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Design and Implementation of an IoT Based Patient's Health Monitoring System

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ABSTRACT
This paper presents an Internet of Things (IoT) based patient's health monitoring system that can be given to patients, especially in remote areas from the hospitals. This system is built around Node MCU (ESP8266) which is used to control the activities of the system. The microcontroller is interfaced to MLX90614 which is the contactless infrared (IR) temperature sensor and MAX30101 which is the High-Sensitivity Pulse Oximeter and Heart Rate Sensor. The software implementation involves the programming of the microcontroller in Arduino IDE environment and the setting up of the Blynk cloud platform for receiving data from the system. This data can be accessed remotely in the Blynk platform through internet connection. The results obtained show that the system performed optimally as the percentage error margin in readings obtained from the system for body temperature, heart rate (pulse rate), and blood Oxygen level when compared with commercially available health measuring devices show a maximum percentage error of 3.51 in heart rate and a minimum percentage error of -3.42 in body temperature. Again, the Root Mean Square Error (RMSE) for body temperature, heart rate (pulse rate), and blood Oxygen level when compared with commercially available health measuring devices are 0.351, 0.935, and 2.503 respectively. These values are less than the 2% stipulated by the US Food and Drug Administration (FDA) requirement of root mean square accuracy for pulse oximeters, and the percentage error values in this work are less than ±5% for oximeter. This means that the system is reliable.

Keywords: Internet of Things (IoT), Health, Patient, measurement, microcontroller.

1. Introduction

Lack of appropriate patient health monitoring has become a serious problem in many African nations, including Nigeria. According to statistics, almost 40% of adults in this area are thought to have treatable ailments such as high blood pressure and cardiac conditions (Stetson, 2019; Vishal, 2019).

A Remote health monitoring system is an annex of a hospital medical system where a patient's vital body state can be monitored remotely. Traditionally, health monitoring systems were only found in hospitals and were characterized by huge and complex circuitry that required high power consumption. Continuous advances in the semiconductor technology industry have led to sensors and microcontrollers that are miniaturized in size, have high speed of operation, are low in power consumption, and are affordable in cost. This has further seen development in the remote monitoring of important health signs of patients, especially the elderly (Antonoviciet al., 2014; Jiuping & Lei, 2017).

A simple patient monitoring system design can be approached by the number of parameters it can detect. In some instances, by detecting one parameter, several readings can be calculated. (Azariadiet al., 2016; Badamasi, 2014)

To aid in the early discovery, monitoring, and treatment of these diseases, a solution to this issue must be provided (Yin et al., 2014; Yehet al., 2015). It is in line with this that Sullivan and Sahasrabudhe (2017) presented a system for proper monitoring of patients's health using IoT to allow for swift medical access and response where necessary.

Human health is one of the most important concerns among many issues in the world in contemporary times. Access to medical care can be greatly improved if the health of patients both at home and in the hospital can be monitored and communicated to healthcare personnel. In line with this, many researchers over the years have worked to see improvements in health monitoring devices.

In pursuance of the above, Uditet al. (2017) presented a new system of IoT-based electrocardiogram (ECG) signal quality detection for constant monitoring of cardiac health applications. This system consists of three major modules, namely, ECG signal detection, automatic signal quality assessment (SQA), and signal quality aware (SQAw) ECG analysis and transmission modules, which were interfaced to Arduino, Android phones, Bluetooth, and cloud servers. The system was expected to be able to categorize ECG signals as acceptable or unacceptable. According to the authors, the system showed a promising result in identifying unacceptable ECG signals. An Arduino-based mobile device-controlled framework for monitoring health parameters was proposed by Trivedi andCheeran (2017). The system involves the Arduino Uno board receiving analog sensor data that has been collected and transmitted through Bluetooth on Android devices to the cloud. This data could be stored over time to keep track of the patient's health information, which can be accessed by a remote doctor for medical services.

Concerned about the security of transmitted medical information as a result of the increase in data use from IoT in the medical sector, Elhoseny et al. (2018) proposed a crossbreed security model by integrating the 2-D discrete wavelet transform 1 level (2D-DWT-1L) or 2-D discrete wavelet transform 2 level (2D-DWT-2L) steganography method. They also suggested an encryption method that will consist of a blend of the Advanced Encryption Standard and Rivest, Shamir, and Adleman algorithms. According to them, the model was able to conceal patients' data in transmission with the least degradation in the received image data.

Subasiet al.(2018) presented what they called an intelligent m-healthcare system based on IoT technology aimed at providing prevalent human action identification utilizing data mining methods. They stated that it is a user-dependent data mining technique for off-line human action categorization, and they developed a human action identification model based on the IoT technique. They further stated that the model performed with an accuracy of 99.89% when tested on 12 human actions as a dataset that included movement of the body and key sign documentation for 10 volunteers with different conditions.

Ashwini and Ramkrishna (2018) proposed an IoT-based health monitoring system built on a Raspberry Pi with sensors for heartbeat rate and body temperature reading and displayed on an LCD. The data will be stored on a computer in the cloud, through which people concerned could have access to it. Noret al. (2020) developed an IoT-based patient monitoring system using sensors to monitor, detect, and analyze only two primary health vital signs, namely the patient's body temperature and respiratory rate, and displayed the values. Similarly, Tamilselvi et al., (2020) employed an IoT health monitoring system for patients in coma. They used an Arduino-Uno board microcontroller that was interfaced with temperature, heartbeat, eye blink, SP02 (peripheral capillary oxygen saturation), and accelerometer sensors which monitor the patient's body temperature, coronary heart disease, eye movement, oxygen saturation percentage, and body movement, respectively, and an LCD was used to show the results of the monitoring. The system was able to trigger an alarm in any case of abnormalities in any of the observed parameters of the patient in a coma using a GSM and Wi-Fi module. According to them, this system was also able to save and analyze the monitored data.

Solomon and Otokiti (2020), in their work, proposed a system structure for appropriate patient health monitoring using IoT technology, which involves real-time data reading from sensors that interface with a patient. According to them, these data are delivered to a local device using Bluetooth and Wi-Fi technology and thereafter through GSM/GPRS to the IoT server for necessary immediate medical access and attention.

In finding improvements to health monitoring systems, the accuracy of the devices is an important factor to be considered. In line with this, Gunawan et al., (2020) and Joseph (1989) have stated that ± 5% is the maximum permissible tolerance of oximeter measurement in comparison with standard apparatus. Again, Wong et al,. (2021) stated that "the US Food and Drug Administration (FDA) requires root mean square accuracy within 2% for values between 70%and 100%, implying that an adequate pulse oximeter returns an SpO2 value within 2% to 3% of the SaO2 value (i.e., a range of 4% - 6%).

Following in the footsteps of Tamilselvi et al., (2020), Paul and Angel (2021) presented a real-time patient health monitoring system using pulse sensors and temperature sensors interfaced with an Arduino board for control. It was also connected to an LCD for display and a wifi module to connect to Thing Speak for cloud storage of the read data. Mohammad et al., (2022), in their work, presented an IoT-based health monitoring system that is non-invasive and could be used by rural dwellers. The system was designed to be able to read the temperature, heartbeat, and oxygen saturation level in the blood of the patients. They also have an app that can receive the data using Bluetooth. This was designed with low cost in mind.

As a result of the many advances and methods espoused over the years on ways of improving health monitoring either remotely or in contact with the patient, Abdulmalek et al., (2022) carried out a detailed review of the health monitoring system and the critical function of IoT in the system. They recommended at the end of the review that there needs to be an integration of IoT healthcare wearable devices with later technology. They also recommended that any proposed system should be convenient, easy to understand, pliable, and secure. They added that IoT could help solve issues by linking health-monitoring devices and sensors to the cloud for 24/7 monitoring.

Sangeethalakshmi et al. (2023) presented a health monitoring system that is based on IoT. It is comprised of a mobile app with GSM as the wireless component and a microcontroller interfaced with sensors for monitoring the patient's temperature, heartbeat rate, blood pressure, ECG, and oxygen saturation level of the blood.

From the preceding, it can be seen that a lot of research has been carried out in this area. This work is set to advance knowledge in this area by implementing an IoT-based health monitoring device for body temperature, pulse rate, and blood oxygen measurements and comparing the measurement results with those of commercially available devices.

2. Materials And Methods

The implementation of this work is divided into two main phases. These are the hardware and the software implementations.

2.1 Hardware Implementation

The block diagram hardware implementation showing the various modules is as shown in Figure 1.

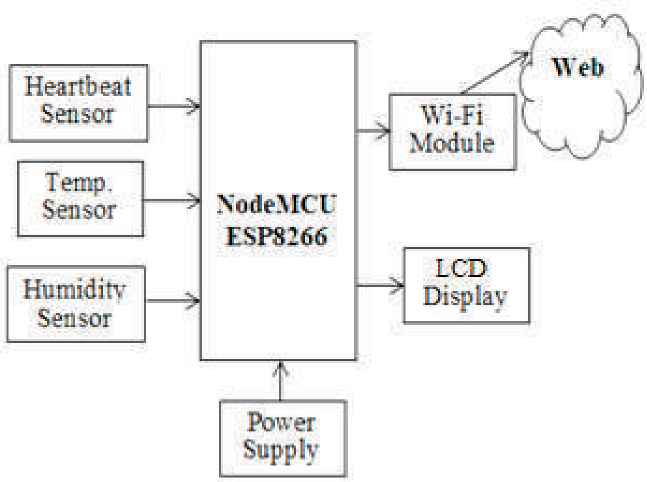

Figure 1: Block diagram of implementation

2.1.1 Interfacing the microcontroller to the components for hardware implementation

The NodeMCU microcontroller is interfaced with the serial data (SDA) and serial clock (SCL) of the infrared temperature sensor (MLX90614) and the LCD on ports 19 and 20 respectively. The microcontroller is the heart of the system that controls and coordinates the activities of the system. Similarly, the High–Sensitivity pulse oximeter and Heart-Rate sensor (MAX30101) were interfaced to the same port of the microcontroller. All the interfaces for power supply and ground were connected appropriately to the power supply. The circuit diagram is shown in Figure 2.

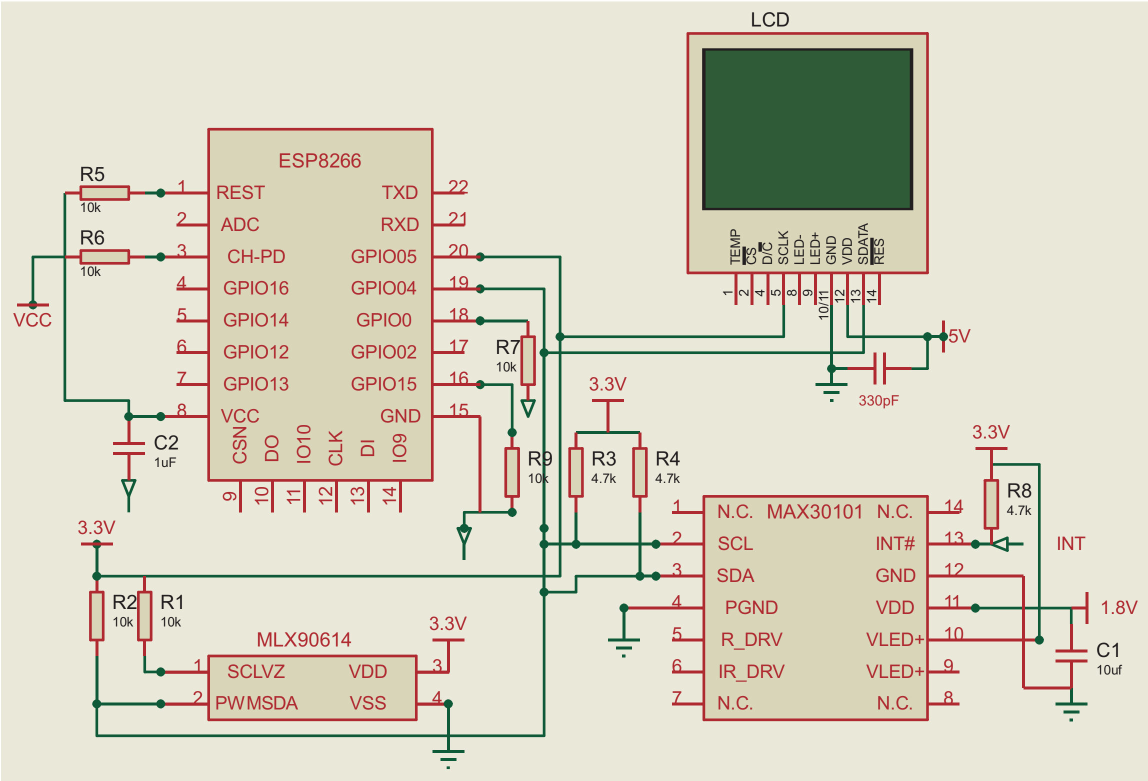

Figure 2: Schematics of hardware implementation

2.2 Software Implementation

The software implementation was in two parts. The first is the programming of the Microcontroller using C++ in Arduino IDE environment. This was suitably done to allow the microcontroller to monitor, direct, and receive data from the sensors and send the signal (the data) to the Blynk Platform. The second part is the setting up of the Blynk IoT Platform for remote access to the device's measurements. Blynk is a Platform with iOS and Android apps to control Arduino, Raspberry Pi and the like over the internet. It is a digital dashboard where one can build a graphic interface for hardware where we can monitor our data and control our system over the internet, using the channels and web pages provided by Blynk. The Blynk platform was set up by first downloading the app into the phone and then an account was created and authenticated. A project was created and Nodemcu was selected as the device and Wi-Fi as the connection. Then, the needed widgets and gauges were selected for heart rate (BPM), oxygen level (SPO2), temperature, and humidity.

2.3 Principle of operations

Figure 3 shows the flowchart of the system operation.

At the start, the system initializes and the microcontroller (NodeMCU ESP8266) takes charge of the device implementation of the various functionalities like reading sensor data, converting them into strings, passing them to the IoT platform, and displaying measured rates and temperature on the LED display. It involves the microcontroller reading real-time data from sensors attached to patients. This data is sent to the Wi-Fi module as a communication channel to the internet for transmitting the data to the Blynk IoT server. The received data is checked for integrity and if the integrity is good, it is displayed, otherwise, the sensors are required to send new data.

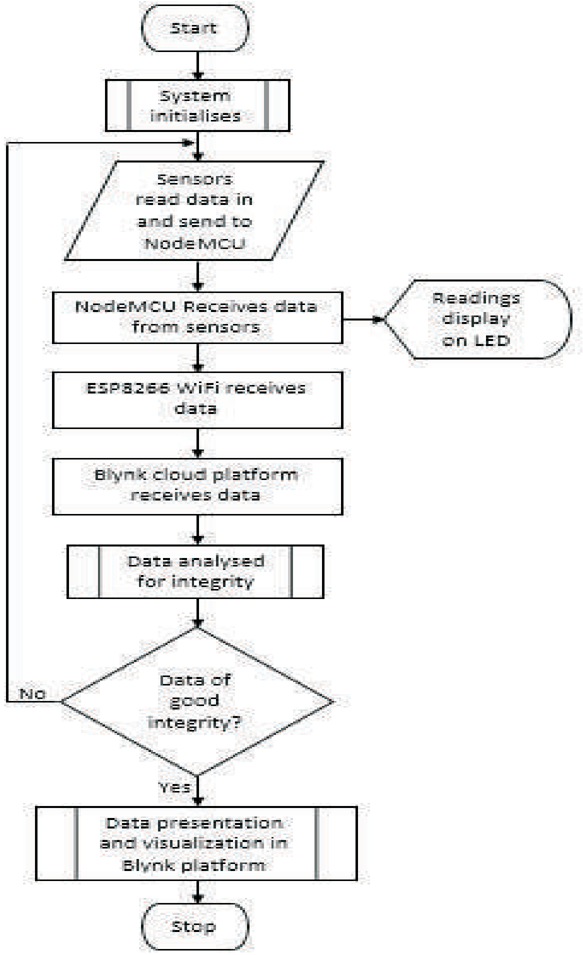

Figure 3: Flowchart of the system operation

2.4 Tests

The IoT-based patient health monitoring system designed and implemented was tested at the Boys Hostel and the computer laboratory in the Faculty of Engineering, respectively, of Edo State University Uzairue. The system was used to take readings of body temperature, the heart rate and the oxygen level (SPO2). In each case, the reading was taken three times, and an average of the reading in each case was taken. Again, a commercial body thermometer, heart rate monitor, and oximeter were used on the same people on whom the prototype was used to take readings. The difference between the prototype readings and the commercial readings, and the RMSE were calculated, and the error percentage was determined.

3.0 Results and Discussion

Tables 1 and 2 show the measurements for body temperature for the prototype and the commercial thermometer, and the error percentage, respectively. Tables 3 and 4 show the measurements for heart rate for the prototype and the commercial heart rate monitor, and the error percentage respectively. Tables 5 and 6 show the measurements for the oximeter for the prototype and the commercial heart rate monitor, and the error percentage, respectively. Figures4, 5, and 6 show a graphical comparison of the average readings of the prototypes and the commercially available thermometer, heart rate monitor, and oximeter.

Table 1: Body temperature measured readings

Persons	DT8806C Body Infrared Thermometer (Commercial)				Prototype			
	Temperature Reading in Celsius (°C)			Average	Temperature Reading in Celsius (°C)			Average
	Trial 1	Trial 2	Trial 3		Trial 1	Trial 2	Trial 3	
1	36.6	36.5	36.5	36.5	36.0	34.3	36.3	35.5
2	36.1	36.2	36.4	36.2	36.3	36.3	36.3	36.3
3	35.2	35.1	35.1	35.1	36.3	36.3	36.3	36.3
4	36.5	36.4	36.2	36.4	36.6	36.6	36.6	36.6
5	36.4	36.7	36.5	36.5	36.9	35.2	36.6	36.2
6	35.8	35.6	35.9	35.8	36.9	36.9	35.2	36.3
7	36.4	36.5	36.5	36.5	36.9	35.5	34.6	35.8
8	35.9	36.0	36.1	36.0	36.0	36.0	36.2	36.1
9	36.1	36.1	36.3	36.2	36.5	36.5	36.5	36.5
10	36.3	36.2	36.1	36.2	36.3	36.6	36.6	36.5

Table 2: Body temperature measured error difference

Person	Commercial (E)	Prototype (O)	***O - E***	***(O - E)^2***	% Error
1	36.5	35.5	1	1	2.73
2	36.2	36.3	-0.1	0.01	-0.27
3	35.1	36.3	-1.2	1.44	-3.42
4	36.4	36.6	-0.2	0.04	-0.55
5	36.5	36.2	0.3	0.09	0.82
6	35.8	36.3	-0.5	0.25	-1.39
7	36.5	35.8	0.7	0.49	1.92
8	36.0	36.1	-0.1	0.01	-0.27
9	36.2	36.5	-0.3	0.09	-0.83
10	36.2	36.5	-0.3	0.09	-0.82
				3.51	

$$RMSE = \sqrt{\frac{(O - E)^2}{n}} = \sqrt{\frac{3.51}{10}} = 0.351$$

Table 3: Heart rate measured readings

Persons	Commercial				Prototype			
	Heart Rate *(Beats Per Minute)*			Average	Heart Rate *(Beats Per Minute)*			Average
	Trial 1	Trial 2	Trial 3		Trial 1	Trial 2	Trial 3	
1	55	58	55	56.0	56	55	56	55.7
2	56	57	55	56.0	57	56	55	56.0
3	58	57	55	56.7	58	57	55	56.7
4	55	54	56	55.0	57	55	56	56.0
5	57	55	55	55.7	56	57	56	56.3
6	57	56	58	57.0	55	54	56	55.0
7	54	57	56	55.7	55	56	57	56.0
8	58	58	57	57.7	56	58	55	56.3
9	55	54	56	55.0	56	57	56	56.3
10	57	55	58	56.7	56	58	55	56.3

Table 4: Heart rate measured error difference

Person	Commercial (E)	Prototype (O)	***O - E***	***(O - E)***^{2}	% Error
1	56.0	55.7	-0.3	0.09	0.53
2	56.0	56.0	0	0	0
3	56.7	56.7	0	0	0
4	55.0	56.0	1	1	-1.81
5	55.7	56.3	0.6	0.36	-1.07
6	57.0	55.0	-2	4	3.51
7	55.7	56.0	0.3	0.09	-0.53
8	57.7	56.3	-1.4	1.96	2.43
9	55.0	56.3	1.3	1.69	-2.36
10	56.7	56.3	-0.4	0.16	0.70
				9.35	

$$RMSE = \sqrt{\frac{(O - E)^2}{n}} = \sqrt{\frac{9.35}{10}} = 0.935$$

Table 5: Blood oxygen level (SPO_2) measured readings

Persons	Commercial				Prototype			
	Trial 1	Trial 2	Trial 3	Ave.	Trial 1	Trial 2	Trial 3	Ave.
1	97	98	98	97.7	95	96	95	95.3
2	96	98	97	97.0	96	95	96	95.7
3	98	98	97	97.7	95	95	96	95.3
4	97	96	96	96.3	96	96	95	95.7
5	97	96	97	96.7	95	96	95	95.3
6	98	96	97	97.0	95	96	96	95.7
7	96	97	97	96.7	96	95	95	95.3
8	97	96	97	96.7	96	95	96	95.7
9	98	97	96	97.0	95	96	95	95.3
10	96	97	97	96.7	96	95	95	95.3

Table 6: Blood oxygen level (SPO_2) measured error difference

Person	Commercial (E)	Prototype (O)	***O - E***	***(O - E)***^{2}	% Error
1	97.7	95.3	-2.4	5.76	2.45
2	97.0	95.7	-1.3	1.69	1.34
3	97.7	95.3	-2.4	5.76	2.45
4	96.3	95.7	-0.6	0.36	0.62
5	96.7	95.3	-1.4	1.96	1.44
6	97.0	95.7	-1.3	1.69	1.34
7	96.7	95.3	-1.4	1.96	1.44
8	96.7	95.7	-1	1	1.03
9	97.0	95.3	-1.7	2.89	1.75
10	96.7	95.3	-1.4	1.96	1.44
				25.03	

$$RMSE = \sqrt{\frac{(\mathrm{O} - \mathrm{E})^2}{n}} = \sqrt{\frac{25.03}{10}} = 2.503$$

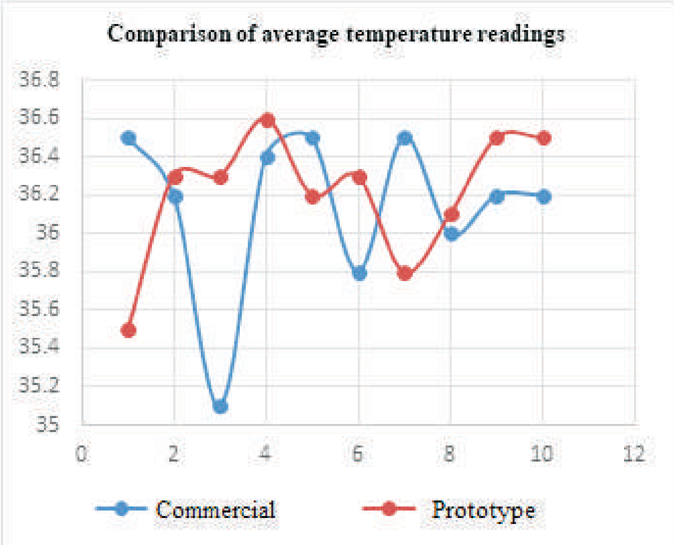

Figure 4: Comparison of average temperature readings

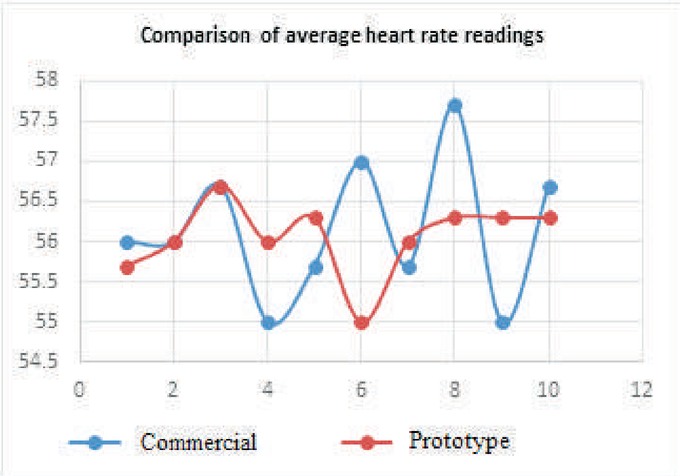

Figure 5: Comparison of average heart rate readings

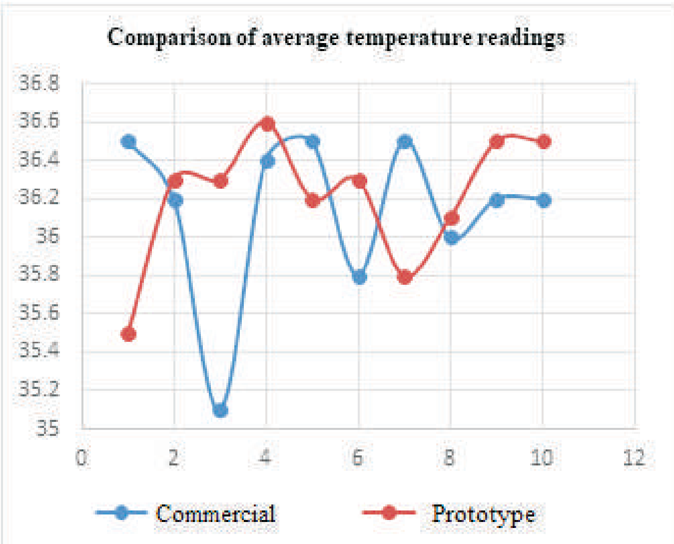

Figure 6: Comparison of average blood-oxygen level readings

Figures 7 and 8 also show the result of oxygen level readings and temperature readings at the serial monitor.

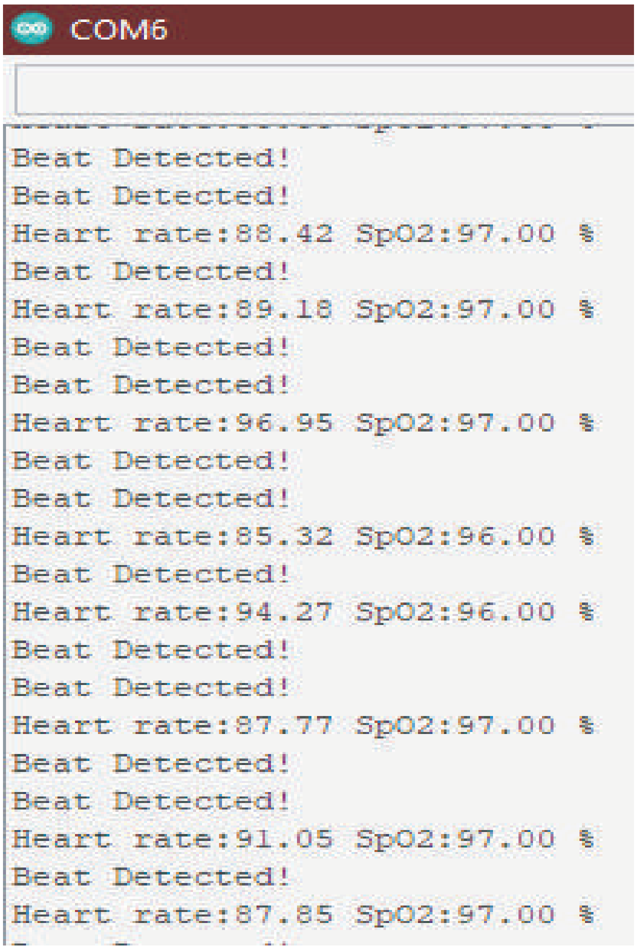

Figure 7: Data of the Oxygen level readings showing at the serial monitor

```
Ambient temperature = 31.37°C   Object temperature = 37.33°C
Ambient temperature = 31.35°C   Object temperature = 36.89°C
Ambient temperature = 31.35°C   Object temperature = 37.35°C
Ambient temperature = 31.37°C   Object temperature = 37.25°C
Ambient temperature = 31.35°C   Object temperature = 37.03°C
Ambient temperature = 31.37°C   Object temperature = 36.95°C
Ambient temperature = 31.35°C   Object temperature = 36.55°C
Ambient temperature = 31.39°C   Object temperature = 36.93°C
Ambient temperature = 31.39°C   Object temperature = 36.87°C
Ambient temperature = 31.37°C   Object temperature = 36.81°C
Ambient temperature = 31.37°C   Object temperature = 36.61°C
Ambient temperature = 31.39°C   Object temperature = 37.17°C
Ambient temperature = 31.37°C   Object temperature = 36.95°C
Ambient temperature = 31.37°C   Object temperature = 37.03°C
```

From Tables 1, 3, and 5, it is evident that the readings of the IoT-based patient's health monitoring system prototype and those of commercially available body temperature thermometer, heart rate monitor and oximeter are not at variance. In Tables 2, 4, and 6, the minimum and maximum percentage errors for body temperature readings, heart rate readings and oximeter blood-oxygen levels are -3.42 and 2.73; -2.36 and 3.51; 0.62 and 2.45 respectively. These error margins are less than $\pm$5% of the readings. This shows that the prototype as designed is performing optimally when compared with the existing measuring system. Figures 4, 5, and 6 also buttress this as the plots for the commercially available measuring instruments follow the same pattern as those of the prototype. However, the readings of the blood-oxygen level in Tables 5 and 6 and Figure 6 show that the readings of the commercially available are higher than that of the prototype even though it is not up to a 5% difference. Figures 6, 8, and 9show that the Blynk platform aspect of the system is receiving data from the sensors through the Wi-Fi as designed and could be accessed remotely by medical practitioners or any other person that is authorized.

4. Conclusion

The developed IoT-Based patient's health monitor in this work performed optimally as the results show great performance when compared to commercially available devices. All the individual sensors such as the heartbeat detection sensor, body temperature sensor, humidity sensor, and remote viewing module gave out the intended results. This system is very important to the health sector as it combines three vital signs measurements for patients in one system. Again, this system can be used in remote locations where health officials are not readily available to monitor their patients as the results of the monitoring of their vital signs are made available online for medical officers to access. This will help in reducing health deterioration of patients as the result of this system will enable the medical officers to monitor their patients and make decisions quickly in case of change in patient's health. This goes a long way to prevent sudden death and enhance better management of patient's health remotely.

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