Internet of things based real-time coronavirus 2019 disease patient health monitoring system

Abraham Ninian Ejin, Hoe Tung Yew, Mazlina Mamat, Farrah Wong, Ali Chekima, Seng Kheau Chung
Faculty of Engineering, Universiti Malaysia Sabah, Sabah, Malaysia

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ABSTRACT

The coronavirus disease (COVID-19) outbreak has led to many infected worldwide and has become a global crisis. COVID-19 manifests in the form of shortness of breath, coughing and fever. More people are getting infected and healthcare systems worldwide are overwhelmed as healthcare workers become exhausted and infected. Thus, remote monitoring for COVID-19 patients is required. An internet of things (IoT) based real-time health monitoring system for COVID-19 patients was proposed. It features monitoring of five physiological parameters, namely electrocardiogram (ECG), heart rate (HR), respiratory rate (RR), oxygen saturation (SpO2) and body temperature. These vitals are processed by the main controller and transmitted to the cloud for storage. Healthcare professionals can read real-time patient vitals on the web-based dashboard which is equipped with an alert service. The proposed system was able to transmit and display all parameters in real-time accurately without any packet loss or transmission errors. The accuracy of body temperature readings, RR, SpO2 and HR, is up to 99.7%, 100%, 97.97% and 98.34%, respectively. Alerts were successfully sent when the parameters reached unsafe levels. With the proposed system, healthcare professionals can remotely monitor COVID-19 patients with greater ease, lessen their exposure to the pathogen, and improve patient monitoring.

Corresponding Author:

Hoe Tung Yew
Faculty of Engineering, Universiti Malaysia Sabah
Kinabalu 88450, Sabah, Malaysia
Email: htyew@ums.edu.my

1. INTRODUCTION

Affecting more than 210 countries worldwide, the coronavirus pandemic (COVID-19) has become a worldwide crisis. According to the World Health Organization (WHO), as of July 9, 2021, the pandemic has infected more than 185,291,530 people which includes the death of 4,010,834 worldwide [1]. With reported mortality rates ranging from 0.7% to 9.4% of the countries most impacted [2], COVID-19 is highly contagious and has become a critical public health issue. Respiratory distress in the form of shortness of breath, coughing and fever are the three main coronavirus symptoms [3]. Without a cure in sight, these numbers will continue to grow, which endangers worldwide public health and impacts numerous other parts of life, particularly the world’s economy. To reduce the spread of the virus, many countries around the world are currently on lockdown and most of the patients who tested positive for COVID-19 or are suspected to be positive, are self-isolating at home. Many healthcare systems worldwide are facing a deficiency in healthcare professionals, mechanical ventilators in intensive-care units (ICU), personal protective equipment and beds, thus emphasizing the need for alternative medical solutions, which includes remote patient monitoring.

The ever-increasing infection among healthcare workers is another major concern of the COVID-19 pandemic. According to a report by WHO from April 2020, there have been almost 22,000 cases of COVID-19 among healthcare workers in 52 countries [4]. By June 2020, a report by the International Council of Nurses states that 7% of all COVID-19 cases globally are among healthcare workers [5]. This shows that nurses and other healthcare workers are at great risk. In 2021, this situation has not improved. Healthcare workers handling COVID-19 patients face many challenges due to manpower shortages. They are also required to work overtime to a point where many face mental health problems. Some ICU doctors have also resorted to taking sleeping pills to resist overwork [6]. Healthcare workers worldwide are constantly handling the COVID-19 outbreak. They are directly exposed to various hazards, including pathogen exposure from infected patients and extended working hours. Therefore, there is a great need for a system that will ease the monitoring of patients in real-time which will also reduce the workload of healthcare workers.

For patient vital sign sensing systems, Chen *et al.* [7] proposed an ambient sensing system for COVID-19 respiration monitoring that utilizes a low-cost pervasive ambient sensor based on the premise that in close proximity, respiration airflow will cause slight air pressure changes. However, some limitations would be in its dependency on a constant environment without any window or door opening and closing which can affect the air pressure of a room and affect the accuracy of the system. Additionally, body movements can also affect sensing accuracy. Stojanovic *et al.* [8] presented a wearable system that utilizes smartphones, headsets, and facemasks equipped with sensors for tracking key COVID-19 symptoms. The implementation of the wearable itself may not be suitable for constant patient monitoring as it lacks comfort. Masks may hinder breathing which may affect the respiratory rate (RR) and headsets may prove to be uncomfortable for some individuals. Akbulut *et al.* [9] designed a thorough and compact monitoring system by evaluating physiological health parameters in long-term usage which is focused on providing a cost-effective and efficient alternative to on-site clinical monitoring systems. However, the system does not support storing data in a cloud environment and can only backup data locally through a secure digital (SD) card. Yew *et al.* [10] implemented a real-time internet of things (IoT) based electrocardiogram (ECG) monitoring system that can provide store-and-forward and real-time modes. However, only ECG signal is monitored.

Much research has been done on health monitoring systems [11]–[18]. However, due to the recent nature of the COVID-19 pandemic, there are not many dedicated systems that are focused on monitoring COVID-19 specifically. The ones that do exist mostly focused on monitoring single or limited physiological parameters. General health monitoring systems are more widespread. Many focus on wearables with multi-physiological sensing abilities. However, many do not include IoT integration or only feature local data storage. For the monitoring of COVID-19, a system must be able to accept multiple parameters that are closely linked to COVID-19 progression. IoT integration is also crucial for remote monitoring to be possible and ideally, the system must be real-time.

This work aims to reduce the risk of infectious diseases such as COVID-19 to medical frontliners and healthcare workers through the development of a real-time e-Health device to remotely monitor vital parameters of COVID-19 patients and persons under investigation (PUI). This work considers five vital signs or physiological parameters namely ECG, heart rate (HR), RR, oxygen saturation (SpO2) and body temperature to assess a patient's condition of potential COVID-19 development. The system utilizes an IoT platform to store the data collected from the sensors and display the collected data through a self-developed web-based dashboard.

2. METHOD

The architecture of the proposed patient health monitoring system is shown in Figure 1. It consists of the ECG sensor, heartbeat and SpO2 sensor, breathing sensor and temperature sensor. These vital parameters collected from the patient by their respective sensors will be fed to a microcontroller. The values of the sensors will then be uploaded to the Google Cloud Platform through Wi-Fi and stored in Cloud Firestore. The physiological parameters can then be viewed using a self-developed dashboard which can be accessed anywhere with a smartphone or a personal computer with an internet connection. Doctors and other healthcare workers can then remotely monitor the physiological conditions of the patients and provide focused attention on more severe cases.

The ESP32 is selected as the main controller of this proposed system. It collects inputs from the pulse oximeter, body temperature, breathing and ECG signal sensors. The readings will then be processed and made ready for transmission to the cloud for display and storage. The ESP32 is also selected because it features an inbuilt Wi-Fi module that makes it suitable for IoT applications. Wi-Fi connectivity is chosen in this system as it is simple to implement and can make use of existing Wi-Fi infrastructures such as hospital Wi-Fi. In the proposed system, an integrated pulse oximetry MAX30102 is used for SpO2 and heart beats per minute (BPM) measurements. The non-contact infrared temperature sensor MLX90614 is employed to measure temperature without contact. To monitor the ECG signal, an AD8232 ECG sensor is used for the acquisition and amplification of raw ECG input signals that display the electrical activity of the heart. ECG data will be collected in real-time by attaching three electrodes at a patient based on the Einthoven triangle arrangement.

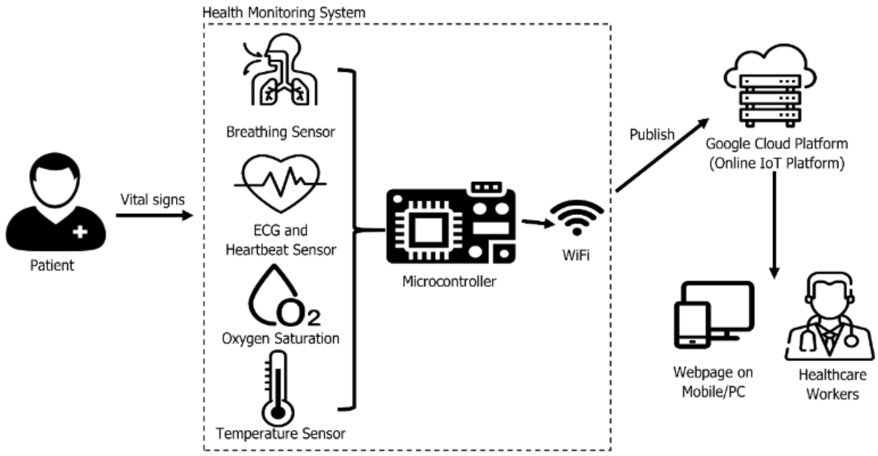


Figure 1. The architecture of the proposed health monitoring system

The ECG sensor is included in the proposed system because heart function can also be affected by COVID-19 and result in myocardial injury causing permanent injury to the cardiovascular system. A study on 416 COVID-19 patients shows that 19.7% experienced cardiac injury during hospitalization [19]. Additionally, patients with a history of cardiovascular disease (CVD) will be at a higher risk of acquiring severe symptoms and poor outcomes which includes death if they contracted the virus [20]. Another study revealed that among the patients with severe COVID-19 symptoms, 58% were hypertensive, 25% had heart disease and 44% with arrhythmia [21]. It can be concluded that measuring HR and ECG will be advantageous for assessing those who are more vulnerable to the SARS-CoV-2 and to provide enhanced treatment for COVID-19 patients with underlying CVD.

In this proposed system, a stretchable sensor is used to measure the respiratory rate. These kinds of sensors work through a change in resistance of the sensor material when force is applied to the sensor. A breathing sensor was self-developed by fabricating a stretch sensor made of elastic waistbands and electric paint. With its property of changing resistance when strain is applied, the stretch sensor can now be used as a strain gauge. For this stretch sensor to be used practically and measure changes in resistance with high accuracy, it is configured as a quarter-bridge strain gauge circuit shown in Figure 2. The stretch sensor can then be used as the strain gauge (R3) of the quarter-bridge circuit. The value of R4 will be set to a value equal to the stretch sensor resistance when it is not stretched while R1 and R2 will be set equal to each other for the bridge to be balanced. The bridge is balanced when V_O=0 and $\frac{R1}{R2}=\frac{R3}{R4}$. The output voltage V_O can be calculated using (1), where V_S is the supply voltage. The rate of breathing can then be observed through the change in the output voltage as the stretch sensor stretches due to mechanical breathing motions. Figure 3 shows the completed prototype of the breathing sensor.

$$V_O = V_S \frac{R_3R_1 - R_4R_2}{(R_2+R_3)(R_1+R_4)} \quad (1)$$

Figure 4 shows the flowchart of the proposed system. The system starts with the initialization of the ESP32 when it is powered on. Next, the ECG, pulse oximetry, breathing and temperature sensors are initialized and start collecting the patient's vitals. The ESP32 collects these data, packs them into JSON format and sends this packed data to the Google Cloud Platform. The e-Health dashboard then fetches this data from Google Cloud Platform and unpacks it for further processing and decision making. The script behind the e-Health dashboard will detect whether each of the vital signs is within the normal range or not. Symptoms of COVID-19 manifest when one or more vital signs are outside the normal range and this will prompt the e-Health dashboard to send an alert message or notification to a smartphone or computer to alert the healthcare workers through the if this then that (IFTTT) service. This happens if the breathing rate is more than 20 breaths per minute, oxygen saturation is equal to or less than 94%, the heart rate is more than 100 beats per minute and body temperature is higher than 38 °C [22]–[24]. The data will then be displayed and presented in the e-Health dashboard for real-time and continuous monitoring of the patient by the healthcare workers.

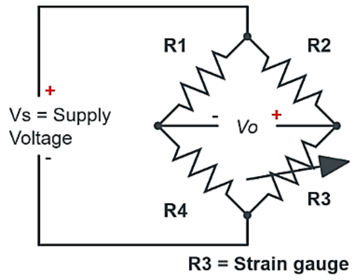


Figure 2. A quarter-bridge strain gauge circuit

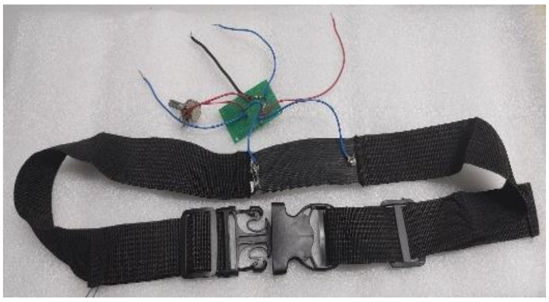


Figure 3. The completed breathing sensor prototype

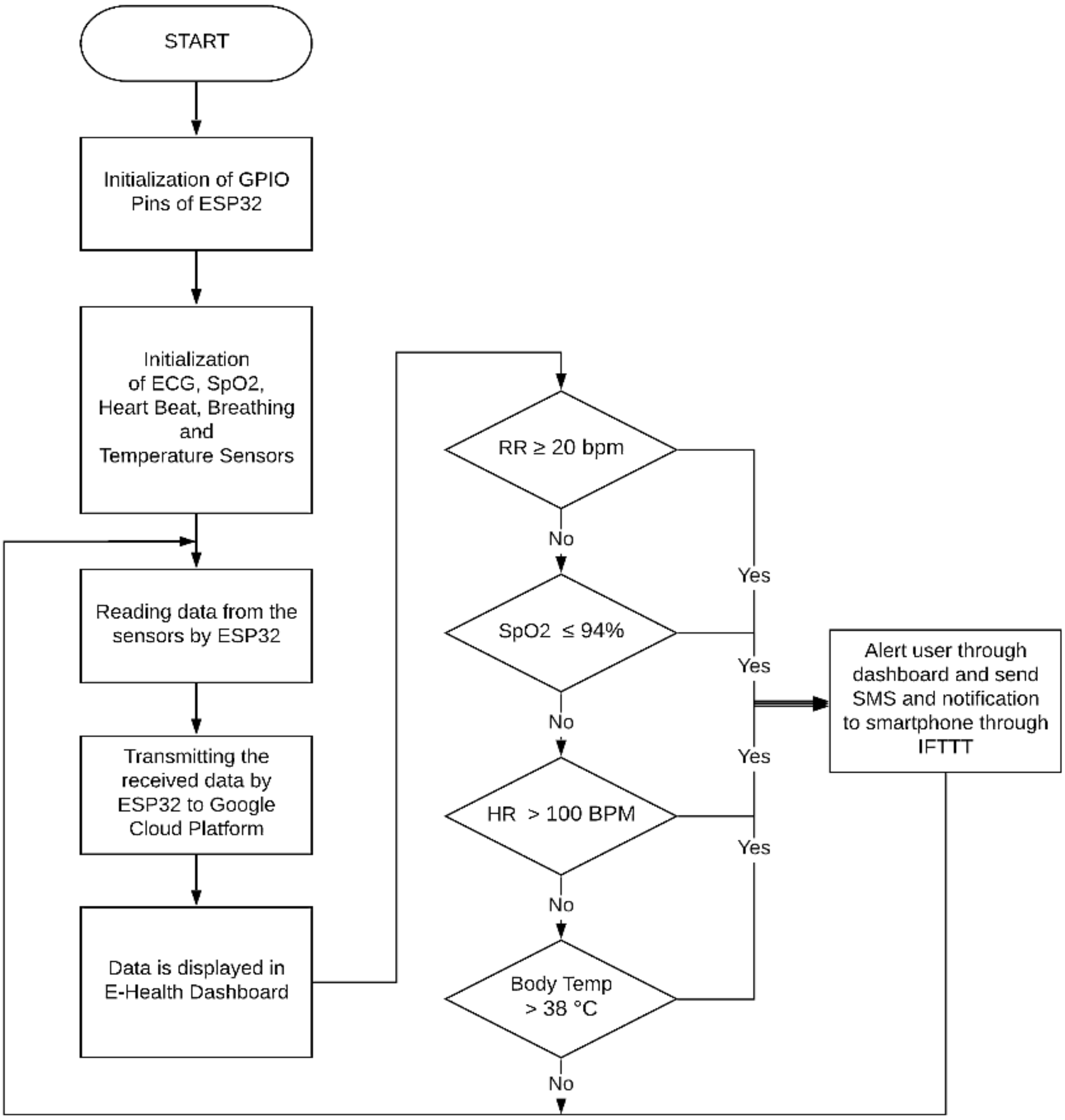


Figure 4. Flowchart of the algorithm of the proposed system

The breathing sensor was self-fabricated for this work. An algorithm was developed to calculate the breathing rate based on the reading given by the breathing sensor. Pseudocode for this algorithm can be seen in Table 1. The ESP32 reads the respective breathing sensors analogue pins every ten milliseconds and stores them in an array. This array is then sent to the Google Cloud Platform for storage.

Table 1. Pseudocode for the calculation of respiratory rate

```
while (true)
 if (breathingSignal>threshold)
    breathStart=true
     while (breathStart=true)
        if (breathingSignal<threshold)
          respiratoryRate++
          breathingStart=false
```

Google Cloud Platform provides a series of modular cloud services including computing, data storage, data analytics and machine learning. This work utilizes cloud IoT core and cloud functions which are part of the Google Cloud Platform and Cloud Firestore which is part of Google Firebase. The architecture of the overall system can be seen in Figure 5. In this proposed system, the message queuing telemetry transport (MQTT) protocol is used as it performs better for IoT development due to its lower bandwidth, overhead and power consumption [25]. Furthermore, the MQTT protocol has the advantage of being highly lightweight and efficient in terms of client resources and network traffic, making it perfect for connecting remote devices with a minimal code footprint [26].

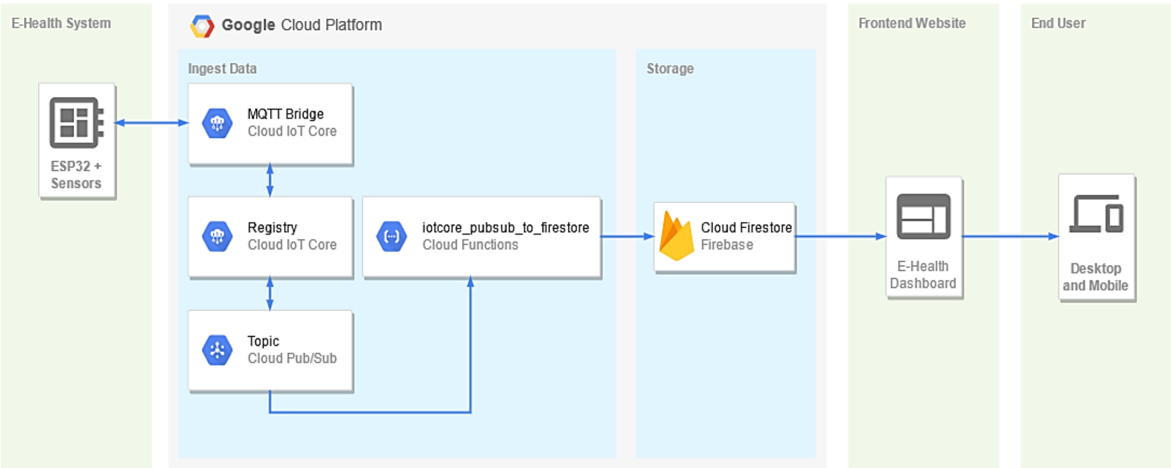
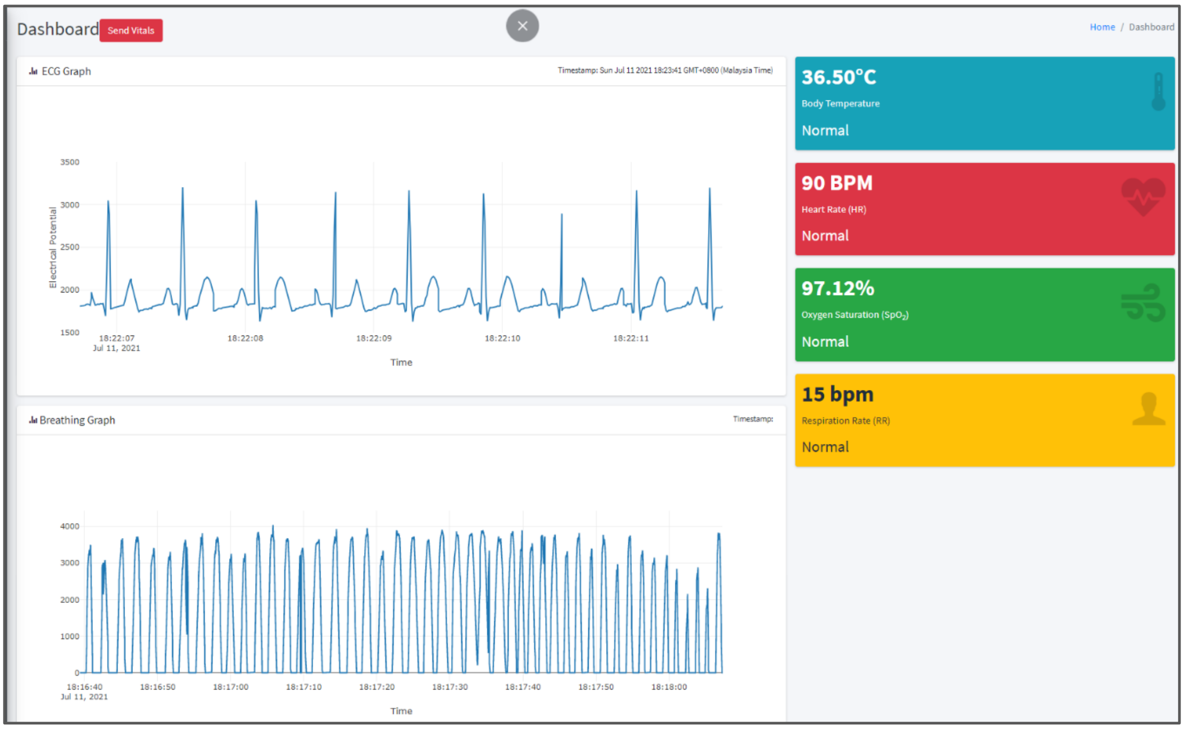


Figure 5. The architecture of the e-Health system with Google Cloud Platform

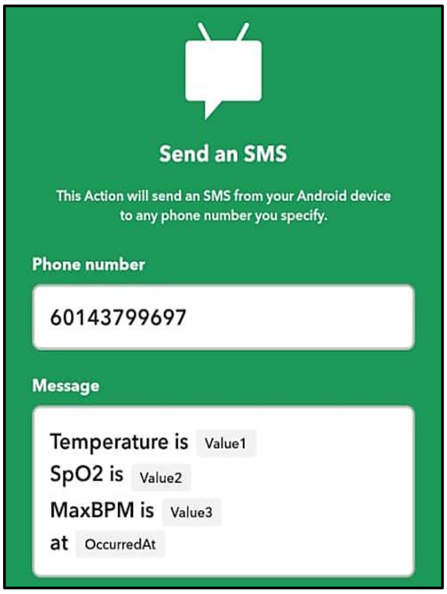
Cloud functions enable backend code to run in response to events triggered by Firebase and Google Cloud features. This is used to marshal device data between IoT Core and Firestore. Using this architecture, Cloud Firestore becomes the central data hub and source of truth for the state of all connected devices and exposes that state to authenticated client applications. By using cloud functions, data collected can be published by the devices to a database. This work uses Cloud Firestore, therefore, a function to ingest the data in firebase cloud functions was developed.

Cloud Firestore is a flexible, scalable NoSQL cloud database to store and sync data for client and server-side development. It keeps data in sync across client apps through real-time listeners and offers offline support for mobile and web through their native software development kit (SDK). The middleware between Google cloud IoT core and the database is Google cloud Pub/Sub. This platform allows write functions to subscribe to events or publish data. The moment that a device gets new values, this data is published and the functions are subscribed to this event.

The web application of the proposed e-Health system is shown in Figure 6. For the data collected from the sensors to be displayed in a presentable manner, a dashboard to display vital information was created. The dashboard can be seen in Figure 6(a). This dashboard was built using Bootstrap which is an open-source hypertext markup language (HTML), cascading style sheets (CSS) and JavaScript framework for developing fast, responsive sites. It runs multiple scripts in the background to fetch data sent by the proposed e-Health prototype to Cloud Firestore to be displayed in real-time. On the top is a send vitals button to manually trigger the vitals alert system to send the vital information to the phone through short message service (SMS). ECG and RR graphs are displayed in the center of the dashboard. Other vitals such as body temperature, heart rate and oxygen saturation are displayed on the right-hand side of the dashboard. IFTTT is used to link a webhook web request from the e-Health dashboard with the SMS service to allow SMS alerts as seen in Figure 6(b). This allows vital signs received by the e-Health dashboard to be passed to SMS through the webhook and trigger the SMS sending.



(a)



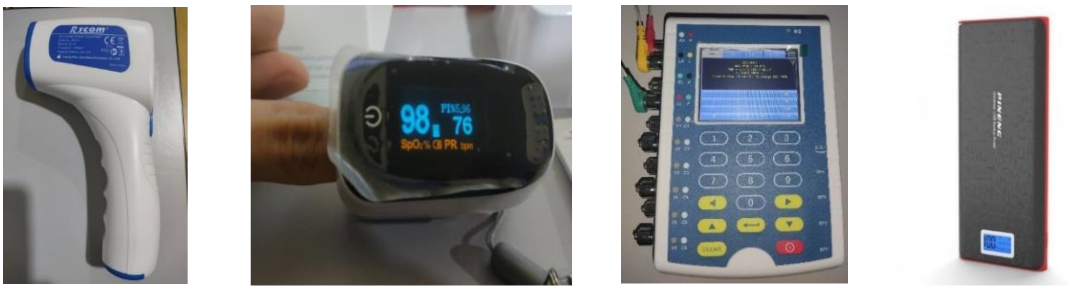
(b)

Figure 6. The proposed e-Health system web application (a) the dashboard display and (b) the contents of the SMS service using IFTTT

3. RESULTS AND DISCUSSION

Four devices are used to evaluate the accuracy and performance of the proposed e-Health system and they can be seen in Figure 7. They are the Rycom JXB-181 handheld non-contact infrared thermometer in Figure 7(a), fingertip pulse oximeter in Figure 7(b), CONTEC MS400 multiparameter simulator in Figure 7(c) and PINENG PN-920 power bank in Figure 7(d). The Rycom JXB-181 has a temperature display resolution of 0.1 °C and an accuracy of ±0.3 °C making it suitable for measuring body temperature. The fingertip pulse oximeter is a pulse oximeter that works by attaching it at the fingertips. It can measure both SpO2 and HR. For SpO2 readings, it has a measurement range of 70%-99%, an accuracy of ±2% and resolution of 1%. For HR readings, the measurement range is 30 BPM-240 BPM with an accuracy of ±1 BPM.

The CONTEC MS400 multiparameter simulator is a multiparameter simulator that can generate 12-lead ECG. It can generate 35 types of arrhythmia and pacemaker waveforms, simulate standard ECG calibration, adult and paediatric ECG signals. The PINENG PN-920 is a power bank with a capacity of 20000 mAh. It features a dual USB input, one with 5 V 2.1 A and another with 5 V 1.0 A and an LED screen display that displays the battery percentage remaining. This feature is used to evaluate the power consumption of the e-Health prototype.



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

Figure 7. The four devices used for testing the e-Health prototype (a) Rycom JXB-181, (b) fingertip pulse oximeter, (c) CONTEC MS400 multiparameter simulator, and (d) PINENG PN-920

3.1. E-Health dashboard performance

The CONTEC MS400 is used to generate the ECG signals. An ECG wave of a normal healthy adult was set and generated. The ECG wires from the prototype were then connected to the respective leads of the CONTEC MS400. Figure 8 shows the ECG graph displayed on the e-Health system dashboard. The y-axis represents the electrical potential in millivolts (mV) while the x-axis represents time. On the top right of the graph is what is called a modebar. This modebar contains several options for interacting with the figure such as taking a screenshot, zoom, pan, zoom in, zoom out, auto scale and reset axes. All of these features apply to the breathing signal graph as well. Figure 9 shows the vitals panels of the dashboard. Each panel displays information in the following manner, a large numerical value displaying the vital value, followed by what the value represents and finally a written indicator on whether the vital value is in a normal or abnormal state.

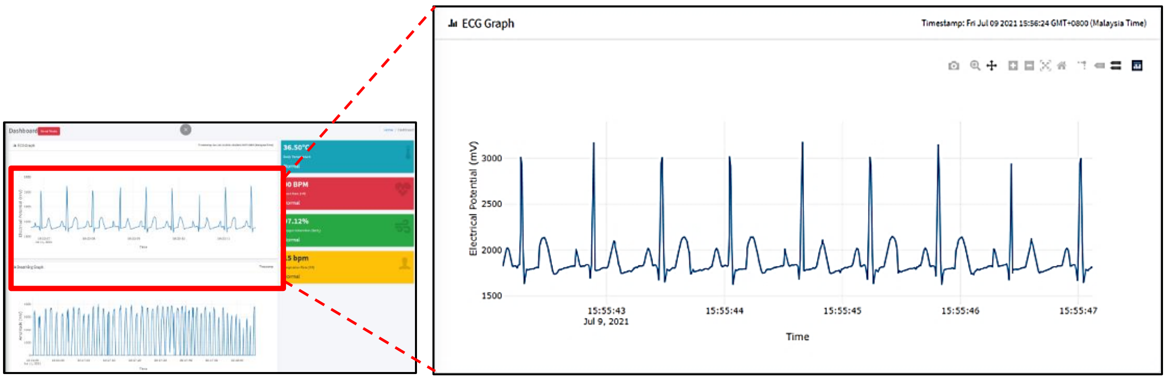


Figure 8. Real-time ECG signal displayed on the e-Health dashboard

3.2. Validation of ECG data

To ascertain the integrity of the data transferred from the proposed system to the e-Health dashboard, 1,000 ECG data points were recorded from the e-Health prototype through the serial monitor and was compared to the ECG data points received by the e-Health dashboard. After comparison, it was found that all 1,000 points received by the dashboard were correct and identical to the data sent by the e-Health prototype. There were no packet loss or packet errors during data transmission. This shows that the e-Health system is reliable and has high accuracy. This high accuracy is due to the MQTT Bridge in the cloud IoT core of the Google Cloud Platform. The quality of service (QoS) (level=0, 1 and 2), which define how the protocol manages content, are a fundamental aspect of MQTT protocol. With a four-part handshake between the transmitter and recipient, QoS level 2 assures that each message is received just once and without duplicates. The integrity of ECG data is essential to avoid misinterpretation of ECG readings by medical officers which may lead to misdiagnosis.

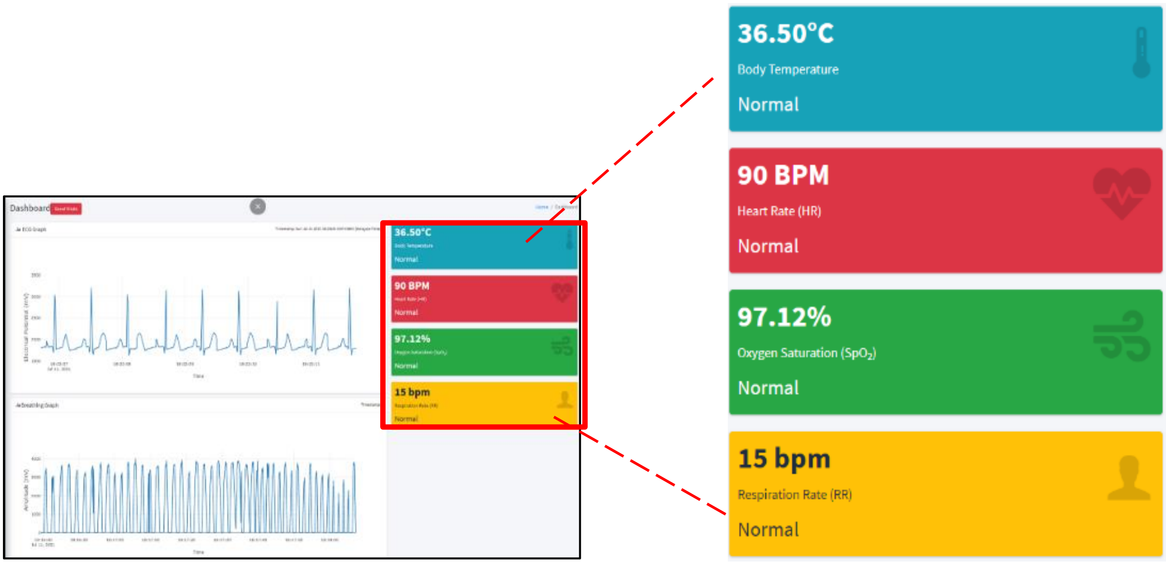


Figure 9. The vitals panel on the e-Health dashboard

3.3. Testing temperature readings

To test the temperature readings of the e-Health system, both the Rycom JXB-181 and the MLX90614 temperature sensor portion of the e-Health board were placed 2 cm from the forehead. Body temperature readings were then taken 20 times and compared. The readings were taken during two different times of day which are during daytime and nighttime. This was done to test if the temperature of the surrounding can affect the reading taken.

The temperature readings of the proposed system were rounded to 1 significant figure as the Rycom only has a resolution of 0.1 °C. The percentage error was calculated using (2), where the temperature values of the Rycom will be taken as the true value and the temperature values of the prototype will be taken as the measured value. The average percentage error during the day is 0.3% and 0.4% during the night. Thus, the accuracy of body temperature readings is 99.7% and 99.6% for day and night, respectively. The difference of measurement between day and night is negligible. This also means that the reading of the temperature sensor of the proposed system is fairly accurate.

$$Percentage\ Error = \frac{|Measured\ Value - True\ Value|}{|True\ Value|} \times 100 \quad (2)$$

3.4. Testing SpO2 and HR readings

To test the accuracy of the SpO2 and HR readings of the proposed e-Health system, the readings are recorded by placing one finger into the fingertip pulse oximeter and another finger on the MAX30102 sensor on the prototype. The readings from both devices are collected and then compared every 3 seconds for six minutes. A total of 120 points of data were obtained. The accuracy of the proposed system is up to 97.97% for SpO2 readings and is up to 98.34% for HR readings.

3.5. Evaluating breathing rate readings

To evaluate the breathing sensor, the sensor was first attached to the chest at the upper thorax. This can be seen in Figure 10. After some testing and adjustment of the breathing sensor, it was found that when taking a deep breath, the fully expanded chest will stretch the breathing sensor to output an analog reading of around 3,500 and the reading reaches 0 when exhaled completely. Therefore, 2,000 was set as the threshold. For 60 seconds, one breathing cycle is counted every time the sensor reading is higher than the threshold followed by the next reading that is lower than the threshold. The longer this period is the slower and deeper the breath and the faster it is, the faster and shallower the breath. Figure 11 shows the real-time breathing signal displayed on the e-Health dashboard. The graph shows a clean and mostly regular reading of the breathing sensor.

Figure 10. The breathing sensor attached to the chest

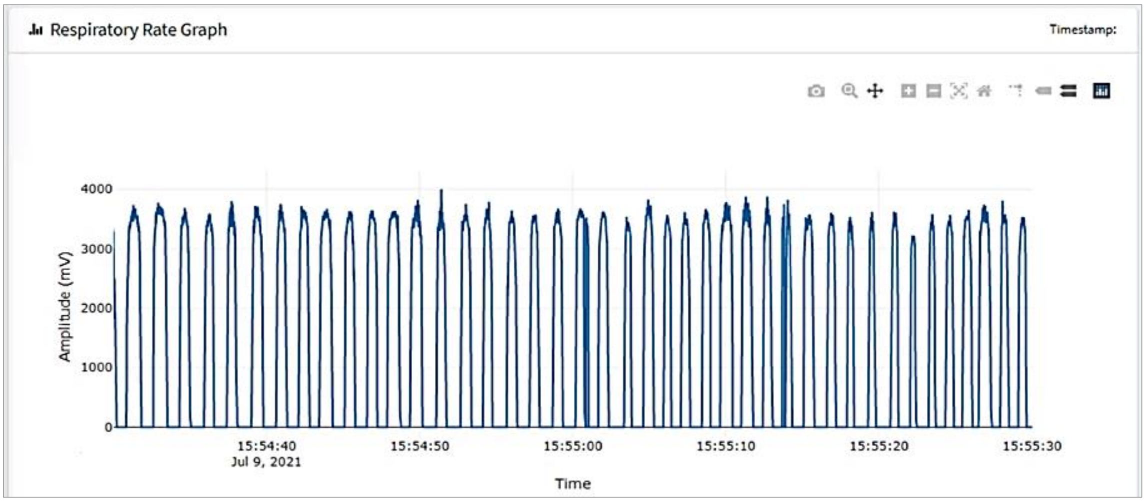


Figure 11. A clean breathing sensor graph reading

In Figure 12, we can see the breathing signal graph along with the vital signs panel displaying the respiration rate. Two types of breathing signals are highlighted here. In Box 1, we can observe a wider breathing interval between each cycle. This shows that the patient is inhaling and exhaling deeply at a slow and regular interval. This type of breathing pattern will result in a lower RR. In Box 2, we can observe a shorter and less regular breathing pattern. In the beginning, in Box 2 we can see that the patient is taking shallow and rapid breaths. The middle signals in Box 2 show that the patient inhales and exhales deeply again but rapidly. This is then followed by shallow and rapid breaths again. This kind of breathing signal will result in a higher RR.

The accuracy of the breathing signal was evaluated and displayed in Figure 13. Here a normal breathing rate is simulated with slow and regular intervals. RR was calculated to be 18 (manually) and this is the same as shown in the dashboard. In Figure 14, the breathing signal was then evaluated with rapid breaths. RR was calculated to be 30 (manually) and this is also reflected in the dashboard.

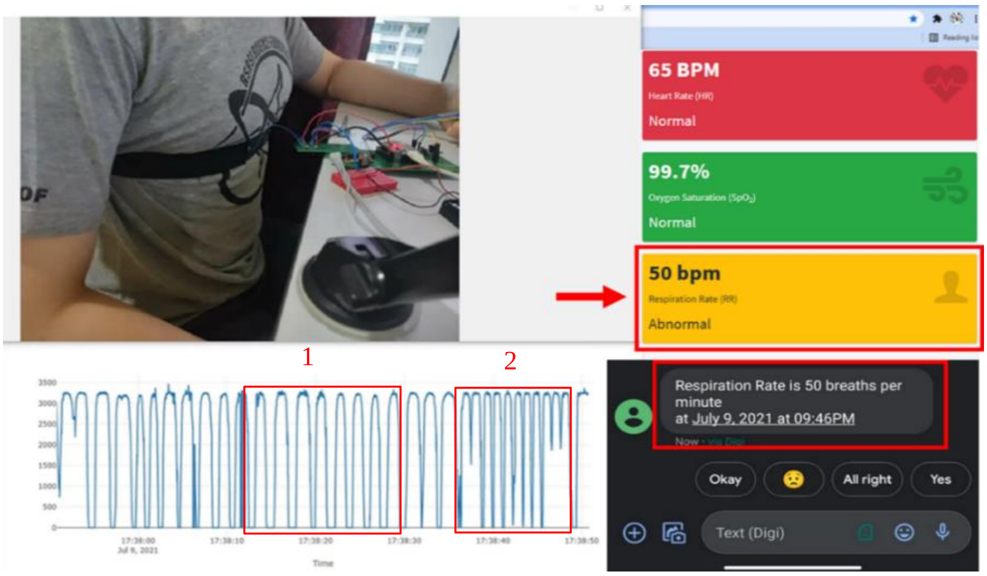


Figure 12. Breathing sensor graph with varied readings and the evaluated respiration rate

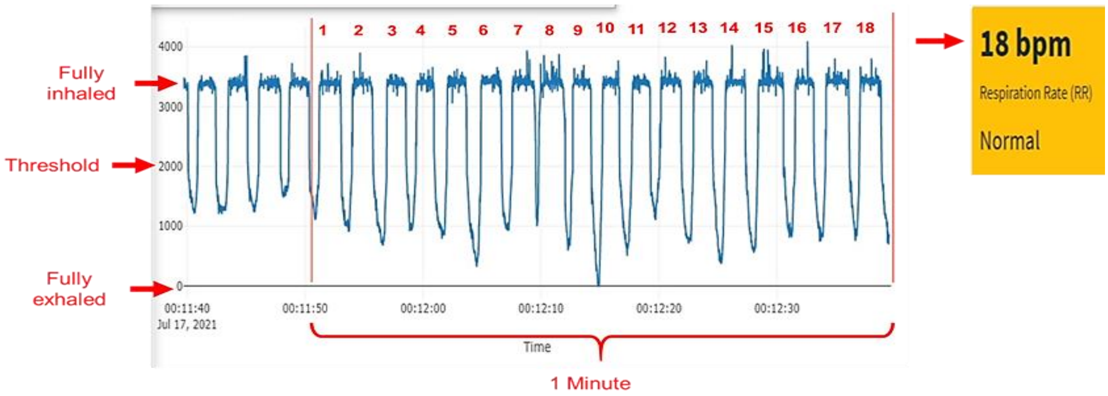


Figure 13. Evaluating RR reading with normal breathing rate

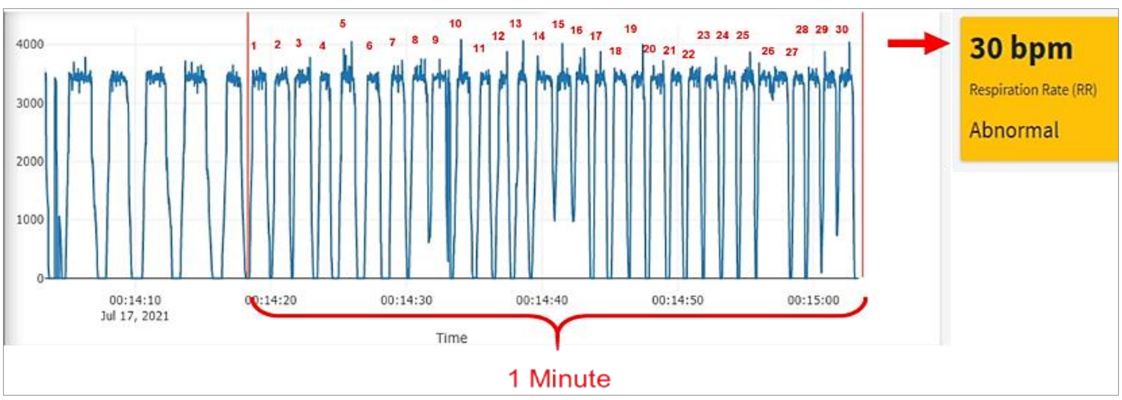


Figure 14. Evaluating RR reading with rapid breathing

3.6. Testing SMS alert

The e-Health SMS alert system which is handled by IFTTT can be triggered in two ways. The first is by pressing the send vitals button at the e-Health dashboard and the other is when the vital signs are within the unsafe thresholds. The send vital signs button is necessary for manually sending vital information to related healthcare workers without the need for any threshold to be reached. An SMS containing all the vital values is sent to the recipient’s phone when the button is pressed. The system will send alert SMS if any of the measured vital values exceed or lower than the threshold values shown in Figure 4. Figure 15 shows a high temperature or fever situation being simulated by lighting a lighter close to the temperature sensor. This triggers the SMS alert automatically once the temperature exceeds 38 °C. The same goes for the RR SMS alert, where the alert threshold activates when RR is more than 20 bpm, which was done by breathing rapidly. The result for the RR SMS alert is shown in Figure 12.

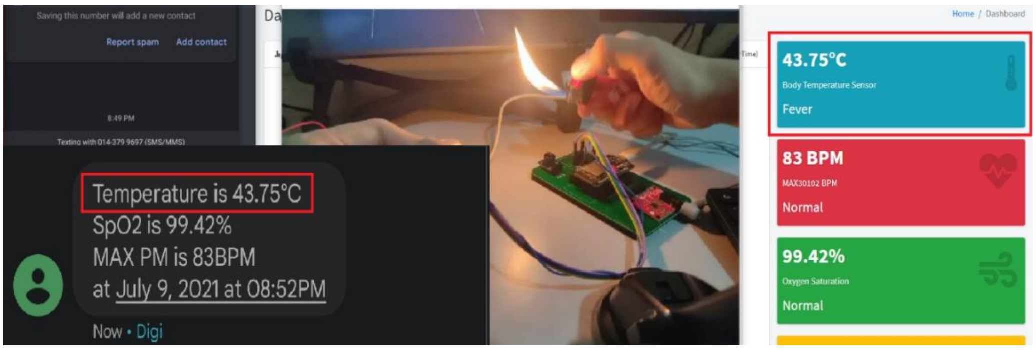


Figure 15. High body temperature triggering SMS alert

3.7. Power consumption of e-Health prototype

The PINENG PN-920 power bank was used to measure power consumption. The e-Health prototype was plugged into the 5 V 2.1 A output of the power bank. The e-Health prototype was then made to transmit data continuously for six hours. Through the LED screen of the power bank, the battery percentage was monitored to determine the power consumption. It was observed that the power bank charge reduces by 2% every hour. Power bank has a capacity of 20,000 mAh. Therefore, up to 400 mA is being used every hour.

3.8. Discussion

The proposed e-Health prototype is able to transmit the reading from the sensors to the dashboard and provide real-time monitoring successfully which includes all vitals, ECG, RR, SpO2, HR and body temperature. Testing have also proved the integrity of the data sent through the validation of ECG data between the serial monitor from the prototype as well as the data received by the dashboard, which is attributed to the MQTT protocol. The prototype also displayed great accuracy of vital readings when compared to standard devices. Body temperature readings achieved an accuracy of 99.7%. SpO2 and HR readings achieve an accuracy of 97.97% and 98.34%, respectively. In terms of RR readings, the prototype can differentiate between normal breathing and rapid breathing by calculating the RR from the breathing signal. SMS alerts were also sent out successfully when any of the vital sign critical thresholds are reached. These results show that the proposed e-Health system is suitable for monitoring the COVID-19 patients. The performance of the proposed e-health system is shown in Table 2.

The proposed system targeted use case is in hospitals to assist healthcare workers in monitoring COVID-19 patients. Should this system be deployed for actual usage, a dedicated Wi-Fi network in the hospital (or anywhere this system is utilized) should be allocated for the usage of multiple e-Health devices. By having a dedicated network to handle the traffic from the e-Health devices, any risk of congested network situations can be minimized. The usage of the Google Cloud Platform also ensures that the proposed system can be scaled easily using Google’s infrastructure to accommodate larger traffic and demand from the proposed system.

Several recommendations and improvements can be made for future iterations of this work. The proposed system can be incorporated as a wearable system to make it smaller, easier to attach, and more comfortable for the patient. The system can also be enhanced by making it more energy-efficient. The system can also be expanded by implementing alternative connectivity options such as cellular connection to allow usage of the system in areas without Wi-Fi connectivity or in independent settings such as in private residents for home quarantine and self-monitoring. The proposed system can also be further expanded by utilizing global positioning system (GPS) and global system for mobile communications (GSM) as used in [27], where emergency alerts through SMS that contains location coordinates can be sent to relevant healthcare workers for swift and immediate intervention. This is especially relevant in cases where a home quarantine is done instead of monitoring at quarantine centers or hospitals. Another noteworthy future implementation is to equip the proposed system with a heterogeneous wireless network [28]–[30] for more robust network connectivity.

Table 2. Performance of the proposed e-Health system

Parameters	Accuracy
ECG	100%
RR	100%
SpO2	97.97%
Body Temperature	99.7%
HR	98.34%

4. CONCLUSION

A prototype COVID-19 health monitoring system was successfully developed. The system was able to collect the five physiological vital signs, namely ECG, RR, SpO2, HR and body temperature. The breathing sensor to obtain breathing signals and evaluate RR was successfully fabricated. A dashboard is used to monitor these collected vital signs which was also successfully developed. It was able to display the vitals sign in real-time. Vital signs were transmitted and received without any packet loss or packet errors during data transmission. The proposed system demonstrated acceptable accuracy when compared to existing devices in the market. The dashboard was able to incorporate and send alerts when the patient vital signs reached unsafe levels. With this system, the target users of the health monitoring system, mainly healthcare workers can monitor COVID-19 patients remotely with greater ease while reducing their exposure time to the pathogen and also optimize the patient monitoring through the alert system by providing medical attention on more critical patients first.

ACKNOWLEDGEMENTS

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BIOGRAPHIES OF AUTHORS

Abraham Ninian Ejin is born in Sabah, Malaysia in 1998. He received his Bachelor's Degree in Electronics (Computer) Engineering from University Malaysia Sabah, Sabah, Malaysia in 2021. Currently, he works as a Graduate Trainee at Intel Microelectronics Sdn. Bhd, Penang, Malaysia. His interests include repair and troubleshooting of computers, electronics as well as the latest trends in smartphone and laptop design. He also enjoys learning and reading about new technologies. He can be contacted at email: abrahamninianejin@gmail.com.

Hoe Tung Yew obtained his PhD degree from Universiti Teknologi Malaysia in Biomedical Engineering. Currently, he is a Senior Lecturer at Faculty of Engineering, Universiti Malaysia Sabah. His main research interests are e-Health, internet of things and vertical handover decision making in heterogeneous wireless networks. He is a Chartered Engineer (CEng) under the Institute of Engineering and Technology (IET), United Kingdom. He is also a Professional Technologist under the Malaysia Board of Technologists (MBOT). He can be contacted at email: htyew@ums.edu.my.

Mazlina Mamat received the B.Eng. and M.Sc. degrees in electrical and electronic engineering from Universiti Sains Malaysia, in 2000, and 2003, respectively. She received her Ph.D. degree in microengineering and nanoelectronics from Universiti Kebangsaan Malaysia, in 2013. Currently, she is a senior lecturer at the Electronic Engineering (Computer), Universiti Malaysia Sabah. Her research interests include sensors, signal processing, machine learning and artificial intelligence. She can be contacted at email: mazlina@ums.edu.my.

Farrah Wong received her Ph.D. in Electrical and Electronic Engineering from Universiti Malaysia Sabah, Sabah, Malaysia in 2004. She joined Universiti Malaysia Sabah as a lecturer in the Faculty of Engineering since 2004. She has been elevated to the Senior Member of Institute of Electrical and Electronics Engineers (IEEE), USA in 2008. In 2019, she obtained her Professional Engineer under the Board of Engineers Malaysia. Her research interests are in intelligent system and computer vision system. She has published more than 50 publications including journals and conference papers. She can be contacted at email: farrah@ums.edu.my.

Ali Chekima has obtained his Bachelor of Electronic Engineering from the Ecole Nationale Polytechnique d'Alger (ENPA), Algeria, in 1976. He then got both his Master of Sciences and PhD degrees in Electrical engineering from Rensselear Polytechnic Institute, Troy, N.Y., USA, in 1978 and 1984, respectively. He joined the Department of Electronics at ENPA as Assistant Professor in 1984, where he was teaching courses at undergraduate and postgraduate levels, besides supervising undergraduate and postgraduate student, undertaking research and serving as Chairman of Scientific Committee as well as Deputy of Head of Department of Electronics in charge of postgraduate studies. In 1995, he joined the International Islamic University Malaysia as Associate Professor at the Department of Electrical and Computer Engineering. In 1996, he joined the School of Engineering and Information Technology (Now, Faculty of Engineering), University Malaysia Sabah, where he was promoted to Professor in 2011. Dr Ali Chekima has supervised more than 30 postgraduate students and more 200 undergraduate final year projects. He has published more than 180 papers in International Journals and International Conference proceedings. His fields of research are communication, pattern recognition and artificial intelligence. He can be contacted at email: chekima@ums.edu.my.

Seng Kheau Chung received the B.Sc. and M.Sc. degrees in computer science from Universiti Teknologi Malaysia, Johor, Malaysia, in 1997 and 2000, respectively, and the Ph.D. degree in computer science from Universiti Malaysia Sabah, Kota Kinabalu, Malaysia, in 2015. Currently, he is a senior lecturer at the Electronic Engineering (Computer), Universiti Malaysia Sabah. His main research interests are in e-commerce and Internet of Things. He can be contacted at email: kheau@ums.edu.my.