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Wearable Device for Telemedicine: An Architecture and Prototype Implementation for Remote Medical Diagnosis using Long Range Communication Protocols

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ABSTRACT
Due to rising population particularly in the developing countries, the need has increased for online medical services mostly for health monitoring and remote medical diagnosis for personal health care using telemedicine. Also, health care facilities and resources have been overwhelmed in many countries leading to poor quality of health care delivery and more expensive medication due to the continuous application of conventional face-to-face consultations in medical diagnosis. In attempt to deliver cost-effective and reliable remote medical consultations and diagnosis using telemedicine, short range communication protocols such as Bluetooth and ZigBee have been adopted for wearable devices. Existing wearable devices developed using these short range protocols for D2D communication are not supported by IoT gateways due interoperability issues. In this paper, a long range MQTT communication protocol with GPRS, GSM and GPS for transmitting vital signs from a wearable medical device to the cloud is proposed. A wearable hardware prototype using an IoT gateway via the A9G module and the Atmega 328 to transmit medical data to the cloud was implemented. The prototype device demonstrates that adopting long range communication protocol offers ubiquitous and fast medical data access for delivering professional healthcare services regardless of user location. The device enables patient and doctor interaction for remote medical diagnosis in real-time using a web interface by means of an API.

Keywords: *Heart rate; IoT; Protocol; Telemedicine; Temperature; Vital Signs*

1 INTRODUCTION

The advent of wearable medical devices has enabled patients to monitor and transmit their vital signs to remote servers for effective health care delivery. Remote Medical Diagnosis (RMD), early symptom detection and e-health awareness are conceivable by employing 5G technology in telemedicine which supports high-speed transmission and sharing of massive multimedia medical data and resources (Duan *et al*. 2020).

Wearable health monitoring (WHM) devices enable the acquisition of patients' vital signs and health status monitoring for long periods outside medical environments. WHM enables acquisition of medical data during different scenarios for applications such as remote medical diagnosis and rapid medical attention in case of emergencies (Dias and Cunha 2018). The major vital signs (Vishnu, Jino Ramson, and Jegan 2020) usually monitored by medical professionals are:

(i) Heart rate (HR)
(ii) Blood pressure (BP)
(iii) Body temperature (BT)
(iv) Respiration rate (RR)
(v) Pulse rate (PR)
(vi) Body mass index (BMI)
(vii) Oxygen saturation
(viii) Blood glucose level
(ix) Systolic blood pressure
(x) Diastolic blood pressure
(xi) Muscular activation
(xii) Urine output
(xiii) Pain
(xiv) Total lung volume
(xv) Level of consciousness

Recently the need for wireless medical services mostly for remote monitoring and personalised health care has led to migration from wired tools to wireless solutions in form of telemedicine. This tends to eliminate the difficult and limiting wirings, thereby increasing patient independence and mobility (Mahfouz, Kuhn, and To 2013).

Telemedicine, which is a means of delivering professional health care and sharing of medical knowledge over a distance by using telecommunication technologies, have been used to provide expert-based health care in remote locations and emergency situations (Kyriacou, Pavlopoulos, and Koutsouris 2006). This is achieved by using several wireless communication protocols like the ZigBee, Bluetooth, Wi-Fi, WLAN, IP/TCP, satellite, GSM and WiMAX deployed for implementing telemedicine designs for real-time scenarios.

Application of Long Range (LoRa) wireless communication protocols such as the WiMAX in telemedicine designs have been proven to deliver high mobile connectivity for audiovisual data transmission and other complex services offering reliable Quality of Service (Rani, Bhat, and Mukhopadhyay 2017). Other advantages of using LoRa communication technology in telemedicine include integrated services, security and QoS support. The network could also be used as an intersection to available wired or commercial networks like the 3G or the DSL (digital subscriber line) networks which supports various stages of interconnections for effective network stability (Cova *et al*. 2009).

Telemedicine system enables patients and health-care professionals to be located anywhere in the globe where there is GSM cellular network coverage (Sukanesh *et al*. 2010). Wireless telemedicine systems could be used to observe patient's health situations such as cardiac activity during emergency by means of WBAN.

2 BACKGROUND AND MOTIVATION

Healthcare services have become more expensive because of rising populations and more expensive medication (Mukhiya *et al*. 2019). Also, health care facilities and resources have been overwhelmed in many countries leading to poor quality of health care delivery. Major health care challenges that require urgent attention include high doctor-to-patient ratio, difficulty in accessing medical experts/specialist from distance, remote access to medical diagnosis and mobility of doctors and patients while delivering medical services. These has led to various research works aimed at deploying ICT to mitigate the growing demand for quality and effective health at a reduced cost. Conventional medical services have not been able to address the above-mentioned challenges effectively largely due to application of obsolete technologies and equipment.

Although several researches have been conducted and deployed in the developed countries, real-time designs to tackle these challenges in developing countries have not received adequate attention. In order to deliver cost-effective and reliable remote medical consultations and diagnosis using telemedicine, researchers have adopted short range communication protocols such as Bluetooth and ZigBee transmitting medical data from wearable devices (Hu *et al*. 2008); Sîrbu *et al.*, 2008); (Dengwei Wang *et al*. 2005). Existing wearable devices that use short range protocols for device-to-device (D2D) communication are not supported by IoT gateways due interoperability issues.

This paper mainly focuses on development of a prototype wearable vital signs health monitoring device for capturing and transmission of physiological signs which include body temperature, heart rate and user location. The measured signals are transmitted through a LoRa wireless communication network with internet accessibility by utilising Internet-of-Things (IoT). To address the problem of interoperability in the D2D medical data transmission, the A9G module is used as an IoT gateway through the microcontroller unit (MCU). The device offers GPRS/GSM and GPS for data transmission over the cloud with user location.

While conventional health care services basically require face-to-face meeting between patients and doctors, telemedicine technologies tend to reduce isolation of experts, nurses and sophisticated equipment (Pandian 2016). In view of the aforementioned, it has become very important and necessary to develop and deploy telemedicine technologies for effective, reliable and quality health care delivery. This research is therefore, intended to provide solutions that could mitigate the use of costly and unreliable conventional medical services that are dependent on obsolete technologies and equipment.

Our proposed prototype telemedicine system uses three telemedicine taxonomies namely: store-and-forward, online/real-time telemedicine and remote health monitoring technology (Pandian 2016), as a single unit in form of a portable wearable device. The device could be utilized to provide appropriate and excellent care by integrating e-health, personalised healthcare and increasing user access, providing high-quality care at a reduced medical cost. The design is capable of performing basic diagnostic tests on patients, equipped with input facilities and a means of transmitting the data to a medical professional via a LoRa communication protocol.

3 REVIEW OF RELATED WORK

3.1 Wireless Communication technologies for vital signs monitoring in Telemedicine

Application of IT solutions particularly in telemedicine, has led to cost reduction and increased quality health care delivery in the medical field (Chorbev and Mihajlov 2009). Several wireless technologies have been implemented in medical systems for vital signs monitoring and easy access to equipment and medication remotely (Mahfouz *et al*. 2013). These technologies include ZigBee and Bluetooth for wireless telemedicine in (Auteri *et al*. 2007); (Hu *et al*. 2008); (Mulyadi *et al*. 2009); (Sîrbu *et al*. 2008), WLAN in (Lin, Hung, and Chiang 2010), WiFi for signal security and accuracy in (Qu *et al*. 2009), internet for mobile telemedicine in (Khoor *et al*. 2001); (Celik *et al*. 2010), satellite telemedicine in China in (Wang and Gu 2009), GSM in (Abo-Zahhad, Ahmed, and Elnahas 2014) and World-wide Interoperability for Microwave Access (WiMAX) technology in (Zhang, Ansari, and Tsunoda 2010).

The LoRa communication technology was chosen in this work due to its BWA (broadband wireless access) for both mobile and stationary situations. It also offers wide bandwidth, integrated services for completely practical telemedicine services, MAC (media access control) layer security features and defined QoS framework that allows effective and reliable medical data transmission (Zhang *et al*. 2010).

3.2 Overview of WBAN architectures for telemedicine applications

Wireless Body Area Network has been utilized in several emergency telemedicine designs due to benefits such as early detection of disease, reduction in health care cost and provision of improved and ubiquitous health care services (Latha & Vetrivelan, 2020). WBAN enables acquisition and transmission of physiological data for continuous monitoring of patient's health by an expert doctor from a remote location. Because of its capability of providing miniaturized sensor nodes, WBAN has been implemented in telemedicine to provide remote health care services that allow mobility for both the patient and doctor.

(De Vicq *et al.* 2007) implemented a WBAN for sleep staging which uses a star architecture that allows all direct communication of all sensor nodes with the master node. This WBAN creates wireless communication among the different miniaturized, intelligent sensors and the gateway node to the access point. The online access is then provided to Body Area Network (BAN) devices through a network infrastructure that delivers remote services to the patients.

Another approach in (Yadav *et al.* 2020) used a wearable textile Ultra-Wideband (UWB) antenna for short distance communication for telemedicine & mobile health. The device uses a fabric containing substrate antenna incorporated into human body because it has negligible radiation effect. It requires low power to be excited and it is used for high data rate transmission for short range coverage. It offers an excellent time-domain characteristics for ultra-wide band (UWB) application with low SAR (specific absorption rate) on human tissue. Although the device was a prototype, it demonstrates the application of the wearable UWB textile antenna for mobile health and telemedicine designs. Ultra-wide band is an innovative wireless communication technology which could be deployed high data rate transmission of medical data over a wide range of frequencies for wireless network applications. It is a high-speed, less expensive, extremely low power capable of signal transmission through impediments and feasible for various applications. One major drawback with UWB design however, is that it lacks of global approval in terms of regulation (Rashvand *et al*. 2008).

In (Donati *et al*. 2019), a short range Bluetooth/Bluetooth Low Energy (BT/BLE) communication which uses android phone or tablet as a local gateway was also implemented. The telemedicine system is an IoT-based network of sensors that utilises BT/BLE consisting of vital signs monitoring devices dispersed at the patients' residence. The system is made up of central server software which contains a local storage device installed at the service provider node. It uses two-way communication with internet subsystems that communicate with broadband technologies such as 3G, LTE, 5G, or Wi-Fi connectivity through access points provided. In order to predict risky and hazardous situations, the use of artificial intelligence (AI) was suggested by the authors.

A similar telemedicine system made up of layers viz.: the IoT, Mobile Edge Computing (MEC), and the cloud computing layers was presented in (Zhang *et al*. 2020). These layers carry out different assigned functions collectively to form a complete WBAN scheme. The IoT layer generates the medical data and transmits to MEC layer for analysis. Further analysis and storage is conducted in the upper cloud layer. The system is a combination of Artificial Intelligence (AI) and edge computing to deliver predictive tasks. This system design approach has the capabilities of carrying out necessary actions if it recognizes abnormalities in ECG signals on the IoT edge device in place of the cloud. It offers high accuracy in predicting multiple categories in the ECG dataset and a very efficient medical information analysis. The authors however suggested combination of MEC and AI in telemedicine to reduce time for data transmission and analysis.

(Di Rienzo *et al*. 2020) developed a similar system named SeisMote, made up of 12 wireless sensor nodes, a USB dongle acting as a receiver, a wireless rechargeable battery, software suit, network file manager and an android app. The overall system is completely wearable while carrying out daily activities or during sleep. The system operates in three different modes namely real-time mode, offline mode and Bluetooth real-time mode. The architecture is based on the ARM-Cortex technology with a programmable flash memory. It also consists of an embedded RF transceiver, a digital memory card, wireless battery charger and power source. Only one sensor node can be used at a time, because The BLE used in this system cannot guarantee the proper time synchronization among all the nodes. While monitoring is done real-time, data analysis is performed offline. To improve on this system, the authors suggested the need for a Digital Signal Processor (DSP) chip, expansion of memory to enhance real-time computation of the acquired parameters and increasing battery duration to ensure long time monitoring.

Also described in (Latha & Vetirvelan, 2020), WBAN has been employed in telemedicine for providing the best monitoring and sending of health-related information to the doctor without affecting daily activities. It uses the IEEE 802.15.6 standard for telemedicine applications. The status, events and health of the patient are monitored constantly by means of WBAN.

4 METHODOLOGY

4.1 SYSTEM ARCHITECTURE

The proposed architecture uses a single IoT gateway for wireless LoRa communication to deliver a reliable network with guaranteed QoS. Three main stages are involved in the design; the electronic unit, the web unit and the mobile nodes (wearable devices for the client and remote server for the care giver). The basic hardware section consists of a WBAN of vital sign sensors to measure patients' condition(s) and transmit through the wireless interface provided for further analysis through the A9G module with GPS and GSM capabilities. The design stages are highlighted in figure 1.

Figure 1: System architecture block diagram

4.1.1 The Electronic Unit

The BP and HR design consists of several sections ranging from the power supply unit via a LiPo battery and charging circuit powering the A9G module. A 3.3V and 1.8V voltage regulators are also used to power the microcontroller and the BP/HR senor respectively. The entire system is wired by means of I2C bus architecture. Figure 2 shows the complete system description of the hardware design of the device to provide remote monitoring of patient BP and HR via IoT platform.

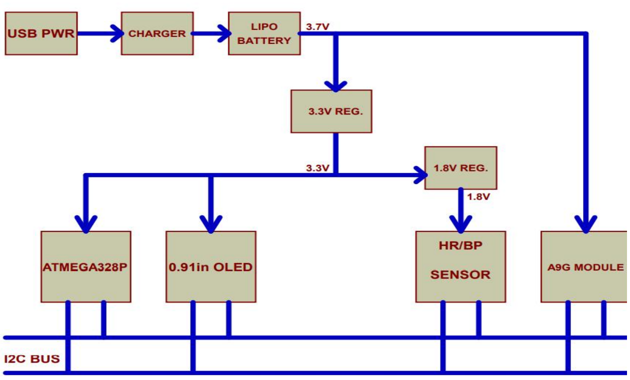

Figure 3: Block diagram of complete HR and BT system architecture

4.1.2 Components description and specifications

The major components in each block are discussed as follow.

a. Power supply

Power is supplied to the system through two sources: USB Power source and Lithium-ion Polymer (LiPo) battery source. A 3.3V linear low dropout regulator is used to provide a stable voltage level for onboard components. The power supply scheme is depicted in the system block diagram.

b. Battery charger

MCP73831 Linear charge management controller is used to handle battery charging operation. The charge controller features a charge status pin for monitoring battery status. This pin is connected to the atmega328 MCU. The USB device is a universal LiPo battery charger that could be plugged to any available DC source with USB port for charging the battery during use or in idle mode. A rechargeable LiPo battery uses polymer electrolyte instead of a liquid electrolyte.

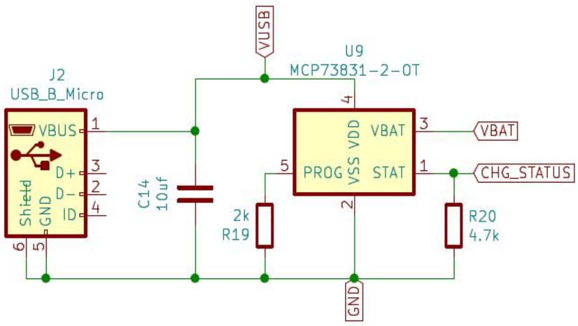

Figure 3: USB LiPo battery charging circuit

c. Voltage Regulator

The voltage regulator uses LM1117 regulator with 3pin configuration that regulates through the output pin 3 as depicted in Figure 3.4.

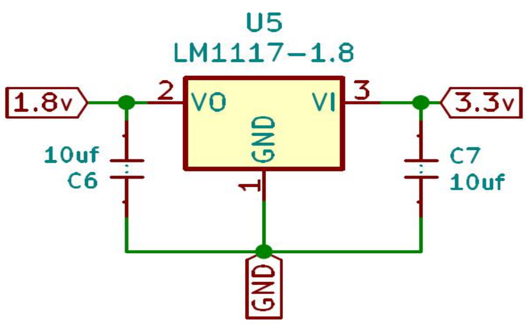

Figure 4: Voltage regulator circuit diagram

d. Heart rate and blood pressure Sensors

The HR and BP sensor uses MAX32664D, a variation of MAX32664 sensing devices which allows a user to obtain raw data including diastolic and systolic BP, SpO2, and HR data using contact from the finger. It could be programmed using accessories needed to connect sensing device via the I2C port (Figure 5). The I2C interface is also a means for communicating with the Arduino microcontroller unit.

Figure 5: MAX30101 HR and BP sensor

e. Onboard microcontroller

An atmega328p Microcontroller Unit (MCU) is used to interface the various peripherals on board like the OLED, HR and BP sensors and the A9G module through I2C bus interface. The purpose is to read the sensor values and perform necessary processing and relay the sensor value to A9G. The MCU is a low power version.

f. Display

The board can work with any display with I2C interface. But a 0.91inch (128x32 Pixel) OLED is recommended and utilized for this application because of the small form factor, low cost and low power feature.

g. A9G Module Overview

The A9G (designed by Ai-Thinker, 2017) is an SMD package module that has the capabilities of GSM and GPRS connectivity for cost and time reduction. It uses low power with GPS support. The A9G module was used as an IoT gateway serving as a bridge or communication link between IoT devices within the field, cloud and the user nodes. It uses MQTT (Message Queuing Telemetry protocol) to send and retrieve data from the Arduino MCU. The module sends sensor data to the cloud for monitoring and feedback using API through smart phones.

The various circuit diagrams and the PCB of the system were developed using KiCad software as depicted in the subsequent figures 6 and 7.

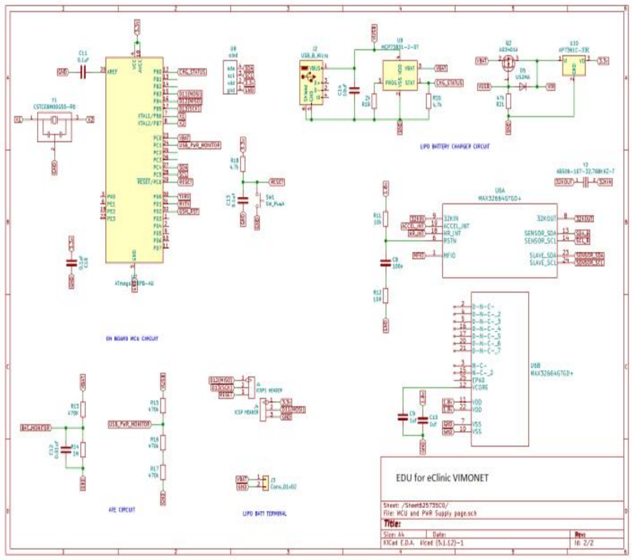

Figure 6: MCU and Power supply unit

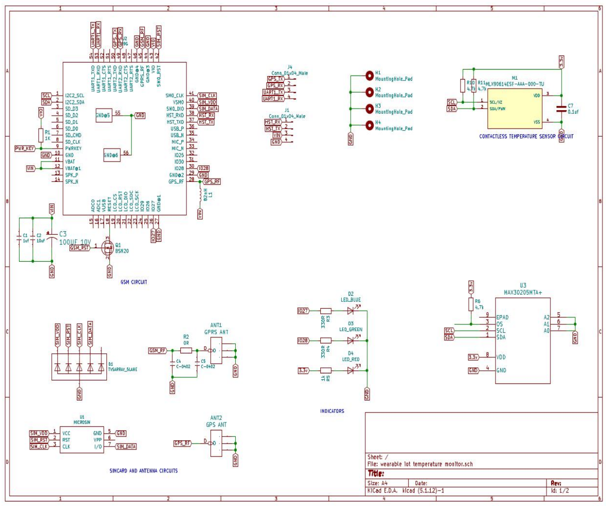

Figure 7: Circuit diagram of contactless temperature sensing and GSM module unit

5 RESULTS AND DISCUSSION

5.1 Identification of major onboard components of the prototyped PCB

The images below show the front and back view of the board, position and identification of the major components used in the design.

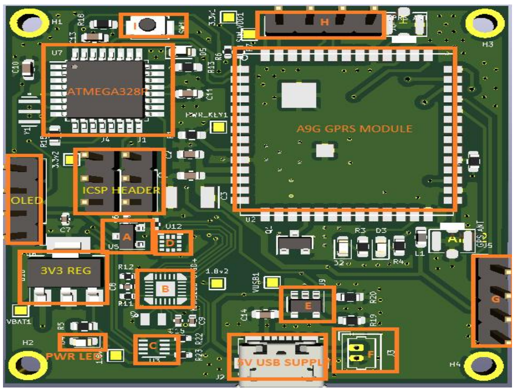

Figure 8: Front view of PCB

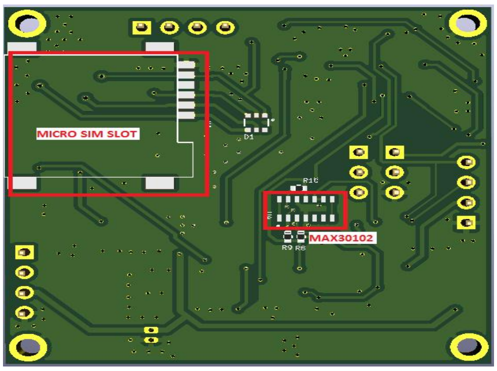

Figure 9: Back view PCB

5.2 Device features

- **a. Connectivity:** The device features A9G module which provides the GPRS/GSM/GPS connectivity. It has an integrated MCU which can be used to develop user application.
- **b. Calibration**: because of disparities in both the finishing and casing of the prototyped device, it is necessary to carry out calibration steps in an organized setting. This will guarantee the validity of the SpO2 calculation. This procedure is usually done in a laboratory that has SpO2 reference device to evaluate the coefficients of the calibration (A, B, and C). These three coefficients obtained are loaded into the MAX32664D before initializing the algorithm.
- **c. Programming interface:** Programming headers are provided for programming the Atmega328 and A9G module

Table 1: Device Peripheral Pin Map

PERIPHERALS		A9G	ATMEGA 328P
MLX 90614		I2C	I2C
MAX30206		I2C	I2C
OLED		I2C	I2C
LED			PB1
	CHG_STATUS	IO25(PIN 32)	PB0
	USB_PWR_ MONITOR	-	PC1
	GSM_RST		PD2
	GPS UART	UART2	
	UART	UART1	
	DEBUG	HST	

The table shows that all peripherals are connected to the same I2C Bus.

5.3 Board Testing/Troubleshooting Procedure

It is recommended to test the board to ensure everything is fine. The PCB design has Test pads placed at critical points of interest to make testing easy. The test pads are for power testing. Follow the procedure described below to test the board after production

5.3.1 Power testing

By connecting a 5V USB power supply to the board, the power indicator turns on at this point. If not, use a voltmeter to test the voltage at the VUSB test point and the 3.3V test points to see if they are supplying the correct voltage level (5V and 3.3V respectively). The power LED is connected to the 3.3V regulator output. Using a voltmeter test all the power test points for each of the peripheral to ensure they are receiving the correct voltage level. The square yellow points in figure 10 show where the test points are onboard.

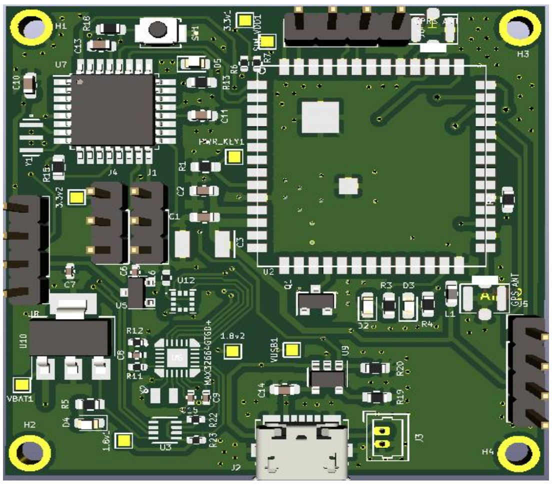

Figure 10: Test points for HR/BP Monitoring PCB

5.3.2 Programming and running a test code

The onboard MCUs namely; Atmegag328p and A9G were programed using the Arduino ICSP programmer. For ATMEGA328P: connect an ICSP Programmer (Arduino as ISP programmer) to the ICSP interface with Arduino Pins are as follows:

Pin 10 – RESET
Pin 11 – MOSI
Pin 12 – MISO
Pin 13 – SCK

The codes are then uploaded to the MCU for testing. The test code could be an LED blinking code or a code to display 'VIMONET TEST' on the OLED as demonstrated in the breadboard shown in figure 11.

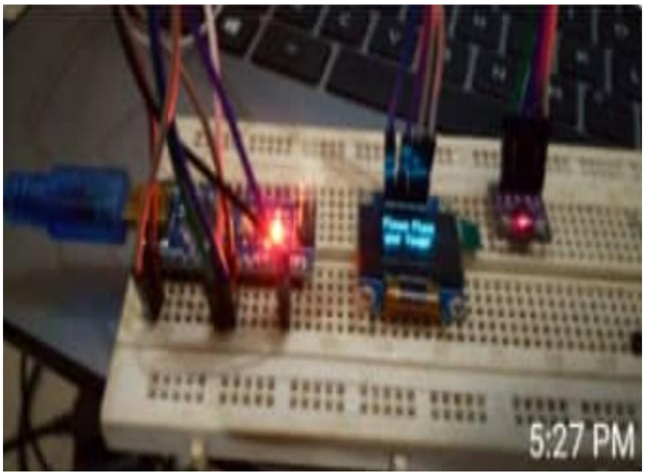

Figure 11: Testing of OLED before mounting on PCB

5.3.3 Sensor testing

After ensuring that the sensors are receiving the adequate voltage level for normal operation proceed to write some codes to read their values and display on LCD. The fabricated prototype PCB is depicted in figure 12 (a & b).

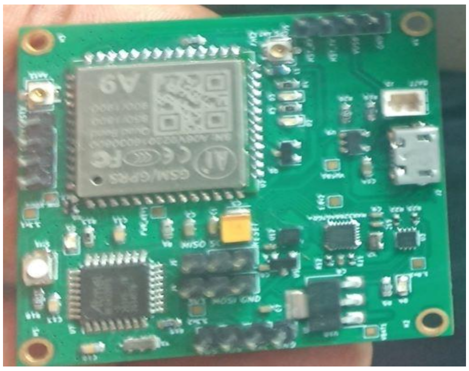

Figure 12a: HR/BP monitoring device (Front view)

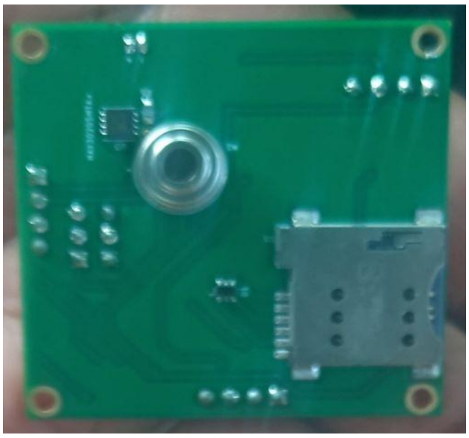

Figure 12b: HR/BP monitoring device (Back view)

6 CONCLUSION

This article reports the design and successful execution of a fully functional wireless Heart rate and Blood pressure monitoring and transmission device for remote medical diagnosis. The prototype architecture uses an approach that adopts the long range wireless communication protocol between the sensor nodes and IoT gateway. The system delivers a reliable network for transmitting sensitive medical data with guaranteed QoS. User interface is provided through an application programming interface (API) in the web platform to access the measured data for analysis and diagnosis by the web-based medical expert in a remote location. Results obtained from measured vital signs could be easily accessed from the web by providing the required fields pre-defined by the web server agent. The device measures body temperature, heart rate and transmits same in real time to the remote server with user location for further analysis.

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