Wearable Remote Patient Monitoring System

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ABSTRACT Remote patient monitoring system uses e-health sensors and wireless technologies to remotely monitor the health performance of a patient. There are still a few challenges in remote monitoring systems, although it has been developed for a long time such as patient privacy and location tracking. This paper proposes a wearable remote patient monitoring system that comes with a location tracking system. The idea is related to the COVID-19 pandemic which has caused certain hospitals to be overpopulated with COVID-19 patients. It leads to problems such as worn-out healthcare workers, affecting the treatment plan and appointments for non-critical cases to be postponed. Hence, a remote patient monitoring system is a great idea in the establishment of an ideal solution to overcome these problems. The proposed remote patient monitoring system not only monitored the patient's health data but also store the data in the MYSQL database management system and track the patient's location using Global Positioning System (GPS). The sensors used in this system are the Electrocardiogram (ECG) sensor, heartbeat sensor, and body temperature sensor. The healthcare professionals can remotely monitor both the COVID-19 or non-COVID-19 patient health data and GPS location through their smartphone or computer at anytime and anywhere. The proposed system can ease the burden for the community from having to repeatedly come to the hospital to track their health condition and reduce the risk of COVID-19 infection.

KEYWORDS: COVID-19; Remote Patient Monitoring System; E-health Sensor; Database, Location Tracking
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INTRODUCTION

In this era, the healthcare system is more towards technology. With an intriguing combination of the latest technology and medical tools nowadays, a remote health monitoring system device has become something too good to be true. A remote patient monitoring system is mainly used to overcome the issue of shortage of healthcare professionals and distance barriers. It uses e-health sensors and wireless technologies to remotely monitor the health condition of a patient.

According to the National Crisis Preparedness and Response Centre (CPRC) Ministry of Health (MOH), as of June 2020, there are 121 deaths in COVID-19 cases and the number has increased to 128 in August 2020 (Kementerian Kesihatan Malaysia, 2020a). Meanwhile, the total cases of COVID-19 for the third wave during the Recovery Movement Control Order (RMCO) is 4996 as compared to the 1831 cases in the second wave (Kementerian Kesihatan Malaysia, 2020b). Furthermore, referring to the World Health Organization publication on 18 March 2020 (Situation reports on COVID-19 outbreak, 2020), health workers are at the front line of the COVID-19 outbreak response and as such are exposed to hazards that put them at risk of infection. Hazards include pathogen exposure, long working hours, psychological distress, fatigue, occupational burnout, stigma, and physical and psychological violence.

During the COVID-19 pandemic, the hospital is the riskiest place for local people to visit. The remote health monitoring system could be the best tool to overcome the barrier of healthcare services such as distance, time, and cost. Also, the remote patient monitoring system allows healthcare to work remotely to monitor the health conditions of the pandemic patients or the person under investigation (PUI) without close contact. In this work, a wearable remote patient monitoring system that comes with GPS location tracking is proposed.

BACKGROUND INFORMATION

Majumder had introduced a top-notch heart monitor called Quadiocore which provides electrocardiogram (ECG) graphs using smartphones (Majumder *et al*., 2019). A similar project has also been done by Touheed Ahmed *et al*. (2016), a Smartphone-based Remote Health Monitoring System that used a custom-built gadget with an assimilated Bluetooth module and photo-electronic detector. Apart from that, the Smart Wearable ECG System was proposed by Vishwanatham *et al*. (2019). This system consists of an ECG sensor, smartphone, and an Android application that acts as a transmitter to send the collected data to the isolated server via cellular. Banerjee *et al*. (2019) presented an IoT-based heartbeat monitoring system using WiFi communication technology. But this system has no data storing function. A wearable low-cost Remote Health Monitoring and Alert System (RHMAS) was invented specifically for elderly patients with heart diseases (Valliappan *et al*., 2017). This system will generate an alert message to family members via a short message service (SMS) if the user is in a critical situation.

Gutte & Vadali (2018) and Yew *et al*. (2020) proposed an IoT Based Health Monitoring system that uses heterogeneous wireless networks. The WiFi and Global System for Mobile Communication (GSM) technologies are used for transmitting the collected health data to the cloud and generating an SMS alert during an emergency. These systems are used primarily for monitoring the patient's heartbeat rate, body temperature and ECG signal. However, these systems did not have a patient location tracking system. The location tracking system could help the healthcare professional reached the patient's location in the shortest time. Table 1 summarizes the advantages and disadvantages of the existing systems.

Table 1. Advantages and Disadvantages of Related Systems.

Patient Monitoring Systems	Advantages	Disadvantages
Quadiocore (Majumder *et al*., 2019), Smart Wearable ECG System (Vishwanatham *et al*., 2019), RHMAS (Valliappan *et al*., 2017), Smartphone-based Remote Health Monitoring System (Touheed Ahmed *et al*., 2016)	• Emergency alert function. • Webserver / Mobile Application for users to monitor health data. • Data storage.	• Depending on single wireless communication technology
IoT Based Remote Health Monitoring System (Gutte & Vadali, 2018) (Yew *et al*. 2020)	• Using heterogeneous wireless networks to transmit data. • Data storage. • Emergency alert function. • Webserver / Mobile Application for users to monitor health data.	• Did not have a data security system (user authentication). • Did not have a location tracking system.

METHODOLOGY

The architecture of the proposed wearable remote patient monitoring system is shown in Figure 1. The proposed system consists of 3 types of e-health sensors (heartbeat, temperature, and ECG sensors), Arduino ESP32 as the main controller, WiFi technology, Global Positioning System (GPS) module. It is assumed that the patient is wearing the proposed system and the e-health sensors are attached to the patient body. WiFi acts as a communication channel to upload the collected health data and GPS location longitude and latitude to the cloud. The system will analyze the collected health data by checking the heartbeat value whether it exceeds the upper or falls below the lower thresholds. The users and healthcare professionals could monitor the real-time health data or history through the mobile application or webpage by login to the system.

A web server is a personal computer framework that processes requests using http, which is the basic network protocol to circulate data on the World Wide Web (Al- Fuqaha *et al*., 2015). Web server function is to store, process, and send the data to the client. MySQL database management system is used in this work because it is an open-source, and most popular SQL database system. Moreover, data can be put in different tables in MSQL that makes it more flexible.

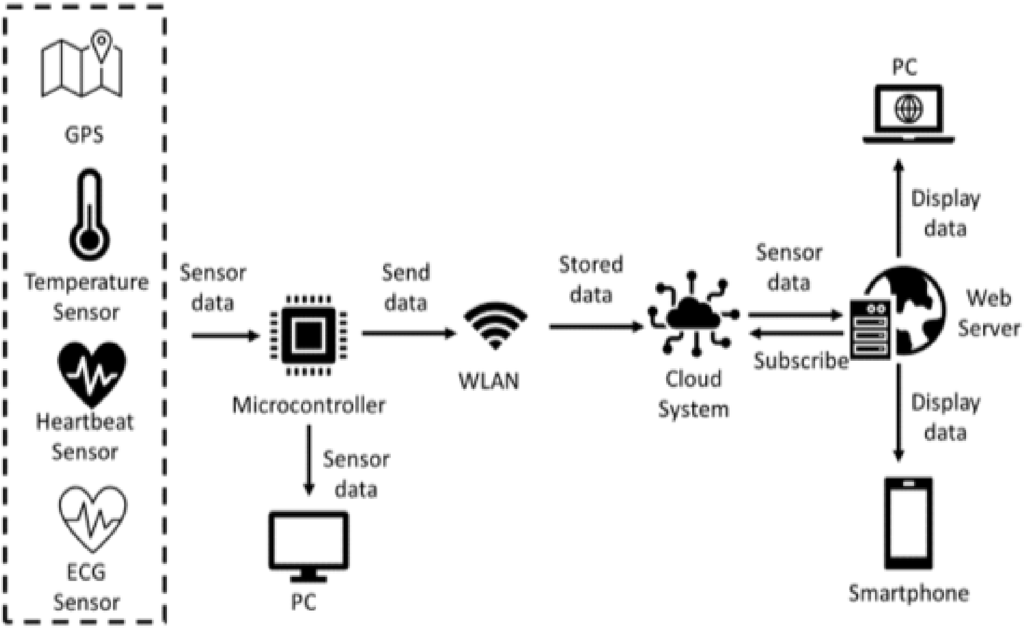


Figure 1. Aarchitecture of the proposed system

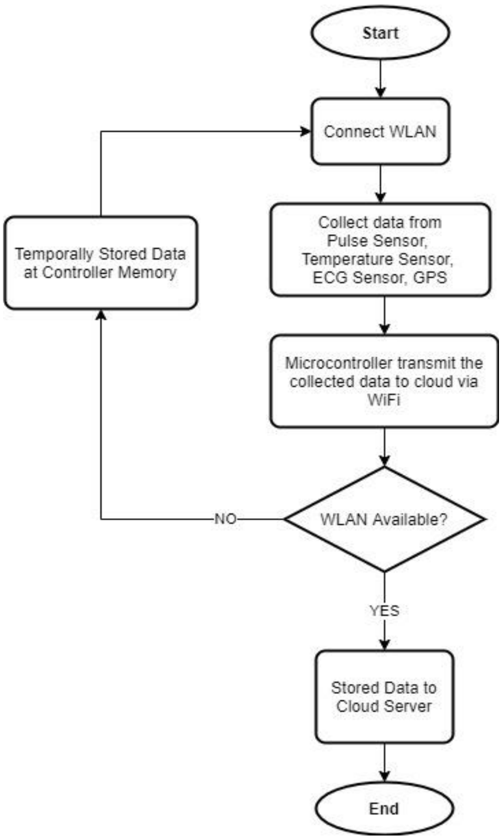
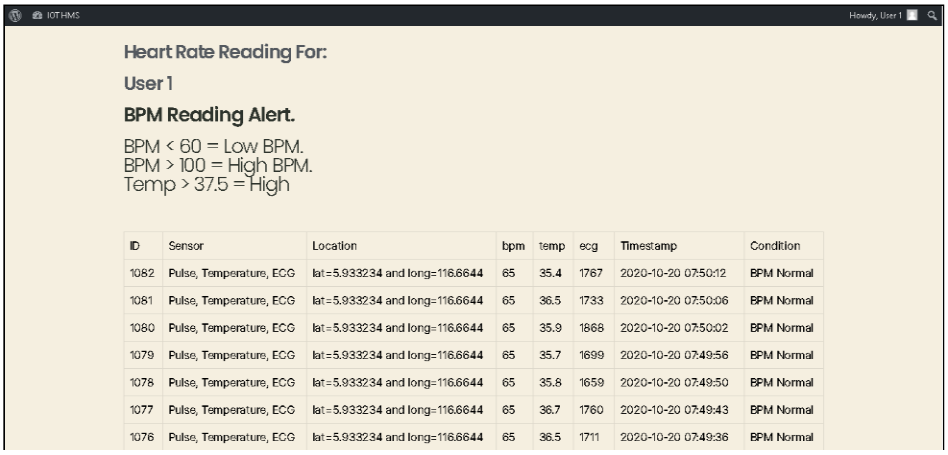


Figure 2. Process flow of the proposed system

Figure 2 shows the process flow of the proposed system. Once the system is power on, it will search and connect to WiFi or wireless local area network (WLAN). Then it starts to collect data from e-health sensors and GPS. The collected data will be uploaded to the cloud via WiFi. If there is no internet connection, the data will be temporarily stored in the microcontroller memory and will be uploaded to the cloud once the internet connection is available.

RESULTS AND DISCUSSION

The proposed system has successfully uploaded the real-time e-health sensors and GPS data to the cloud. The webpage, as shown in Figure 3, illustrates the GPS location, heartbeat rate in beat per minute (BPM), temperature (°C), ECG, timestamp, and the BPM condition of "User1". By referring to the American Heart Association (2015) website, the low and high BPM thresholds for resting heat rate are set at 60 and 100, respectively. Other than the webpage, the readings can also be accessed through mobile apps. Figure 4 shows the interface of the developed Android mobile apps. There is only one button to redirect the user to the same webpage. To enhance user privacy, user authentication is developed, as shown in Figure 5, to ensure that only an authorized person can access the system as it contains confidential information such as location.



Heart Rate Reading For:
User 1
BPM Reading Alert.
BPM < 60 = Low BPM.
BPM > 100 = High BPM.
Temp > 37.5 = High

ID	Sensor	Location	bpm	temp	ecg	Timestamp	Condition
1082	Pulse, Temperature, ECG	lat=5.933234 and long=116.6644	65	35.4	1767	2020-10-20 07:50:12	BPM Normal
1081	Pulse, Temperature, ECG	lat=5.933234 and long=116.6644	65	36.5	1733	2020-10-20 07:50:06	BPM Normal
1080	Pulse, Temperature, ECG	lat=5.933234 and long=116.6644	65	35.9	1868	2020-10-20 07:50:02	BPM Normal
1079	Pulse, Temperature, ECG	lat=5.933234 and long=116.6644	65	35.7	1699	2020-10-20 07:49:56	BPM Normal
1078	Pulse, Temperature, ECG	lat=5.933234 and long=116.6644	65	35.8	1659	2020-10-20 07:49:50	BPM Normal
1077	Pulse, Temperature, ECG	lat=5.933234 and long=116.6644	65	36.7	1760	2020-10-20 07:49:43	BPM Normal
1076	Pulse, Temperature, ECG	lat=5.933234 and long=116.6644	65	36.5	1711	2020-10-20 07:49:36	BPM Normal

Figure 3. Webpage result

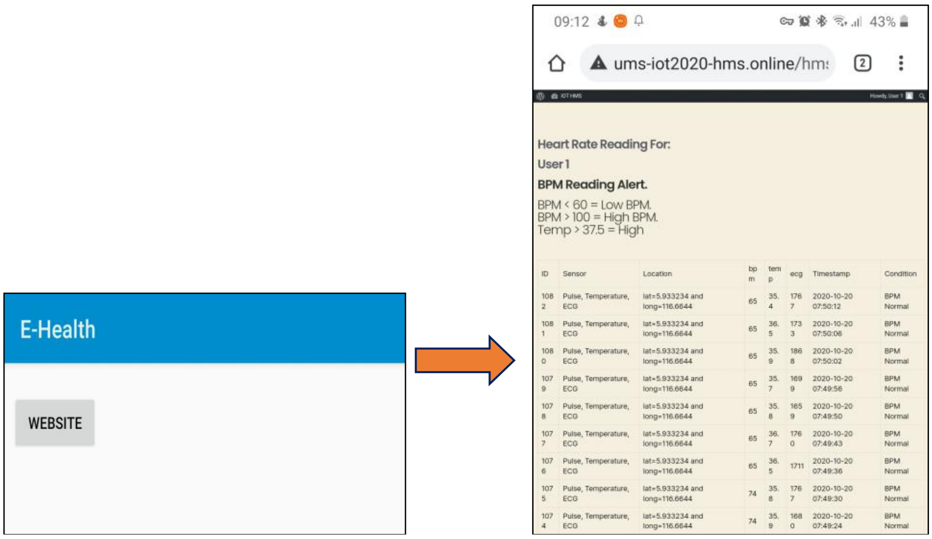


Figure 4. Mobile application interface

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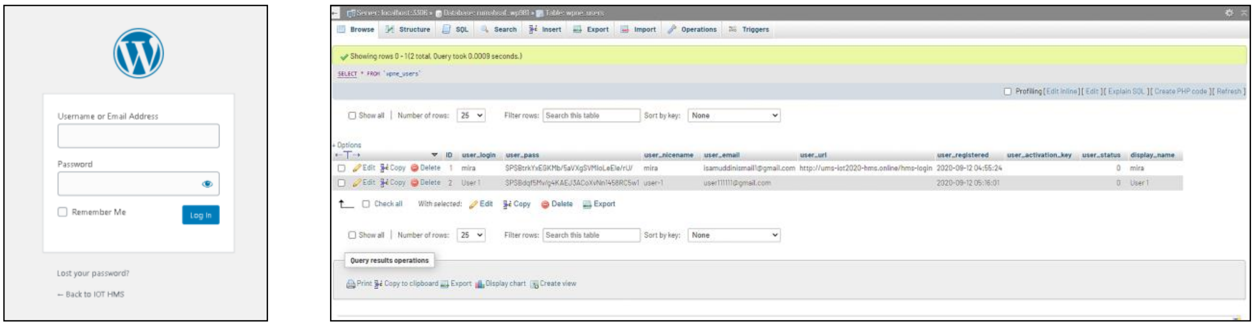

Figure 5. User authentication interface and user registration details

To validate the results of this work, we compared the BPM readings of the developed prototype with the BPM value that was recorded using the OMRON eHealth device HEM-7120. This machine not only read the blood pressure but also read the pulse (BPM). A total of nine readings were taken from different persons with age ranging from 10 to 55 years old, as shown in Table 2. The highest error rate was 5.3%. The error may be due to the finger movement on the Max30102 sensor while measuring the BPM value.

Table 2. Comparison of BPM values between the proposed system and OMRON eHealth device HEM-7120.

No.	Age of Subjects	BPM readings		Error (%)
		Proposed Remote Patient Monitoring System	Omron HEM7120	
1	51	71	75	5.3
2	55	75	77	2.6
3	25	86	86	0
4	28	67	70	4.2
5	41	103	99	4.0
6	10	91	93	2.1
7	15	99	95	4.2
8	32	81	80	1.3
9	13	73	70	4.3

CONCLUSION

This paper presented a wearable remote patient monitoring system. The proposed system added user authentication to enhance patient privacy and GPS location tracking. The results showed that the proposed system has successfully collected health data using e-health sensors and uploaded them to the cloud. Healthcare professionals can remotely monitor the health conditions of the pandemic patients and the PUI by login to the webserver through their smartphone or computer. The proposed system could reduce the risk of COVID-19 infection to healthcare workers because healthcare workers could monitor several COVID-19 patients simultaneously without moving around the hospital ward. It reduces the workloads of healthcare workers.

For future works, the GSM module can be added to the proposed system as a backup communication technology in case of Wi-Fi signal loss; the system can still transmit the collected data to the cloud. Furthermore, this work only successfully uploaded the numerical values of ECG to the cloud. A Graphical User Interface (GUI) for displaying the ECG signal is needed. This work can be integrated with the systems presented in Fung *et al.* (2019), Yew *et al*. (2015), and Yew *et al.* (2015) to improve the healthcare quality.

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