which vital signs parameters should be closely monitored.

Through the inbuilt WiFi on the ESP32 micro-controller, the medical worker was able to remote visualize the vital signs parameters on both cloud and mobile applications. With the detection of vital signs critical conditions, the notification alarm and message on the mobile phone will be sent. The developed system will help health workers to easily measure and monitor vital signs parameters in real-time.

5.2 Recommendations

The use of the developed system will effectively improve the current measurement and monitoring method used in vital signs monitoring in Burundi and the EAC region. This study recommends the following:

- (i) The involvement of medical professionals through the minister of health is required to assess the designed system's performance before it can be successfully implemented.
- (ii) The use of the developed system in promoting healthcare innovation in Burundi and the EAC region.

- (iii) Medical staff are recommended to always ensure that patients in postoperative unit care are well monitored to avoid any complications due to the vital signs problem.
- (iv) Hospitals are recommended to use the developed system to easily measure and monitor postoperative patient vital signs parameters in real-time.

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APPENDICES

Appendix 1: Questionnaire for Healthcare Professionals

Current practice in Postoperative patient care at your hospital

Introduction:

You are invited to participate in a study being conducted by Jesus de la Paix Irakomeye, a graduate student of the Nelson Mandela African Institute of Science and Technology undertaking a Master in Embedded and Mobile system specializing in Embedded System. Currently, I am working on an embedded system project which is about creating a system to monitor Postoperative Patient Vital Signs.

Purpose:

This study is to assess how Doctors and Nurses monitor Postoperative Patient Vital Signs in hospitals.

Procedure:

Participation should take 10min to complete. Your participation in this survey is voluntary and you may take part in or exit the survey at any time without penalty.

Privacy and Confidentiality

Kindly note that your identity and Hospital name will remain confidential, and your IP address or email will not be collected. Data will be later downloaded for analysis and reporting. The result of this study will be used only for the purpose of satisfying the Nelson Mandela African Institute of Science and Technology Masters board project report requirements.

Contact:

If you have any question concerning the study, please feel free to contact me (Jesus de la Paix Irakomeye) at irakomeyej@nm-aist.ac.tz

* Required

1. Full name *

2. Name of the Hospital *

3. Role occupation in Hospital? *

- ☐ Medical
- ☐ doctor
- ☐ Enrolled nurse
- ☐ Nurse
- attendant's
- Other

4. If other specify

5. What vital signs are monitored during post-operation? *

6. How often should the vital signs be monitored post-operatively after surgery? *

- ☐ Continuous monitoring for all
- ☐ patientsEvery 2 hours
- ☐ Every 4 hours
- ☐ Every 6 hours
- ☐ Only when patient or guardian have a

complaint/issueOther:

7. How often should post operative monitoring of a patient post elective surgery be done? *

8. How often should a nurse check on a patient? *

9. What are the methods used to monitor post-operative patient in healthcare facilities? *

10. Are there any challenges faced during monitoring post-operative patient in healthcare facilities? *

☐ Yes

☐ No

Yes

No

Other

11. What are those challenges? Name at least 5 challenges. *

Appendix 2: Ethical Approval Application for Project Study



Université Espoir d'Afrique CLINIQUE VAN NORMAN

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Agréée sous l'Ordonnance Ministérielle n°630/2110/Cab/2012 du 09 Août 2012

Bujumbura, January 24, 2022

Dear Mr. Jesus,

Re: Ethical approval application for project study.

This is in reference to your application request dated 21st January, 2022 at Van Norman Clinic.

The clinic has accepted your ethical approval application for project for a period of one week and you will be attached in surgery intensive unit care, you will work under their supervision. This application takes effect from 24th January, 2022 and expires on 31th January, 2022.

However, the clinic does not offer any form of financial assistance, you will be responsible for your own upkeep during the whole period of your project study.

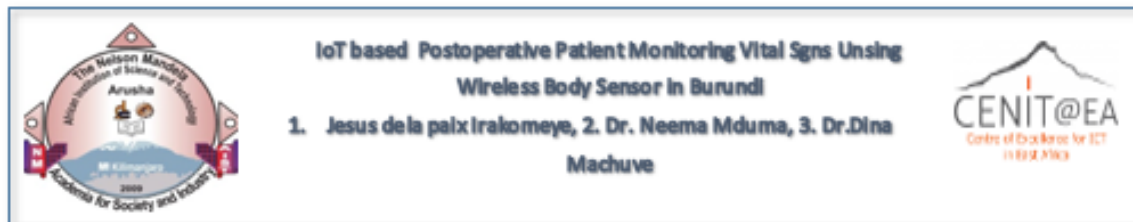
The Medical Director

Rév Dr YAMUREMYE Fulgence



« La protection qu'offre la Sagesse est comme celle que procure l'argent, mais la Sagesse a un avantage : elle fait vivre ceux qui la possèdent » (Ecclésiaste 7 : 12)

Appendix 3: Poster Presentation



Introduction

Internet of Medical Things (IoMT) plays a crucial role in the care and monitoring of telemedicine. Vital signs are critical in diagnosing and monitoring different medical issues at an early stage. Connecting post-operative patients to their physicians can reduce unnecessary hospital visits.

Problem Statement

Most hospitals have a low-resource setting with limited personnel such as rural district hospitals. Healthcare workers practically do not have sufficient time because of the overburden of patients. Postoperative recovery, on the other hand, is not that straightforward. There may be a variety of complications that arise for the patients, causing them discomfort or even resulting in the operation a failure. A study developed a postoperative patient monitoring vital signs system that will help health care providers to monitor the patient remotely.

Tools



Figure 1: ECG sensor



Figure 5: Max 30100

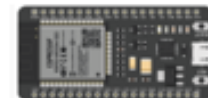


Figure 2: ESP32 Microcontroller



Figure 3: : DS18B20 temperature sensor

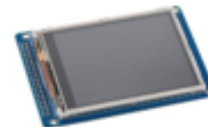


Figure 6: LCD display

Results

Electronic components are mechanically supported and electrically connected via printed circuit boards. PCBs are constructed of copper sheets bonded to a non-conductive substrate and carved with conductive channels, tracks, and signal traces. After that, the board is loaded with electrical components, and etchings are made on the surface to allow electricity to flow from component to component via copper

Conclusion

The study aims to contribute to the reduction of patient health complications by using wireless sensor measures and monitoring. The developed system proved that the system can provide vital signs parameters in real-time. Through the inbuilt WIFI on the ESP32 micro-controller, the connected monitoring system determines the patient that needs more attention.