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Development of IoT-Based Heart Rate and Oxygen Saturation Alert System in COVID-19 Wards

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Abstract: The increasing number of Coronavirus Disease 2019 (COVID-19) patients gives it a tough time for the hospital staff to manage and monitor the patient's oxygen levels and heart rate. Therefore, this research was done to create an alert system that enables the hospital staff to monitor and provide immediate care for COVID-19 patients who experience a drop in oxygen saturation (SpO2) and heartbeat levels. The objectives of this research were to develop the heart rate and oxygen saturation system, to develop the alert notification system using a buzzer, ThingSpeak, and SMS, and to evaluate the performance of the developed system. For the hardware development, two MAX30102 sensors, a NodeMCU ESP8266, an Arduino UNO, two OLED Displays (0.96in 128x64 SSD1306 Blue), and two buzzers were used. The integration with ThingSpeak allowed the data to be displayed and monitored. The IFTTT played an important role in allowing notifications through SMS to the users. The buzzer successfully beeped, and the alert notification was sent to the authorized personnel in the form of SMS when the SpO2 dropped below 94%, BPM was less than 60 and when exceed 120. Obtaining a high degree of accuracy is the goal of the research's future work since it is important to verify the device's accuracy and to conduct the measurement in an appropriate setting.

Keywords: Oxygen Saturation, Heart Rate, IFTTT, Arduino, IoT

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1. Introduction

In late December 2019, a previously unnamed coronavirus, now dubbed the 2019 new coronavirus, emerged from Wuhan, China, and caused a massive outbreak across China and the rest of the world including Thailand, the Republic of Korea, Japan, the United States, Philippines, Vietnam, and many other countries (as of 2/6/2020 at least 25countries) [1]. The disease was officially named Coronavirus Disease-2019 (COVID-19, byWHO on February 11, 2020) [1]. COVID-19 is a potential zoonotic disease with a low tomoderate (estimated 2%–5%) mortality rate [1]. Coronavirus disease 2019 (COVID-19) was spread through large droplets produced during coughing and sneezing by symptomaticpatients, as well as asymptomatic individuals before having symptoms [2]. A person withCOVID-19 will experience a dangerous drop in oxygen saturation. As a result, medical oxygen had to be given to maintain the oxygen levels within the usual range. When the oxygen levels are low due to COVID-19, the body's cells don't have enough oxygen to carry out regular functions. To function properly, every cell in the body requires oxygen.If the oxygen levels are low for an extended period and are not treated, the cells will stopworking properly and eventually die. When there is insufficient oxygen supply in the body, cells that make up the organs will begin to malfunction, which in the worst-case scenario could result in death.

The measurement of oxygen saturation was crucial in the management and comprehension of patient care. The amount of hemoglobin bound to oxygen against the amount of hemoglobin that was unbound was measured by oxygen saturation. The National Institutes of Health recommends a target oxygen saturation range of 92% to 96% for COVID-19 patients [3]. In patients with COVID-19, oxygen saturation < 90% on admission was a substantial predictor of in-hospital mortality. Efforts to reduce mortality inCOVID-19 should focus on the early identification of hypoxemia and timely access to hospital care [4]. Oxygen saturation was measured by pulse oximetry (SpO_2) often used todetect hypoxemia [5]. Pulse oximetry was based on the absorption characteristics of oxygenated and deoxygenated hemoglobin in red and infrared light. Oxygenated hemoglobin absorbs more infrared light and allows more red light to pass through whereasdeoxygenated hemoglobin absorbs more red light and allows more infrared light to pass through [6]. Patient’s heart rate may become rapid or irregular as a result of having COVID-19"It was clear that people who arrived in the hospital sick with a heart condition were the ones who were most likely to require mechanical ventilation and, as a result, we're at the greatest risk of dying," said Aaron Baggish, MD, director of Massachusetts General Hospital's cardiovascular performance program [7]. As the heart works harder topump more blood around the body to battle the illness, the pulse rate may rise in reactionto a fever or inflammation. A resting heart rate of 60 to 100 beats per minute isrecommended for adults.

Pulse oximetry is a valuable tool for determining a patient's oxygenation state and can be utilized in a variety of clinical settings. Through the use of pulse oximetry, oxygenation can be monitored easily and non-invasively [8]. Pulse oximetry has a 95% confidence rating of 4%, therefore results between 70% and 100% SpO_2 are deemed reliable. This means that, although pulse oximetry was not a replacement for blood gas testing, it can be used as a screening tool when poor oxygen saturation is suspected [8]. Using this significant ability in light absorption, the emission of pulse oximeter comes from two types of light wavelengths: red at 660 nm and near-IR at 940 nm. It comes froma pair of diodes that emits light located in one arm of a finger probe. The light that was delivered through the finger then was ascertained by a photodiode on the opposite arm of theprobe [9]. How the pulse oximeter detects SpO_2 was based on the amount of red and IR light absorbed. The absorption may fluctuate because of the increase in arterial blood volume when in systole-state and decrease when in diastole-state [9]. Pulse oximeter offers a fast,easy, and non-costly technique. In comparison to blood gas analysis, the pulse oximeter offers no blood samples taken, which was particularly convenient. Monitoring of hypoxemia was allowed using this moderator accurate device. This condition was the reason why a pulse oximeter can be applied in evaluating COVID-19 patients from the early stage(isolated stated) until the highest stage (ICU stated) [9].

This study aims to develop the IoT-based heart rate and oxygen saturation alert system in the COVID-19 ward for COVID-19 patients. There are three objectives for this study which are, to develop the heart rate and oxygen saturation system, to develop the alert notification system using buzzers, ThingSpeak, and SMS, and to evaluate the performance of the developed system. In this project, Arduino technology was used to create a heart rate and oxygen saturation system. Additional measurements using this system will be the body temperature. MAX30102 pulse oximeter sensor was used to detect the heart rate in BPM, oxygen saturation level in SpO_2 percentage, and body temperature in degrees Celcius. In addition, Arduino UNO and NodeMCU ESP8266 were used as the microcontroller that connects components and lets data transfer using the Wi-Fi protocol. The OLED Displays (0.96in 128x64 SSD1306 Blue) were added to the prototype to display the reading of patients' heart rate and oxygen saturation levels. At the end of this project, the heart rate and oxygen saturation readings were displayed via ThingSpeak with an alert message and SMS that were sent to the family members to alert them of the patient's condition. Furthermore, two buzzers were connected to alert nurses when there was a drop in oxygen saturation level to act immediately by providing ventilators to the COVID-19 patients.

2. Materials and Methods

In this section, the components, block diagram, circuit connection, software development flowchart, hardware design, and performance evaluation of this study were explained.

2.1 Block Diagram and Circuit Connection

Figure 1 shows the block diagram of the hardware. There were seven components used in this project which were 2 MAX30102 sensors, Arduino UNO, NodeMCU ESP8266, 2 buzzers, 2 OLED Displays, and connecting wires. There were two circuits for this device, the NodeMCU ESP8266 is powered by Arduino UNO. This component was connected to MAX30102 Sensor 1, OLED Display 1, and Buzzer 1 which releases low-frequency beeps. The next circuit will be using Arduino UNO microcontroller that is connected to MAX30102 Sensor 2, OLED Display 2, and Buzzer 2 which gives out a high-frequency beep. The output of both these circuits was the data will be analyzed on the different channels which were channel Pulse Oximeter 1 and channel Pulse Oximeter 2 from NodeMCU as it uses Wi-Fi protocol that helps to transfer the data to ThingSpeak. Then, once the SpO_2 reading drops below 94% or the BPM reading was less than 60 and more than 120, the buzzer connected to Pulse Oximeter 1 beep at a low frequency, and the buzzer at pulse oximeter 2 beeps at a higher frequency while sending out alert SMS notification triggered thru IFTTT application to two different users at the same time. Figure 2 shows the resulting hardware connection with its labeling.

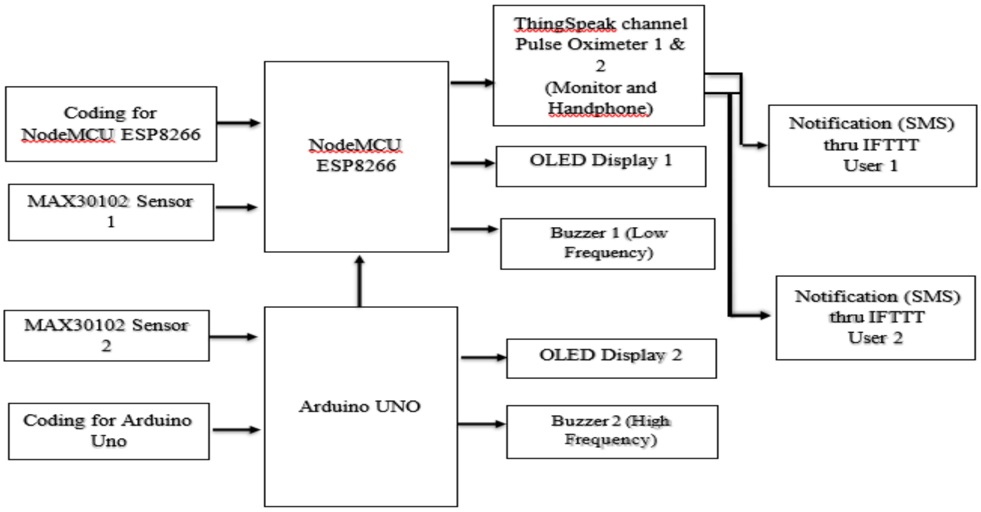

Figure 1: Block Diagram of Hardware

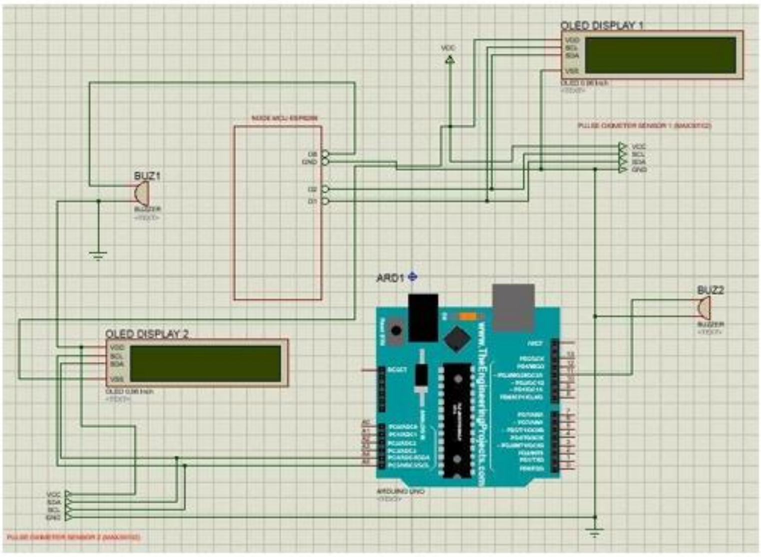

Figure 2: Schematic Circuit Connection in Proteus

2.2 Software Development

Figure 3 shows the flowchart of the system. Once the finger was placed, the BPM reading, SpO_2 reading, and body temperature were displayed on the OLED as an output. If the SpO_2 reading was less than 94%, the heart rate reading in BPM was less than 60 or more than 120, the buzzer beeps as an alert sign. Then the reading of SpO_2 and heart rate will be analyzed on ThingSpeak. An alert notification will be sent out when there was a drop of SpO_2 to the family members via SMS. If the SpO_2 and BPM readings were in a normal state, the data will be analyzed on ThingSpeak on a monitor or handphone and no alert will be sent out.

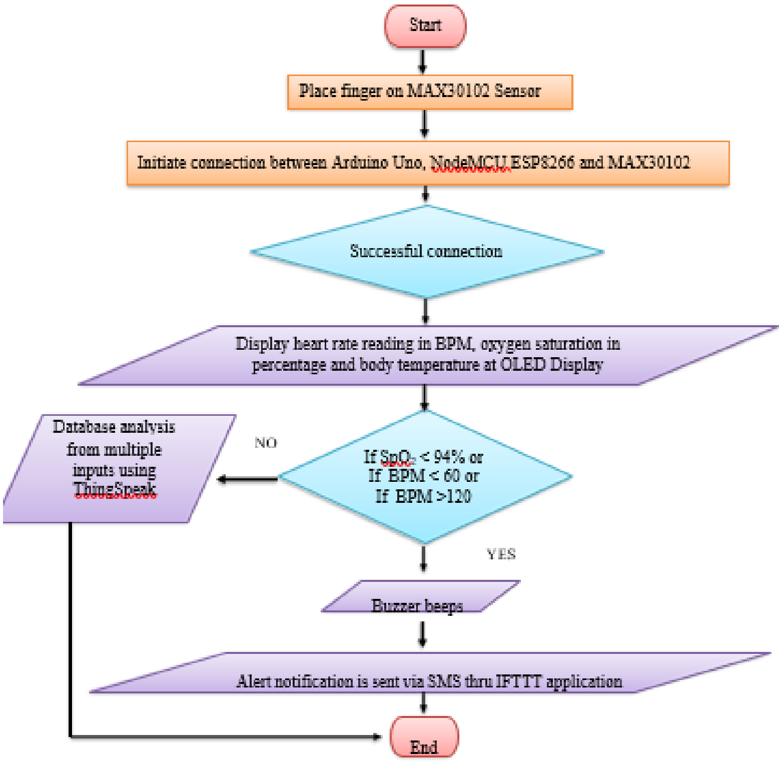

Figure 3: Flowchart of the System

Figure 4 shows the three channels created on ThingSpeak which enabled the analysis of the three data collected (heartbeat, temperature, and SPO_2). Meanwhile, Figure 5 shows the SMS notification received by two users with different handphone numbers once they drop in SpO_2 is detected. The notification was created through IFTT using applets, Webhooks and Android SMS. In brief, the users' numbers were first inserted in applets. Then, the URL link was generated by Webhooks. Next, the URL link was pasted in the ThingHTTP (ThingSpeak) and the limit of SPO_2 was set at the reaction widget which was less than 94 %. The IFTT will send out the SMS notification once the system detects a sudden drop in SPO_2 level. Hospital Tunku Aminah was used as an example to create a situation where the message was sent by the hospital management.

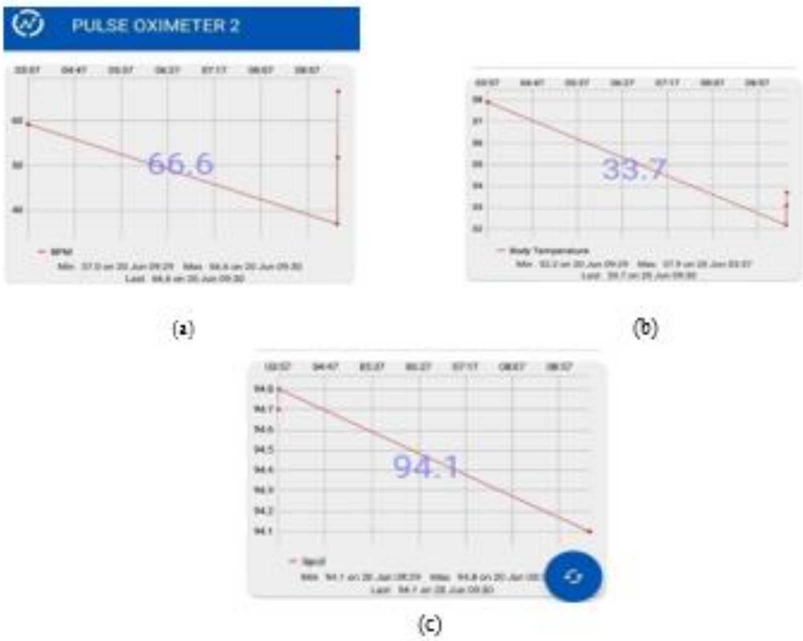

Figure 4: ThingSpeak channels showing (a) BPM, (b) Body Temperature, and (c) SpO2

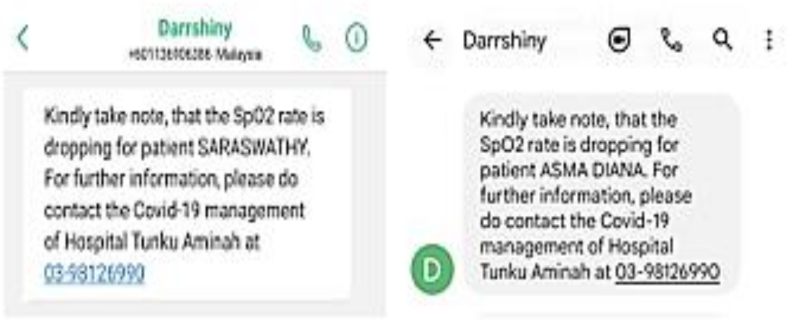

Figure 5: Notification from IFTTT

2.3 Finger Clip Customized Design

Figure 6, and Figure 7 show the hardware finger clip design for this research. A finger clip design was created using SOLIDWORKS as shown in Figure 6.The design was developed to customize the finger clip so that it can house the MAX30102 sensor which can measure the oxygen saturation, heart rate, and bodytemperature of COVID-19 patients. The pulse oximeter designed was light-weighted, easy to carry, small, and compactas shown in their measurements. The display box that consists of the components' connection was made out of plastic material which was light weighted.

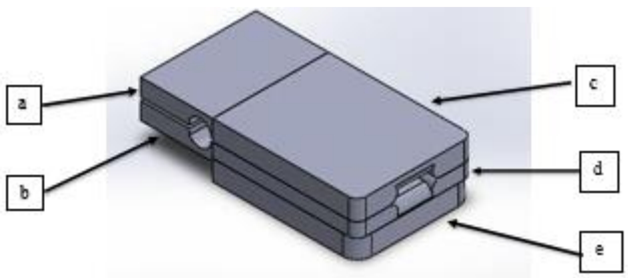

Figure 6: Finger clip designed in SOLIDWORKS

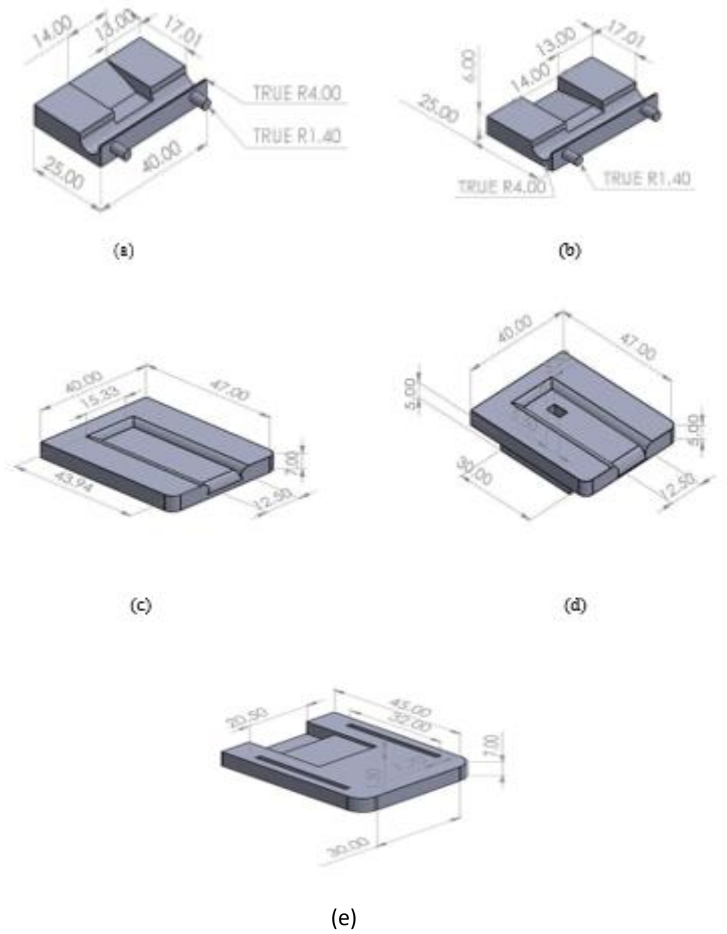

Figure 7: (a) Design of the upper clip of finger clip, (b) Design of the lower clip of finger clip, (c) Design of the first layer of finger clip, (d) Design of the second layer of finger clip, (e) Design of the third layer of finger clip

2.4 Performance Evaluation

2.4.1 Oxygen Saturation

The validation method was to compare the results of the developed oximeter to the pulse oximeter in the market. According to ISO9919:2005(E) the definition used to determine the SpO_2 accuracy of the pulse oximeter is "the root-mean-square (A_{rms}) which is the difference between measured values, SpO_{2i}, and reference values, S_{Ri} [10], and is given by the following formula:

$$A_{rms} = \left| \sqrt{\sum_{i=1}^{n} \frac{(SpO_{2i} - S_{Ri})^2}{n}} \right| \qquad \text{Eq. 1}$$

Regardless of the measurement site or sensor utilized, the accuracy of SpO_2 given by pulse oximeter equipment should ideally be less than 4% [10]. Take a reading with both the oximeters at the same time, and if the readings differ by less than 4%, the developed oximeter is good. However, if the readings differ by more than 8% to 10%, the test is considered inconclusive.

2.4.2 Heart Rate

The evaluation of heart rate was done by calculating the percentage of error. The reference BPM for this study will be the X1805 fingertip pulse oximeter BPM value. From equation 2, BPM_i refers to the device measurement data while BPM_R refers to the X1805 fingertip reading. The acceptable percentage of error will be not more than 5 percent. Therefore, the formula for calculating the percentage of error is as below:

$$\text{Percentage of error} = \left|\frac{BPM_i - BPM_R}{BPM_R}\right| \times 100\% \qquad \text{Eq. 2}$$

2.4.3 X1805 Fingertip Oximeter

Figure 8 shows the market fingertip oximeter that was used as a reference measurement for this study. The reason why this oximeter was chosen is that it gives out an accurate reading of SpO_2 and BPM that was needed for the calculation of A_{rms} and percentage of error. On the other hand, this oximeter was also light-weighted, small, and easily carried around during data collection from the respondent.

Figure 8: X1805 Fingertip oximeter used as a reference for data measurements

3.0 Results and Discussion

Based on Figure 9, two parts were included in the software development which were the connection of the MAX30102 sensor with Arduino UNO and the connection of the NodeMCU with the Max30102 sensor. Arduino programming was used in this project and MAX30102 was interfaced. The API key generated by ThingSpeak will be added to the programming codeto enable the project to fully function. The conditions of oxygen saturation and heart ratewere added in the coding too for the buzzer to function. IFTTT application was used to trigger SMS notifications. This was made possible by inserting the URL of IFTTT into ThingHTTP of ThingSpeak and reactions were created. One finger was placed on the MAX30102 sensor, the OLED Display (0.96in 128x64 SSD1306 Blue), and ThingSpeak displayed the heart rate and oxygen saturation reading. If the SpO_2 percentage was below 94%, or BPM was less than 60 or more than 120, the buzzer beeps and SMS notifications will be sent as an alert sign and there will be a drop in the graph displayed on the ThingSpeak which indicatesthat the patient needs immediate care. If the SpO_2 percentage was above 94%, there wouldn'tbe any notification sent and the patient was healthy. Figure 10 shows the display of the reading shown on the device once measurements were taken.

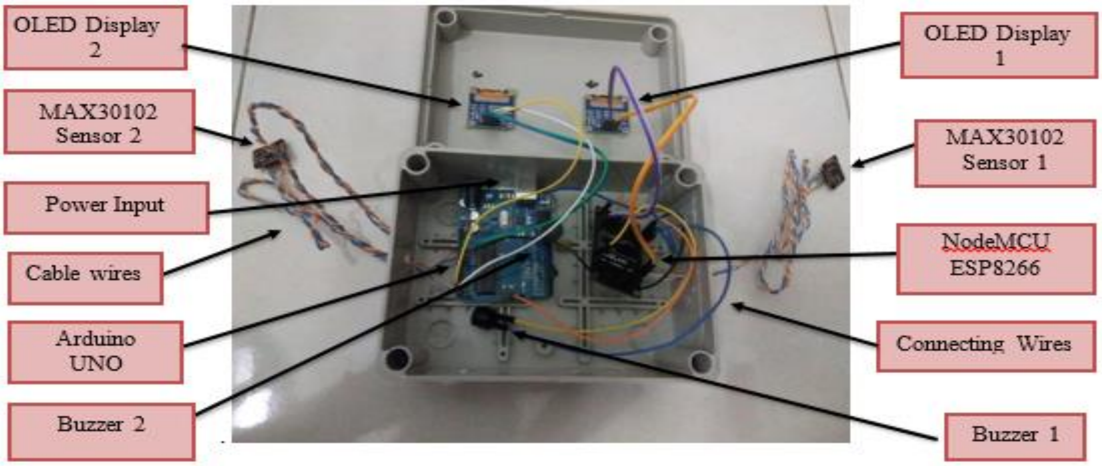

Figure 9: Main Hardware Connection

Figure 10: OLED Display showing the SpO_2, BPM, and Body temperature

To collect the results, 15 respondents were selected to participate in this study. All these participants were given a google form that consist of 3 sections which were a declaration form to participate in this study, questionnaires, and a thank you note for their involvement. After filling up the form, the respondents were approached to set a time for a meet-up to collect their data respectively. All the respondents were asked to use three layers of the mask to replicate a breathing difficulty situation as a COVID-19 patient. Three readings of each SpO_2, BPM, body temperature, and market oximeter were taken to calculate the average reading, A_{rms}, and percentage error.

Figure 11 shows the data collected from 15 subjects of different age groups ranging from 20 to 50 years old respondents in this study.

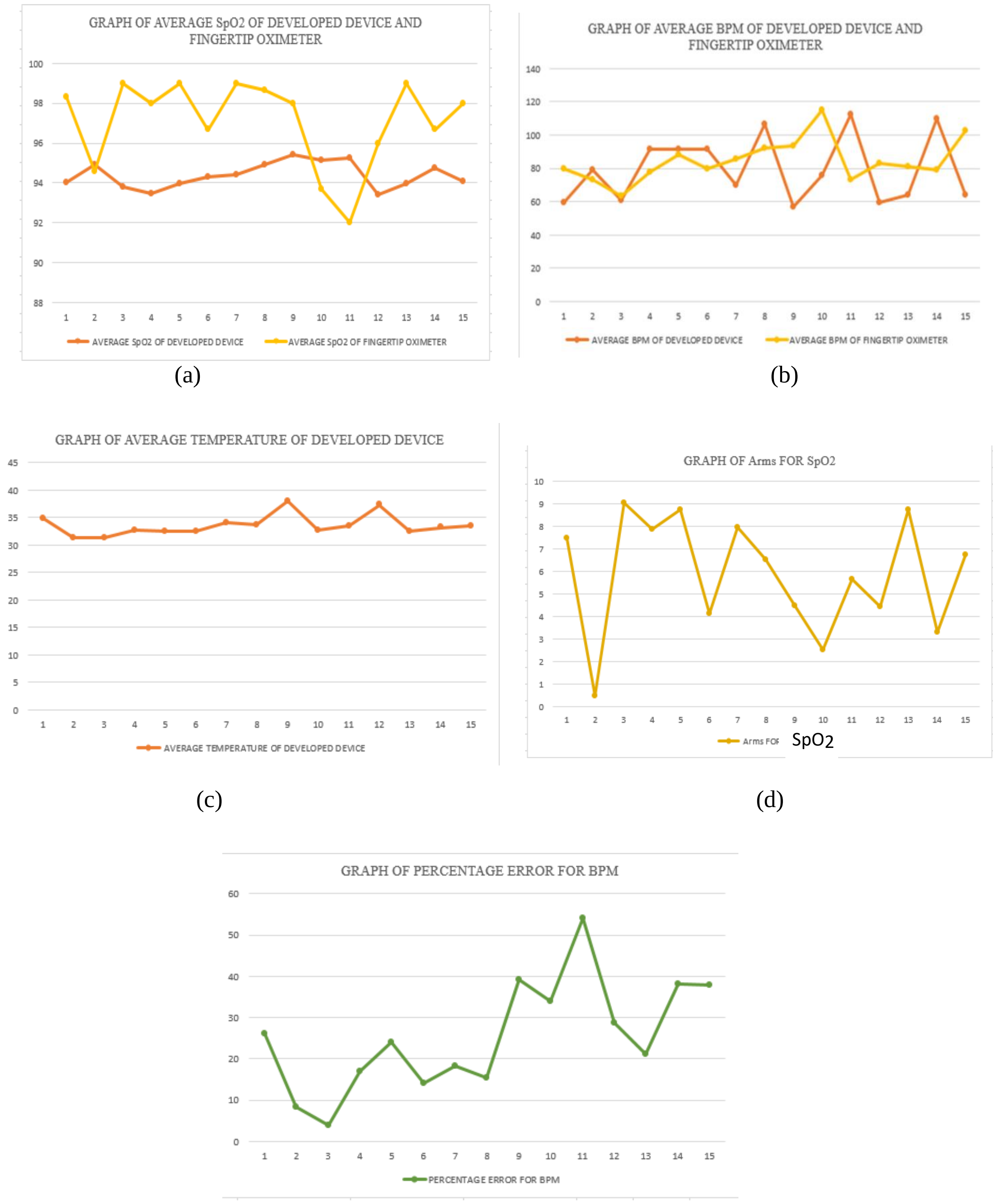

Figure 11: (a) Graph of average SpO_2 of developed device and fingertip oximeter, (b) Graph of average BPM of developed device and fingertip oximeter, (c) Graph of the average temperature of the developed device, (d) Graph of A_{rms} for SpO_2, (e) Graph of percentage error for BPM

The results collected during this study were then tabulated in table form. Based on Figure 11 (a), shows that Subject 1 had anaverage reading of 94 which triggered the buzzer to beep. The BPM reading of subject1 measured from the device created shows that the reading was quite low from the normal BPM reading which should be between 60 to 120 BPM while having a low body temperature. Therefore, the A_{rms} value for the SpO_2 was 7.51 as could be seen in Figure 11 (c) which could be considered an inaccurate reading as the acceptable A_{rms} value should beat least 4%. On the other hand, the percentage of error for the BPM reading of Subject 1 was 26% whereby the result obtained has a huge difference between the reference BPM value.

Next was Subject 2 who had a constant measurement of SpO_2 as 94.94% and an averageBPM of 79.09 BPM. The results obtained had a slight difference from the reference data collected from the fingertip oximeter. The A_{rms} of this Subject was also really low with a value of 0.47 which shows that the data obtained was acceptable while the percentage of errorof BPM was 8.35% which was lower compared to Subject 1.

Subject 3 obtained a SpO_2 value of 93.73 which was low that the reference oxygen saturation. Thus Subject 3 also had an inaccurate BPM reading of 45.63 which was too low for a living human. Both these conditions had caused the buzzer to beep with an alert notification message sent out. The body temperature of Subject 3 was really low than the normal human body temperature. The A_{rms} and percentage of error for Subject 3 were 9.06and 3.93% respectively. Subject 4 also had a low oxygen saturation reading and the buzzer beeped three times during each reading. The BPM of Subject 4 was within the normal range and has an A_{rms} reading of 7.9 while the percentage of error for BPM was 17 which was quite high. Next wouldbe Subject 5 which had a small increment in the oxygen saturation reading and a normal BPM when measured on the device created. But the percentage of error was high at 23.95%.

Moving onto Subject 6, the A_{rms} value was 4.13 which was good but it has a percentage of error of 14%. This shows that the reading of BPM consists of some inaccuracywhen compared with the reference value. Besides, subject 7 has a good oxygen saturation level and BPM but the percentage of error for BPM was quite high when compared to the reference results. Next will be subject 8 which had a high BPM measurement of 127.77. TheA_{rms} value of Subject 8 was 6.51 which was quite acceptable but has a high percentage error. The next subject would be Subject 9. The A_{rms} measurement of Subject 9 was 4.5 which shows that the oxygen saturation reading tallies with the reference oxygen saturation measurements.

Subject 10 has the lowest A_{rms} value which was 2.52 it was good that the SpO_2 reading was close to the reference reading while subject 11 has the highest percentage of error readingat 54.19. I noticed the BPM value of Subject 10 measured from the fingertip oximeter was constantly high because Subject 10 has some health issues as. Besides that, Subjects 12 and 14 have a low A_{rms} value which proves the SpO_2 data taken for these subjects were accurate. Subject 13 had some fluctuation in the BPM reading measured from the developed device that made the buzzer beep while Subject 14 and 15 didn't have an alert as the readings were within the conditions set. From all the above subjects, it could be said that Subject 2 had the lowest value of A_{rms} which was 0.47, and Subject 3 had the lowest value of percentage of error which was 3.93.There was an inaccuracy in the BPM value measured by the developed device that resulted in a high percentage of error.

4. Conclusion

In conclusion, the aim and objectives of this project were successfully achieved. The developed device was able to collect data and send out the alert notifications as well as display the three pertinent data on ThingSpeak, buzzer, and SMS. The system was also evaluated for its function and it was found that the device has some inaccuracies that need to be looked into for future study. Further improvements could be done to this device in terms of its design so that is easier to use by Covid-19 patients and easily to be handled. The limitations of this device arein terms of its accuracy as it is hard to be adjusted as it is already set to function as it is.

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