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IoT-Based Indoor and Outdoor Self-Quarantine System for COVID-19 Patients

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Abstract. Even after two years since the declaration of the new virus Coronavirus Disease 19 (COVID-19), the reported cases are still considerably high in many countries, including Malaysia. The health authorities cannot monitor the health condition and track the location of every home-monitored patient at once due to many confirmed cases in a day. In order to overcome the shortage of manpower, an Internet of Things (IoT)-based self-quarantine system with Radio Frequency Identification (RFID) and Global Positioning System (GPS) tracking is proposed in this paper to monitor the health conditions of the Covid-19 patients and track their real-time location via mobile application. Biomedical sensors are used to measure health conditions such as temperature, pulse oximetry, and heart-rate monitor. In addition, the RFID readers are used to detect patients that intend to leave the quarantine area, and the GPS modules are used to track their actual geometrical location so that the authorities can take further action. The real-time data is automatically pushed to the cloud server for the authorities to remotely view the patient's health condition and location on the Google map using smart devices. Finally, a hardware prototype and a mobile application have been successfully developed in this project. The system is able to display the temperature, heartbeats, and blood oxygen saturation properly on a liquid crystal display (LCD) screen. All these measured values, together with the information from RFID detection and GPS location tracking, can be viewed on a smartphone.

Keywords: COVID-19; Global positioning system; Internet of things; Radio frequency identification; ThingSpeak

1. Introduction

In 2020, a new virus was identified: Coronavirus Disease 19 (COVID-19). The World Organization (WHO) has declared COVID-19 as a new pandemic (Dos-Santos, 2020). A retrospective analysis of healthcare workers (HCWs) who had COVID-19 telephonic symptom screening and nasopharyngeal Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) testing was conducted (Lam et al., 2020). In this article, the symptons of COVID-19 are found as fever, cough, shortness of breath, myalgia, sore throat, nasal and gastrointestinal symptoms, etc. Malaysia's Ministry of Health (MOH) has classified five different categories of COVID-19 according to the patients' symptoms (Malaysia's Ministry of Health, 2022). Every adult under the age of 60 with mild Category 1 and Category 2 illnesses, without or with stable or controlled comorbidities only, are eligible for self-quarantine at home or at special isolation units (Yatmo et al., 2021).

As reported in (Reddy et al., 2021; Sabukunze et al., 2021), biomedical sensors can be

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used to monitor the health conditions of COVID-19 patients at home. In these two articles, sensors such as infrared temperature and oximeter were used to monitor the patients whether they had fever or shortness of breath. This research has been extended in (Patii et al., 2017; Mazuki et al., 2021) by including a Global Positioning System (GPS) module. The feature of GPS is very useful for tracking the position of patients, but it requires a microcontroller board with a standalone wireless function, such as a NodeMCU wireless module. All these articles implemented the function of the Internet of Things (IoT) (Singh et al., 2020), which shared the results collected from the sensors with the health authorities and the patients to monitor the patients' illness without any human involvement at any level (Kamarozaman & Awang, 2021). Another indoor IoT-based system (Petrović et al., 2020) has also been reported to detect mask and social distancing. Besides that, the related work in (Akash et al., 2020) showed the functions of the mobile application, such as displaying the data and notifications, which are useful for the health authorities to monitor the patients' illnesses and receive notifications for abnormal health conditions.

Although many systems have been developed for COVID-19, none offer a complete solution on how the health authorities can monitor every patient's health conditions in real-time, while ensuring that they do not leave the quarantine area intentionally. This is crucial as patients cannot get treatment early if their illness has developed from mild to severe, and they might spread the virus to others, leading to more citizens being infected by COVID-19. Reports in Indonesia showed catastrophic losses due to this pandemic (Berawi, 2020a), leading to fatalities and bringing instability to many social and economic urban areas globally (Berawi, 2020b). As a result, this project proposed using the IoT platform to create a complete self-quarantine system for COVID-19 patients. It consists of an indoor health monitoring and tracking system using biomedical sensors and RFID, and an outdoor location tracking system using the GPS module. For the indoor system, the patients' readings of the temperature, beats per minute (BPM) and blood oxygen saturation (SpO2) will be pushed to the IoT platform to allow the health authorities to view the real-time data collected. The RFID reader, placed near the door in the patients' house, will also detect the RFID tag kept by the patients if they try to leave the quarantine area without permission. For the outdoor system, health authorities can remotely track the patients' real-time location using the GPS tracker worn by the patients if they are not within their self-quarantine area. Finally, a mobile application will be developed to register the COVID-19 ' information and allow the health authorities to view the health readings collected from the patients and their current geometrical locations and receive important notifications regarding their abnormal health conditions.

2. System Architecture

2.1. System Overview

In this project, there are two types of proposed systems: indoor and outdoor systems. The indoor system would be used to register and monitor the patients' health conditions and track whether they left the quarantine area indoors. In contrast, the outdoor system is used to track the patients' location if they leave the quarantine area. Figure 1 illustrates the overall system architecture of the proposed system.

For the indoor system, the Arduino Mega is used as a microcontroller to collect the results from the sensors and send them to the IoT server. The MLX90614 non-contact infrared temperature sensor will measure the patients' temperature. The MAX30100 pulse oximeter and heart-rate oximetry sensor module will measure the pulse rate and SpO2 of the patients. The Mifare RC522 RFID reader is used to detect the RFID tag and placed at the room's exit. The liquid crystal display (LCD) will display the results and alert the patients to abnormal health conditions. The ESP8266 ESP-01 Wi-Fi module will connect to the internet and send the data to the IoT server, ThingSpeak, through Hypertext Transfer Protocol (HTTP). A mobile application is developed to display the results sent from the Arduino, send a notification if the patient's health condition is abnormal, and also send an alert when the RFID tag is detected.

For the outdoor system, a GPS tracker is used to track the patients who have left the house. The hardware used to develop the GPS tracker is the NodeMCU Lua V3 ESP8266 ESP-01 Wi-Fi module and the GY-NEO6MV2 flight control GPS module. First, the GPS module will detect the latitude and longitude of the location, and then the NodeMCU will send the result to the cloud-hosted database, Firebase. Finally, the mobile application will display the latitude and longitude of the location obtained from the Firebase on the map.

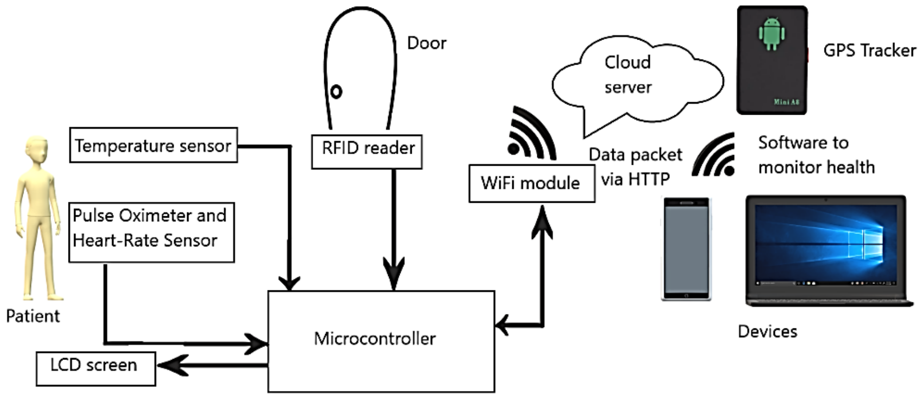


Figure 1 Block diagram of the proposed system

2.2. Hardware Description

The schematic diagrams of the indoor and outdoor systems are designed as shown in Figure 2 and Figure 3. The components used are labeled on the schematic diagrams, and their functions are described in Table 1. The novelty of the developed electronic circuits is the measurement accuracy, wearability (outdoor system), and cost of less than $50.

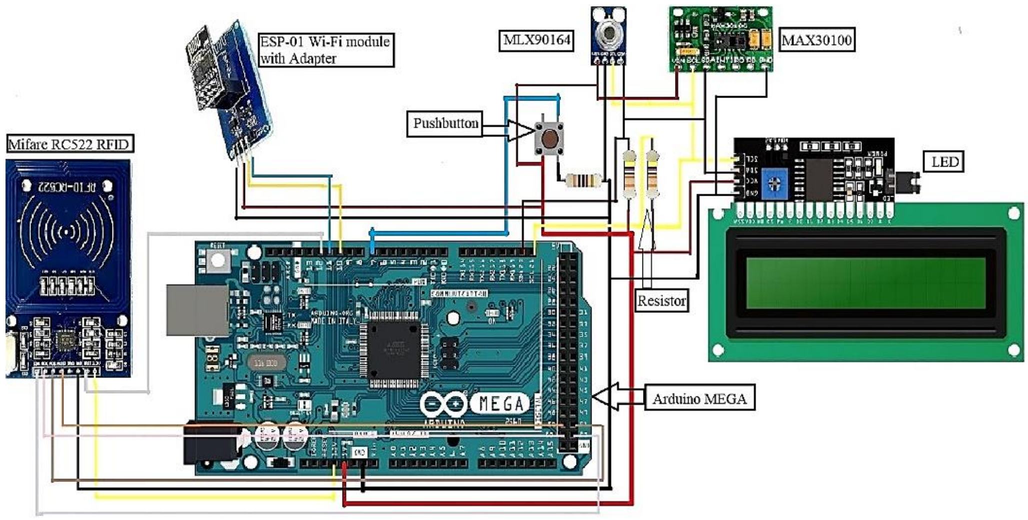


Figure 2 Schematic diagram of the indoor system

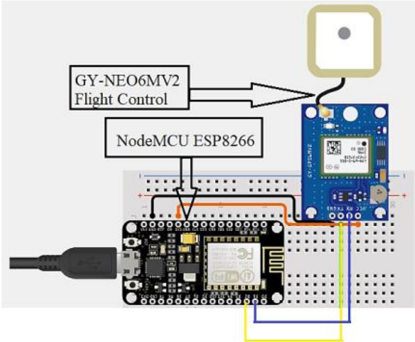


Figure 3 Schematic diagram of the outdoor system

Table 1 Functions of the components

Component	Function
Arduino Mega	To control the functions of the components connected to it and process the received results from the modules.
MLX90614 infrared temperature sensor	To measure the temperature of the patients.
MAX30100 pulse oximeter and heart-rate oximetry sensor	To measure the BPM and SpO2 of the patients.
Mifare RC522 RFID	To detect RFID tags, the patients carry to know whether they leave the quarantine unauthorized.
LCD	To display the results obtained from the sensors.
NodeMCU ESP8266	To control the functions of the component connected to it, connect to the internet, and process the received results from the module.
GY-NEO6MV2 flight control GPS	To get the position of the patients in terms of longitude and latitude.
ESP8266 ESP-01 Wi-Fi	To connect to the internet and push the data to the cloud server.

2.3. *Software Description*

The self-quarantine system's proposed algorithm, and flow charts are shown in Figures 4, 5 and 6. The system will first detect any patient leaving the quarantine area by checking the status of the RFID tag, *RFID_val*, that is installed on each exit. If yes, the system will track each patient's GPS location from Firebase and count the number of a person leaving, *counter_RFID*. Otherwise, it will check any abnormal temperature, *temperature_val*, when the patient wants to measure it by pressing a button. It will also check the patient for abnormal SpO2, *SpO2_val,* and BPM, *BPM_val* when the patient puts a finger on the oximeter. The status of these readings as well as alerts will then be sent to the user's or authorities' mobile phone through ThinkSpeak for necessary action.

The detailed process of the indoor system is shown in Figure 6. The Arduino will first connect to the internet through the Wi-Fi module and turn on all the sensors. Then, it will count how many times the RFID module detects the RFID tag. Otherwise, it will check the input signals from the push button and oximetry sensor. If the push button is pressed, the temperature sensor will measure the patient's temperature. For example, if the patient's temperature is higher than 37.5˚C, the LCD screen will display "Fever", or else it will display "Normal". On the other hand, if the oximetry sensor detects a finger by reading the IR value, the oximetry sensor will measure the BPM and SpO2 of the patient. For example, if the patient's BPM is higher than 100 or lower than 60, the LCD will display "Abnormal BPM". Then if the patient's SpO2 is lower than 94%, the LCD will display "Low SpO2", else it will display "Normal BPM and Normal SpO2". All these results are then displayed on the LCD screen and also sent to ThingSpeak.

Algorithm 1. Detection algorithm for self-quarantine system.

```
counter_RFID ← 0
read RFID tag, temperature & oximeter sensors
if RFID_val > 0 then
    counter_RFID = counter_RFID + 1
    send counter_RFID value to Thinkspeak &
            check for GPS location in Firebase
else if button = 1 then
    store temperature value & send it to Thinkspeak
    if temperature_val > 37.5 then
        display "fever" on LCD & send alert to Thinkspeak
    else
        display "normal" on LCD
    end if
else if SpO2_val > 0 then
    store BPM/SpO2 values & send them to Thinkspeak
    if BPM_val > 100 or BPM_val < 60 then
        display "abnormal BPM" on LCD & send alert to Thinkspeak
    else
        display "normal BPM" on LCD
    end if
    if SpO2_val < 94 then
        display "Low SpO2" on LCD & send alert to Thinkspeak
    else
        display "Normal SpO2" on LCD
    end if
else
    return invalid
end if
```

Figure 4 Algorithm of the self-quarantine system

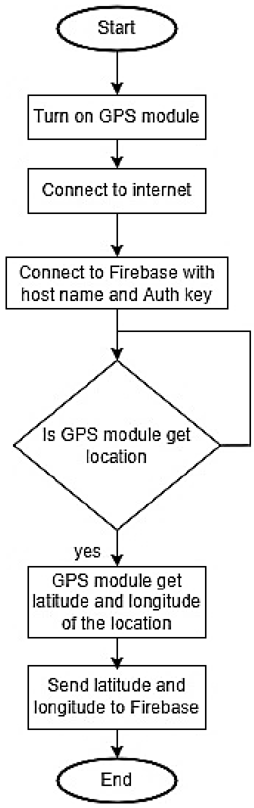


Figure 5 Outdoor system flow chart

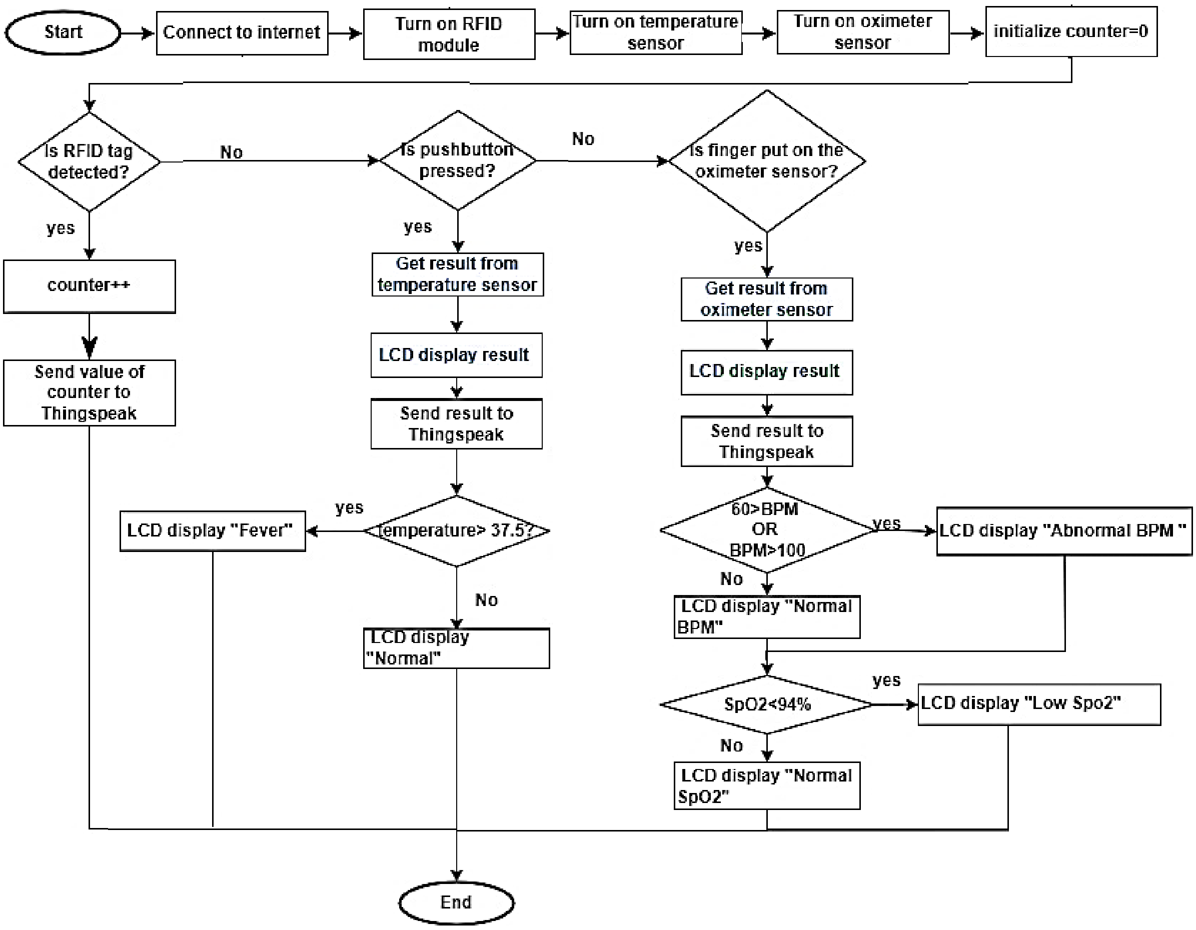


Figure 6 Indoor system flow chart

The detailed process of the outdoor system is shown in Figure 5. The NodeMCU will first turn on the GPS module and connect it to the internet through the mobile network. After that, it will connect to the Firebase database with the hostname and the authentication (Auth) key. If the GPS module is able to detect the location, it will generate the latitude and longitude of the geometrical location and then store them in the Firebase database. Or else it will continue searching for the satellites to lock down the location.

3. Results and Discussion

The developed system consists of a hardware prototype and a mobile application. The prototype can be placed in any quarantine area to detect RFID and GPS location and provide temperature, SpO2, and BPM measurements of the quarantined patients. Due to privacy concerns, the practical testing can only be done on several family members of the project members during their home quarantine period, but not on the other COVID-19 patients. The RFID module is tested by putting it near the doorknob to detect a user that intends to open the door and exit the quarantine home. The furthest distance from the reader's placement is 5 cm since the Mifare RC522 uses passive tags. GPS is worn on the hand of each user. Once the RFID is detected, the GPS is then used to get the geometrical location using the u-center software. On the other hand, the temperature sensor, oximeter sensor, LCD, push button, etc., are placed in their quarantine home. The user can use them to get temperature, SpO2, and BPM readings according to the instructions given by the local medical experts. The user needs to place his forehead in front of the temperature sensor within 3 cm of the sensor and place his fingertip on the oximeter tightly for at least a few seconds to obtain accurate readings. All these measured values and obtained information will be sent to the cloud server via IoT to be displayed on a mobile application.

The following sections describe the performance analysis of the developed system. The temperature, SpO2, and BPM sensor readings are first taken and compared with other standalone measurement devices to improve their accuracy. The RFID and GPS modules are only tested for basic functionality. If they are working properly, alerts will be shown in the mobile application. The operation of the mobile application is also tested by showing functions such as the login/monitoring page, real-time measurement, and notifications on the detection of abnormal temperature, SpO2, and BPM values.

3.1. Hardware Prototype

The design of the prototype is done by using a paper box and a kitchen paper roll as shown in Figure 7, for recycling purposes. The LCD, MAX30100, and push button are placed on the top of the paper box, while the MLX90164 is placed on the kitchen paper roll at the forehead level. A 12V 1A wall adapter powers the indoor system and a 5V 1A power bank powers the GPS module. The GPS is not shown here since it has to be worn on the body.

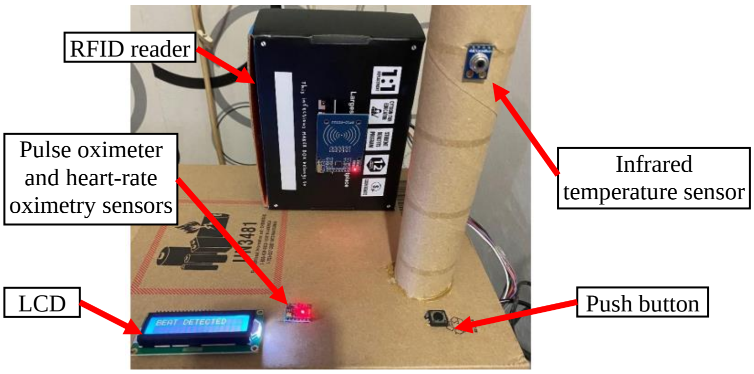


Figure 7 Developed prototype of the self-quarantine system

3.2. Temperature Measurement

Two experiments have been conducted to test the temperature sensor using different methods under hypothermia (< 35˚C), normal (36-37˚C), or fever (> 38˚C) conditions in order to ensure the sensor's reading is accurate and effective. The first experiment is done by using the original calculation included in the MLX90164 library of the Arduino IDE. The relative errors are calculated by comparing the average measured value from the experiment with the average value obtained from the ProFix thermometer, as shown in Table 2. The results obtained have relative errors of between 5% and 15%, which is not accurate because the standard emissivity value calibrated in the MLX90164 is one, but the emissivity value of the human skin is between 0.95 and 0.98.

The second experiment is done to improve the results obtained from the sensor by adding a constant value calculated from the original calculation with 3.5 to measure the human temperature again. The relative errors of the average measured temperature between the MLX90164 and the thermometer are only reduced to below 3%, as shown in Table 3. However, to avoid false alarms, the system will notify users if only there are more than three detections in a roll. The next section also implements this for the BPM and SpO2 measurements.

Table 2 Average measured temperatures of the first experiment

MLX90164 temperature reading, A (°C)	Thermometer temperature reading, B (°C)	Relative error, 100×|A-B|/B (%)
32.11	33.90	5.28
30.87	34.20	9.74
34.93	36.60	4.56
32.09	37.00	13.27
34.62	38.70	10.54
36.07	39.30	8.22

Table 3 Average measured temperatures of the second experiment

MLX90164 temperature reading, A (°C)	Thermometer temperature reading, B (°C)	Relative error, 100×|A-B|/B (%)
33.54	34.20	1.93
33.76	34.60	2.43
36.13	36.40	0.74
36.21	36.60	1.07
37.86	38.70	2.17
38.42	39.00	1.49

3.3. BPM and SpO2 Measurement

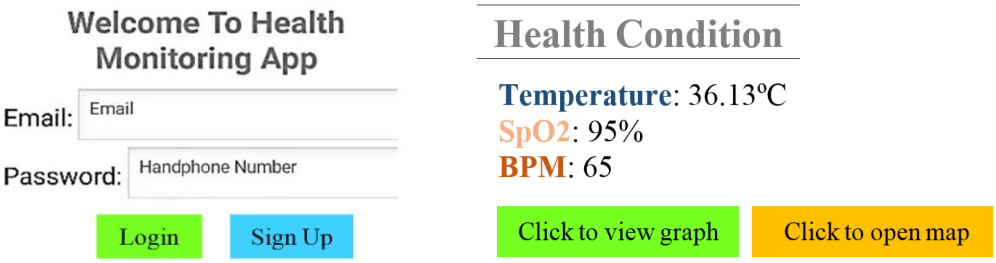
The experiment started by measuring the human's BPM and SpO2 with the MAX30100 oximetry sensor and continued using the SurgiPlus oximeter. Both of the results obtained under low BPM (< 60) and low SpO2 (< 95%) are compared to ensure the sensor's reading is accurate and effective. As shown in Table 4, most of the relative errors for both comparisons are less than 3%, except for one of the average readings from BPM and SpO2. Since the oximetry sensor needs some time to measure the BPM and SpO2 values correctly, some modifications have been made to the code to read the average measure values over a longer time period.

Table 4 Readings of BPM and SpO2

MAX30100 BPM / SpO2 reading, A	Oximeter BPM / SpO2 reading, B	Relative error, 100 × |A-B|/B (%)
60.18 / 95%	59.00 / 96%	2 / 1.04
62.76 / 96%	58.00 / 97%	8.21 / 1.03
72.53 / 96%	72.00 / 97%	0.74/ 1.03
72.41 / 244%	71.00 / 96%	1.99 / 154.17
73.44 / 94%	72.00 / 93%	2 / 1.08
40.28 / 94%	71.00 / 92%	43.27 / 2.17

3.4. Mobile Application

The mobile application is developed using the MIT APP Inventor online tool (Massachusetts Institute of Technology, 2022). The mobile application has four pages: the login page, the monitoring page, the graph page, and the map page. Firstly, the user enters his email and password to log into the application, as shown in Figure 8 (a). If the user has never registered before, he needs to sign up for a new account at Firebase, and the information will be hidden for security reasons. Then, the user will enter the monitoring page, as shown in Figure 8 (b). The user can view the data from ThingSpeak. The temperature, BPM, and SpO2 results will be displayed and updated on this page. There are two buttons on this page: "Click to view graphs" and "Click to open map".



(a) (b)

Figure 8 (a) Login page and (b) Monitoring page of the self-quarantine system

Four types of notifications will be shown on this page. Figures 9 (a) to (d) are the notifications sent to the user if the value is above or below the threshold value. The notifications alert the user that the patient has abnormal health conditions, such as the temperature is higher than 37.5°C, the SpO2 being lower than 94%, and the BPM being lower than 60 or higher than 100. Besides that, if the value of the RFID counter is greater than zero, the mobile application will be triggered to notify the user to track the patient's position.

(a) (b) (c) (d)

Figure 9 Notifications when the (a) temperature is higher than 37.5°C, (b) SpO2 is lower than 94%, (c) BPM is lower than 60 or higher than 100 and (d) RFID tag is detected

Furthermore, when the user clicks the button "Click to view graphs", the mobile application will enter the graph page. The user can view the graph for temperature, BPM and SpO2. ThingSpeak generates the graphs by entering the webpage's link. In this paper, a demonstration of obtaining real-time data on the temperature, SpO2, and BPM measurements has been carried out on several family members of the project members from 9am to 9pm as shown in Figure 10. Despite the constant reading of BPM at around 100, the temperature will increase dramatically whenever the sensor is placed on a hot body, while the SpO2 will fluctuate a certain range of values whenever the sensor is not placed properly on the finger. The temperature and SpO2 remain around 36°C and 95% respectively if the sensors are placed on the correct body parts.

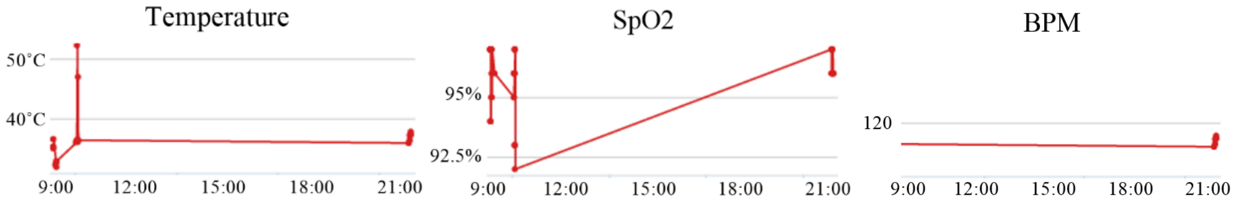


Figure 10 Graph page of health monitoring

Last but not least, when the user clicks the button "Click to open map", the mobile application will enter the map page as shown in Figure 11. The user can view the longitude and latitude values from Firebase and the position on the map. Suppose the user wants to open the map on the Google Map. In that case, the user needs to click the button "Open Google Map", which is linked to the webpage of longitude and latitude, and then the mobile application will redirect to the Google Map application. Figure 11 shows the practical testing on the location of one of the project members' homes in Seremban.

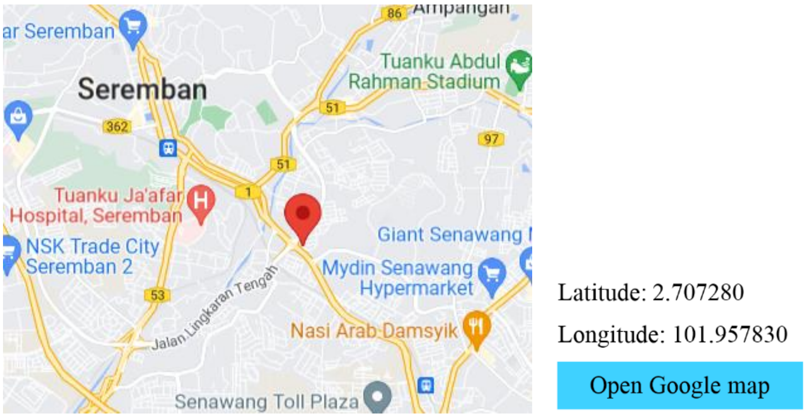


Figure 11 Map page of location tracking

4. Conclusions

Due to the high number of confirmed COVID-19 cases per day in many countries, health authorities are unable to keep up with the massive task load of tracking the health conditions of each patient under their care. This project aims to construct a prototype system with biomedical sensors for COVID-19 patients and assist the health authorities in monitoring the COVID-19 health conditions using an IoT platform and mobile application. The relative errors of the measured data, such as temperature, BPM, and SpO2 have been improved to below 3% by modifying the coding. Furthermore, the developed system has two tracking methods: an RFID to track whether the patient trespasses the quarantine area and a GPS tracker to track the patient's location. A mobile application is developed with several functions to display the health conditions, their position, the results' graph, and a notification system. However, some areas can be improved in the future for this project by adding more biomedical sensors to it, such as ECG sensors, blood pressure sensors, breath rate sensors, etc. An active RFID tag can be used to broaden the reading range of the RFID reader. Besides that, machine learning techniques can be used to train the system to analyze the degree of the illness by analyzing the results from the sensors.

Acknowledgements

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