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Development of E-Health Monitoring System for Vital Signs Capturing in Pregnancy

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ABSTRACT: An e-health monitoring system enables medical personnel or relatives of patient to check the status of patient health remotely without being in direct contact with the medical personnel. The implemented system is designed to measure the key health parameters: heart rate (HR), blood pressure and body temperature, simultaneously. The physiological signals such as blood pressure, heart rate and temperature are captured using MAX32664D biometric sensor hub and MAX32102. The captured data are processed and encrypted using the Advanced Encryption Standard (AES) algorithm before sending them to the cloud. An ESP32 integrated unit is used for processing, encryption, and providing connectivity to the cloud server, ThingSpeak through cellular network provided by SIM800L. The system measures the heart rate, blood pressure and body temperature of patient and if it goes out of the normal range, immediate informative alert message will be sent to the registered numbers. The data uploaded to ThingSpeak can be visualized or monitored using ThingView Android App from Play Store or directly from ThingSpeak server. 250 sampled data was collected at two hours interval from a patient simultaneously using developed system and standard medical system OmRon automatic blood pressure monitor and digital thermometer. The strength of the relationship between the instruments was determined by the use of linear regression coefficient R^2. Regression coefficients (R^2) of 0.7223, 0.7429, 0.8335 and 0.7513 were estimated for body temperature; diastolic; systolic and pulse rate. This demonstrates high correlation between the proposed and standard systems; thus demonstrating a fit-for-purpose of the proposed system.

I.INTRODUCTION

A. Background to the Work

Having babies in developing nations may be life threatening. Research has shown that every minute, a woman dies from pregnancy related complications and when add up it is approximately half a million fatalities per year (WHO 2023). It is a known fact that majority of pregnancy in developing countries such as Nigeria is not without one complication or the other. One of severe hypertension induced pregnancy complication is toxemia (Dulay, 2020). Toxemia of pregnancy, known medically as preeclampsia, has sometimes been called "first pregnancy disease." Pre-eclampsia strikes 19 in 100 pregnant Nigerian women (Osewa, 2016). Poor access to and utilization of quality reproductive health services contribute significantly to the high maternal mortality level in Nigeria.

B. Mortality in Pregnancy and Childbirth: The need for e-health monitoring system

Health monitoring is the major problem in today's world. Due to lack of proper health monitoring, patient suffer from serious health issues (Arpan *et al.*, 2021). Health Monitoring is becoming very necessary, especially in pregnancy because of its associated complications. More than 70 percent of maternal deaths in Nigeria are due to five major complications: hemorrhage, infection, unsafe abortion, hypertensive disease in pregnancy and obstructed labour (Olagbuji *et al.*, 2020; Adeyemi *et al.*, 2021). Poor access to and utilization of quality reproductive health services contribute significantly to the high maternal mortality level in Nigeria (Fawole and Okunlola, 2018; Lawal *et al*, 2019; Galadanci *et al.*, 2021).
According to WHO 2023, globally, 800 women die every day in year 2020 from preventable causes relating to pregnancy. The maternal mortality ratio (MMR) in low-income countries in 2020 was 430 per 100,000 live births as against 12 per 100,000 live births in high income countries. Almost 95% of all maternal deaths (MMR, number of maternal deaths per 100,000 live births) are from developing countries (WHO, 2023). Sub-Saharan Africa and Southern Asia accounted for around 87% (253,000) of the estimated global maternal death in year 2020. Nigeria, which constitutes just 2.4% of the world's population, accounts for 10% of global deaths for pregnant mothers. Currently, Nigeria is the fourth highest globally with maternal mortality rate of 576 per 100,000 (UNICEF, 2023). Most of these pregnancy related issues are preventable and treatable diseases (Rodreck, *et al*, 2021; WHO, 2023). Improvement in pregnancy outcome is achieved through regular and periodical checking of their blood pressure, protein in urine, temperature, pulse rate and weight.

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Wearable devices capture, record, and transmit non-invasive biomarkers like heart rate, temperature, and activity through integrated clothing or body placement (Walter et al. 2022). Pregnant patients and healthcare providers show high acceptability rates for non-invasive monitoring, with nearly half expressing amenability to wearing sensors or embedded in maternity clothing. 76% reported using wearable for pregnancy, while 67% for personal fitness or dieting. Data security and privacy concerns were identified as concerns, but over 90% felt comfortable sharing results with physicians (Runkle et al. 2019). These kinds of solutions are very useful especially when a treatment includes monitoring of some vital parameters for long period of time as in the case of pregnant women with health issues who are to be monitored throughout their gestation period.
Monitoring of pregnant women's vital signs is often limited to hospitals or other health care centres, and this makes the process time consuming and expensive thus, making many pregnant women not to book early for antenatal and in most cases they restore to traditional birth homes. Studies showed that prenatal care experienced disruptions during the COVID 19 pandemic due to stay-at-home orders, clinic closures, and fear of hospital visits (Fryer et al. 2020; Miller et al. 2021; Sakowicz et al. 2021). Development of remote monitoring systems, which on one hand, will reduce costs and travel time, and on the other will increase health service efficiency and user satisfaction have been made possible.

In this work, an e- health monitoring system was developed for measuring pregnant women body temperature, blood pressure and pulse rate at the same time analysis them and transmit information to the doctor for further actions through appropriate applications.

II. LITERATURE REVIEW

A. The Concept of e-Health

The healthcare system has long be plagued with problems, such as patients spending too much time before meeting the doctor, unreadable writing by some medical personnel, misplacement of files and doctor not able to access patients information easily. We also have this problem of limited space, time and personnel for monitoring patient.Some of the problems enumerated above can be eliminated if patient's physiological data are collected transmitted and stored digitally using devices with wireless capabilities.
Health Monitoring System (HMS) is a high-tech alternative to the conventional methods of managing patients' health. The aim of HMS is to not only reduce costs but to also provide timely e-health services to individuals wishing to maintain their independence (Mshali *et al*, 2018). It consists of a wearable wireless device with sensors that are paired with an application for a doctor to access the medical information. With increasing innovation in wireless technology and portable devices, the development of remote health monitoring system can be useful in the following ways: real time monitoring where both patient and healthcare providers can know and measure the state of their health outside the walls of a clinic or hospitals; it can help in patient management so helping clinics/hospitals manage their space effectively and reduce cost in the process; user friendly interfaces and apps make it easy to use almost for anyone and more lives can be saved if patient are well monitored.
The revolution in healthcare resulting from the introduction of e-health, is fundamentally changing the way healthcare services and information are provided and health is managed, enabling individuals to monitor and manage their own health, in a safe, cost effective manner with improved quality of life (Al-khafajiy et al., 2019; Jebane *et al*., 2021).The development of new health monitoring technologies suitable for long term personal use are key element in enabling e-health systems for home health management. E-health technologies utilize telecommunications, the internet, clinical monitoring systems, clinical information systems and decision support systems to provide integrated solutions for health and disease management.
The works so far developed in e-health monitoring include Teaw, *et al* (2005) designed a wireless sensor system, the health tracker 2000 that can monitor users' blood pressure, heart rate, and temperature and notifies relatives and medical personnel of their location during life threatening situations. This system is designed for senior citizens age 65 and above. Chan *et al* (2008) presented a multi-agent architecture for mobile health monitoring involving a team of intelligent agents that collate patient data, reason collectively and recommend actions to patient and medical staff in a mobile environment. Microcontroller based heart rate monitor was developed by (Fezari et al 2008). The system developed was portable. Hang Su (2009) observed that, the conventional physiological monitoring system used in hospitals cannot be used for wearable physiological monitoring applications because; the conventional physiological monitoring systems are bulky to be used for wearable monitoring and the sensors used in conventional monitoring systems are bulky and are not comfortable to wear for longer durations. Khairelseed, (2011) designed microcontroller based heart rate monitor using finger-tip sensor. The system designed can only monitor heart rate, being bulky and has no provision for graphic users interface (GUI). Chourasia and Tiwari (2012) carried out a work on implementation of foetal e-health monitoring system through biotelemetry that is used in continuous monitoring of foetal phonocardiography (fPCG) signals using mobile phones and

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wireless sensors for providing advanced healthcare services in the home. A wireless foetal monitoring system was proposed by Bhong and Lokhande (2013) aimed at decreasing foetal mortality rate and to reduce the number of time the pregnant woman must visit the hospital for ANC and at the same time cause no compromise in the wellbeing of both the mother and the child. The system consists of wearable sensors, built into a fabric belt, that collects and sends vital signs of patients via Bluetooth to smart mobile phones for further processing and made available to the required personnel allowing efficient monitoring and alerting in emergency situations. Mittal *et al.*, (2018) designed Iot Based E-Health Monitoring System Using Arduino Uno Basargi *et al.* (2019) designed a GSM based patient health monitoring system using microcontroller that calculates the heartbeats and body temperature of patient. Omeje *et al.* (2019) evaluated the feasibility of an e-health system for maternal care in rural Nigeria. This study found out that the e-health system was feasible and acceptable to both health care providers and pregnant women, and had the potential to improve access to care and reduce maternal and neonatal morbidity and mortality. Ezeama *et al.* (2019) developed an e-health monitoring system for antenatal care in Nigeria using a qualitative approach to explore the perspectives of health care providers and pregnant women on the development and implementation of the e-health system.

III. DESIGN METHODOLOGY

The e-health monitoring system development is subdivided into two major design parts which are: hardware and software developments.

A.Hardware Development

A Health Monitoring System (HMS) consists of a wearable wireless device with sensors that are paired with an application for a doctor to access the medical information as shown in Figure 1.

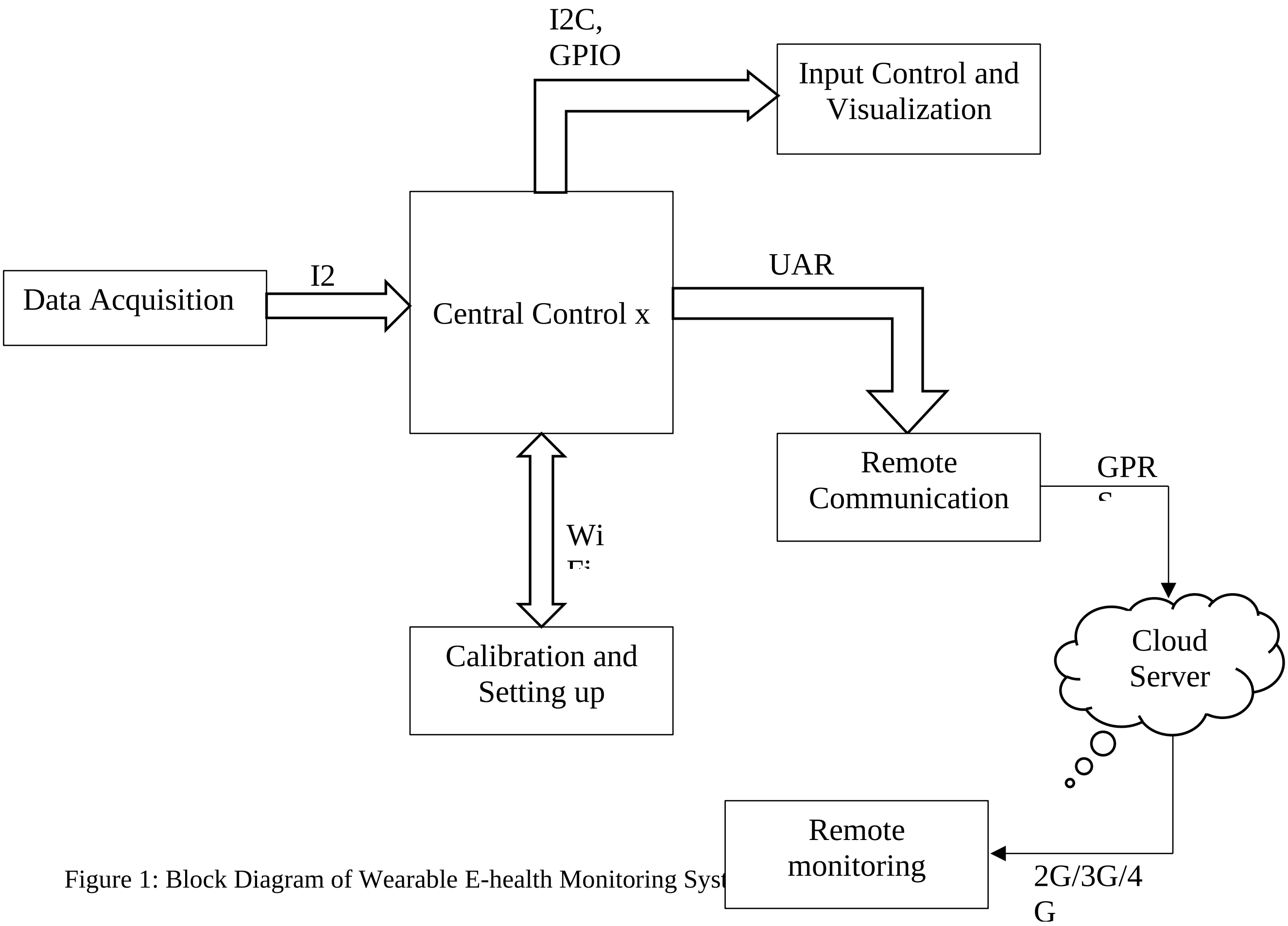

Figure 1: Block Diagram of Wearable E-health Monitoring Syst

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B.Data Acquisition Unit

At the heart of the monitoring system is MAX32664D Biometric sensor hub for blood pressure calculation and oximetry sensor for the MAX30102 for the measurements of blood pressure, heart rate (pulse rate) and body temperature.
The MAX32664D sensor module operates on 5V. It has an on-board 3.3V regulator. The module contains the temperature sensor, the heart rates sensor and the Blood Pressure Estimation sensor. The MAX32664 Version D communicates with the MAX30102 through I2C to perform finger-based heart rate, body temperature and blood pressure monitoring. The embedded algorithm uses digital filtering, pressure/position compensation, advanced R-wave detection, and automatic gain control to determine the heart rate in beats per minute while minimizing power. Estimated blood pressure is reported for systolic and diastolic blood pressure.
The MAX30102 has an accurate on-board temperature sensor with a precision of 0.0625^{o}C. The temperature can be read through the I2C interface of the MAX32664D which is connected to the Central Control unit. The module connects directly to the SDA and SCL pins of the microcontroller. Data acquired from this stage are read by the Central Control unit for further interpretation, processing and decision. The MAX30102 was chosen over MAX30100 heart rate module for this research due to its lower power consumption, high sampling rate, improved noise performance, better LED driver and availability.

C.Central Control Unit

The Central Control Unit (CCU) was achieved using an ESP32 development board. It is a 32-bit microprocessor, operating at 240 MHz with built-in antenna switches; power and low-noise receive amplifiers; filters and power-management modules. It has 34 programmable General Purpose Input and Outputs (GPIOs), 12-bit Analogue to Digital Converter (ADC), 2 × 8-bit Digital to Analogue Converter (DAC), 2 Inter-integrated Circuit (I2C) interfaces, 3 Universal Asynchronous Receive Transmit (UART) interfaces and many more. It has internal low-dropout regulator with 5µA deep sleep current which makes it suitable for wearable applications.

D.Input Control and Visualisation

This is the part of the device whereby the user can interact with the device. A 128 × 64 Organic Light Emitting Diode (OLED) display circuit is employed to show measurements and other relevant information like battery status, SIM signal level. The OLED display was connected to the SDA/SCL line of the CCU through the Logic Level Converter where it receives information via an I2C interface. The logic level converter ensures the conversion of voltages to the different voltage levels at each end as the 5V level will damage the 3.3V pins on the microcontroller as they are not 5V tolerant. An OLED display was preferred for its high contrast, light weight, low power consumption, visibility (even in the bright light) and readability.

E.Remote Communication and Cloud Server

The remote communication was achieved using SIM800L GSM/GPRS module. SIM800L allows healthcare providers to interface with measurements taken by MAX 32664D and MAX 30102.The SIM800L module makes a full-fledged GSM/GPRS operations using cellular network. It communicates with the CCU using UART protocol. The SIM module also reports the GPS location of the nearest base station it is connected to. This feature helps to determine the approximate location of the user. The SIM800L module was selected for this device implementation due to its low power consumption, network compatibility, smaller form factor, audio processing capabilities, and availability.
The SIM800L module connects to the Transmit (TX) and Receive (RX) pins of the microcontroller. The SIM module operates on 3.7V to 4.2V supply voltage, which is able to handle a surge current of up to 2A needed when the module is searching for network. Subsequent operational supply current is around 100mA. The entire board is powered by a BL-5C 1200mAH Lithium ion Battery. The battery is compact in size and has voltage and current protection pre-installed.
The Cloud server is an online service. ThingSpeak which is an open IoT Cloud platform used to send the sensor data to the cloud and monitored remotely. The mode of connecting to ThingSpeak server was through cellular network for easy of accessibility and also for the device to make calls or send SMS as it may be demanded. Measurements taken are uploaded to ThingSpeak at intervals to be determined by the user, but the device is calibrated to ensure accurate measurement of Blood Pressure (BP). Calibration is done by measuring the user's BP using a clinical grade sphygmomanometer; three (3) measurements of Systolic and Diastolic blood pressure were measured. This was inputted into the form provided as presented in Figure 2.

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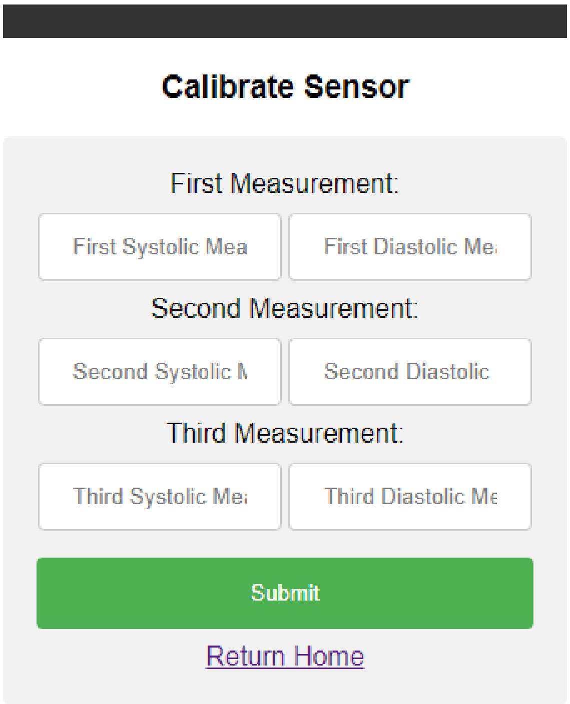

Figure 2: Calibration Page Hosted by ESP32

F.Software Development

The program for the wearable E-Health Monitoring System was written in C++ using Arduino Integrated Development Environment (IDE). Arduino IDE is open source software that is mainly used for writing and compiling the code into the Arduino Module. The main code, also known as a sketch, created on the IDE platform ultimately generate a Hex File which was transferred and uploaded in the controller on the board. Indicated in Figure 3 is the flowchart for code execution.

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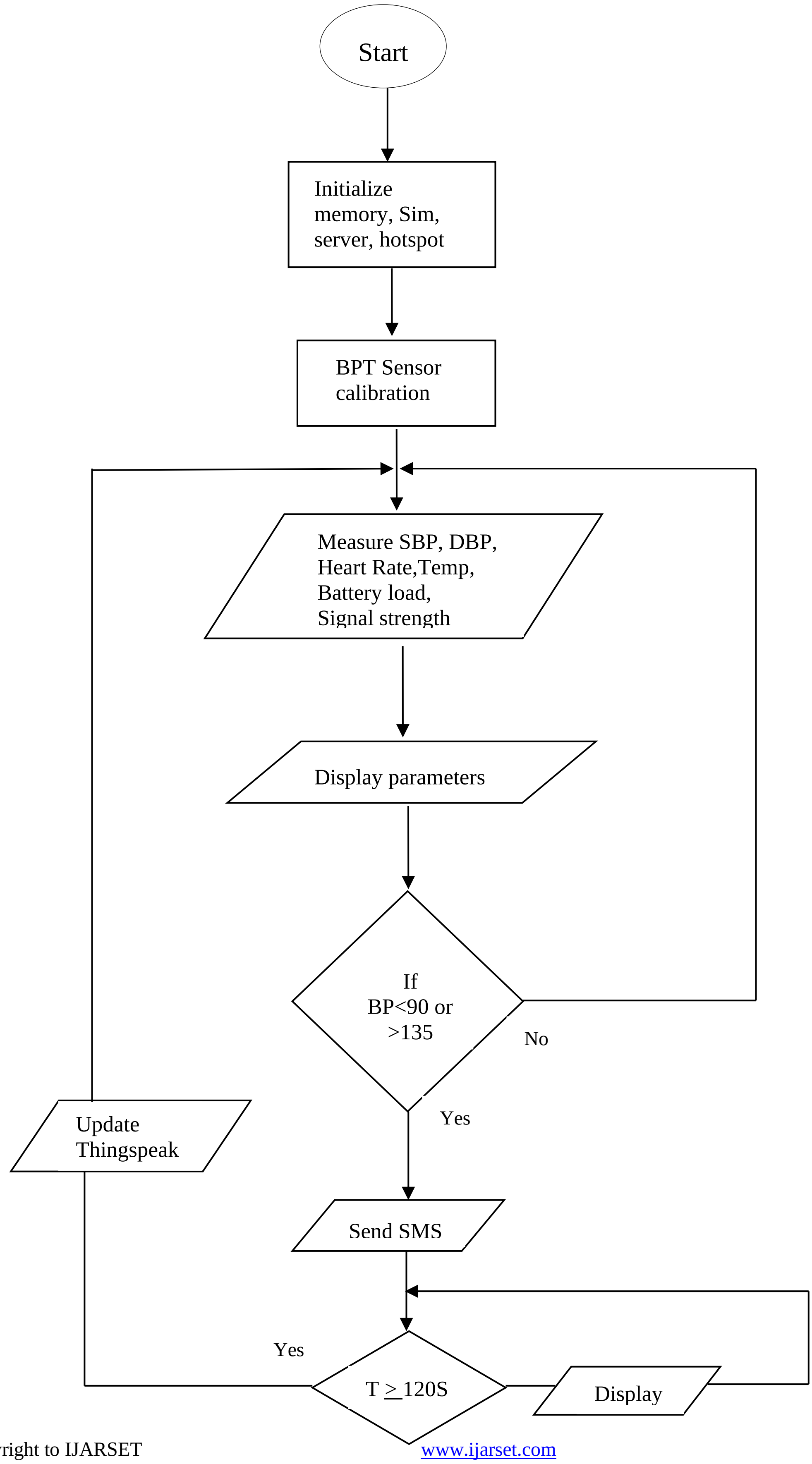

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Figure 3: Flowchart of Code Execution

G.System Testing, Results, and Discussion

The accuracy of the proposed system was tested through calibration measurements against one of such standard equipment used by hospitals and health centres OmRon automatic blood pressure monitor, Model: M2 Basic, serial No. 20150460932VG of OMRON HEALTHCARE Co. Ltd Kyoto Japan) for blood pressure, pulse rate measurement and digital thermometer mode: GF-MT502 with range of measurement: 32ºC- 42.9ºC and 89.6ºF-109 ºF by Mediklin for temperature measurement.
The proposed system measurements of the vital signs were taken by wearing it on the finger while the standard digital thermometer was inserted in the armpit and OmRon was wound around the upper arm and their readings were taken simultaneously. Data samples were collected from a pregnant woman for a period of six months before birth (second trimester) and two months after birth for at least 2 times a day using the standard instrument and the proposed system for effective comparison. 250 sampled data were used on a scatter diagram for the comparisons. The comparative graphs and correlation of data acquired from the standard health monitor and the proposed device for health monitor for body temperature, diastolic, systolic and pulse rate respectively are shown on figures 4, 5, 6 and 7 on Appendix I. As seen in Appendix I, the strength of the relationship between the instruments (i.e., the proposed and standard devices) was determined by the use of linear regression coefficient R^2.The regression coefficients R^2 of 0.7223, 0.7429, 0.8335 and 0.7513 were estimated for body temperature, diastolic, systolic and pulse rate. This demonstrates high correlation between the proposed and standard instrument; thus demonstrating a fit-for-purpose of the developed device.

IV.CONCLUSION

A health monitoring device has successfully been developed and tested. The device was able to measure up with hospital device for the measurement of body temperature, blood pressure and pulse rate with high correlation which was determined by subjecting the sampled data to linear coefficient regression.

Appendix 1

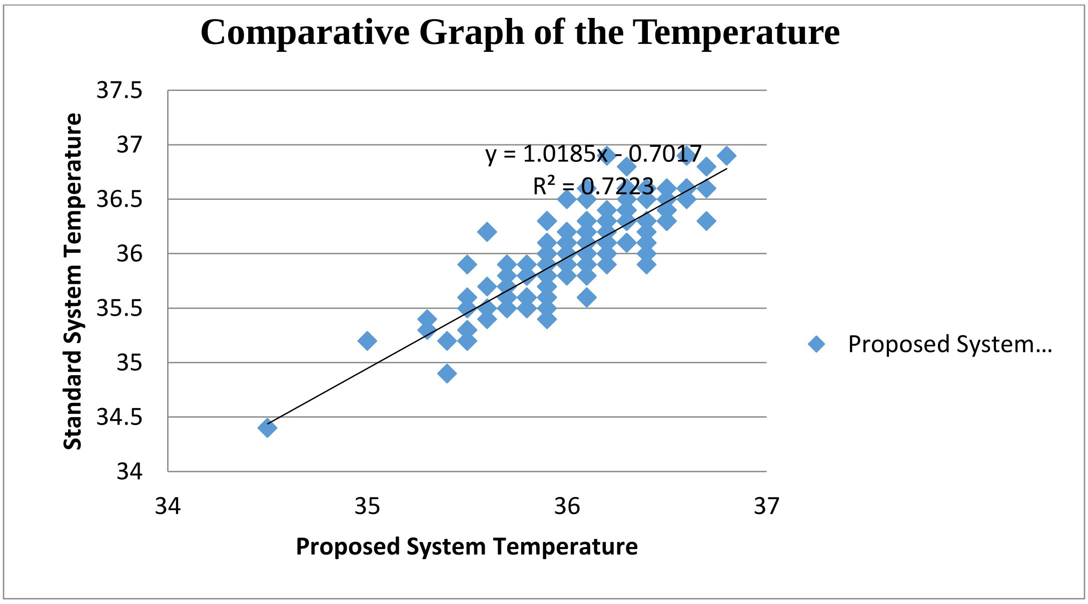

Figure 4: Comparative Graph of the Temperature

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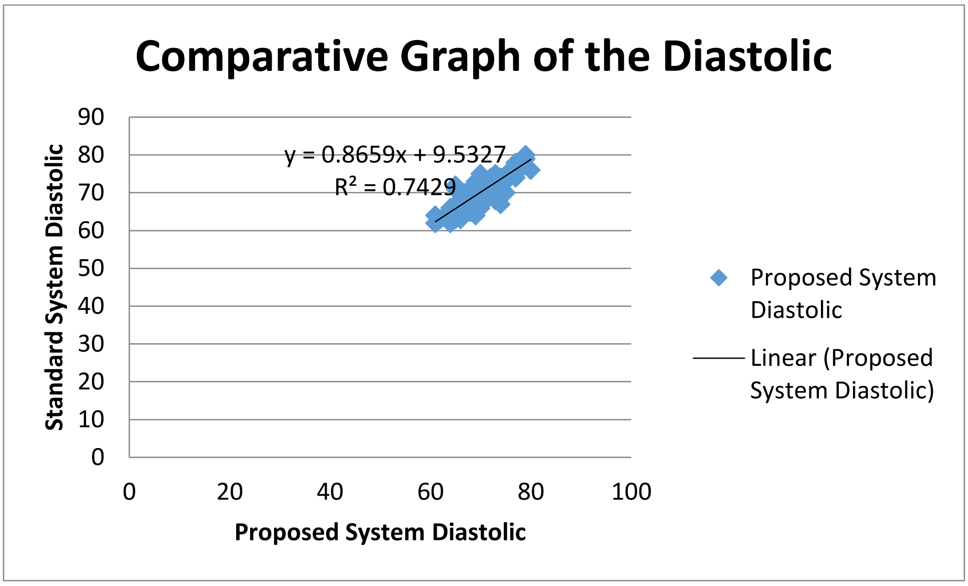

Figure 5: Comparative Graph of the Diastolic

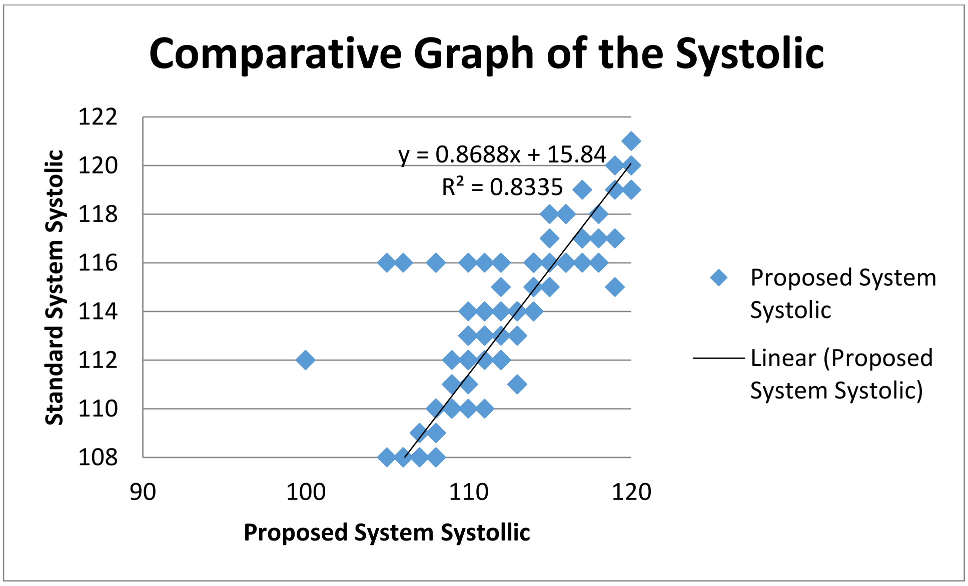

Figure 6: Comparative Graph of the Systolic

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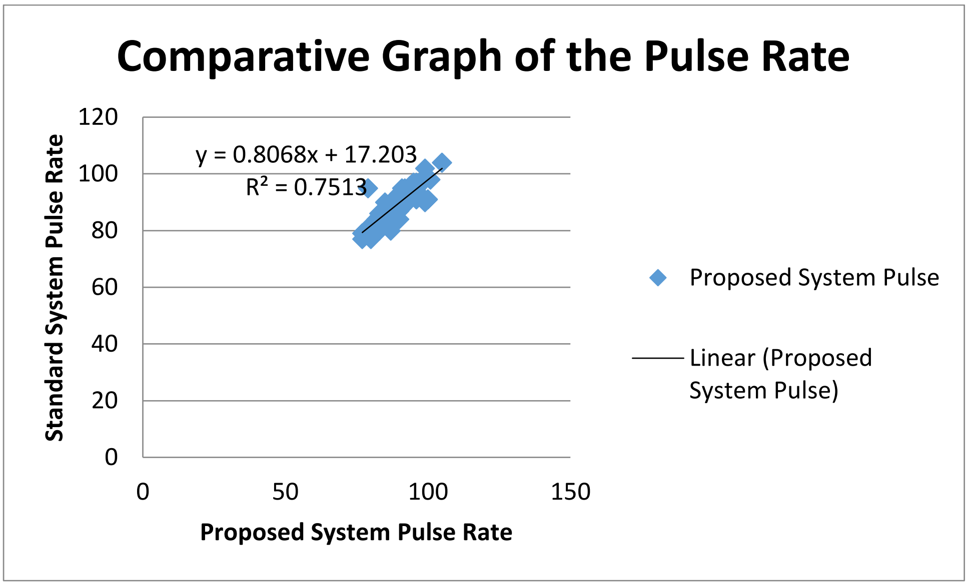

Figure 7: Comparative Graph of the Pulse Rate

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