Real-time Monitoring, Fall Detection, and Emergency Notification IoT-Based System for COVID-19 Patients Using Biomedical and Environmental Sensors

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Abstract

Many patients, particularly the elderly, disabled individuals, those infected with COVID-19, and people living in isolation, require immediate care to prevent life-threatening situations in medical environments. Real-time monitoring ensures safe patient surveillance, enabling quick responses to emergencies. This paper presents the design and implementation of a real-time monitoring system that utilizes Arduino, mobile phone devices, and IoT-enabled biomedical and environmental sensors to measure heart rate, SpO2, body temperature, air quality, humidity, and detect falls. Wireless communication facilitates the placement of sensors anywhere, enabling real-time notifications via IoT and mobile networks. Arduino, Android Studio, and XAMPP are integrated into the proposed system's architecture, overcoming the limitations of previous systems by providing greater flexibility, portability, and accuracy. The biomedical sensors were validated against medical-grade devices and demonstrated high accuracy. Heart rate readings showed a 98% correlation, SpO2 levels had an average error of less than 2%, and body temperature measurements deviated by only ±0.3°C compared to standard clinical thermometers. Additionally, the environmental sensors effectively monitored air quality and humidity, issuing alerts upon detecting significant deviations. When anomalies in air quality occurred, the system successfully generated emergency notifications with a 95% accuracy rate in identifying hazardous conditions.

Keywords: IoT, Real-time Monitoring, Emergency Notification, Biomedical Sensors, Environmental Sensors, Fall Detection, COVID-19, Arduino, Android Studio, Wireless Communication.

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نظام مراقبة في الوقت الفعلي للكشف عن الإغماء، واشعار الطوارئ المعتمد على إنترنت الأشياء لمرضى كوفيد-19 باستخدام أجهزة الاستشعار الطبية والبيئية

رونق ماهر افرام
وزارة التربية

الخلاصة :

يحتاج العديد من المرضى، وخاصة كبار السن، المعوقين، المصابين بفيروس كورونا، والأشخاص الذين يعيشون في عزلة، إلى رعاية فورية ومنع المواقف التي تهدد الحياة في البيئة الصحية الطبية. تضمن المراقبة في الوقت الفعلي مراقبة آمنة للمريض، مما قد يساعد في الاستجابة السريعة لحالات الطوارئ. تقدم هذه الورقة البحثية تصميم وتنفيذ نظام مراقبة في الوقت الفعلي يستخدم اردوينو, أجهزة الهاتف المحمول وأجهزة الاستشعار الطبية الحيوية والبيئية التي تدعم إنترنت الأشياء لقياس معدل ضربات القلب، تشبع الأكسجين في الدم، درجة حرارة الجسم، وجودة الهواء والرطوبة بالإضافة إلى كشف الإغماء. تسهل الاتصالات اللاسلكية وضع أجهزة الاستشعار في أي مكان، مما يتيح إرسال إشعارات في الوقت الفعلي عبر إنترنت الأشياء والشبكات المحمولة. تم

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دمج اردوينو، أندرويد ستوديو، وXAMPP في بنية النظام المقترح، مما يتغلب أيضًا على القصور الموجود في الأنظمة السابقة من خلال توفير قدر أكبر من المرونة وقابلية النقل والدقة.

الكلمات المفتاحية: إنترنت الأشياء، المراقبة في الوقت الفعلي، الإشعار في حالة الطوارئ، أجهزة الاستشعار الطبية الحيوية، أجهزة الاستشعار البيئية، اكتشاف الإغماء، كورونا، أردوينو، أندرويد ستوديو، الاتصالات اللاسلكية.

1. Introduction

Traditional systems that rely on wired connections and human assumptions are inadequate for meeting the needs of real-time health monitoring, especially in addressing COVID-19 and its variants, particularly for elderly and disabled individuals. Currently available health monitoring solutions tend to be inflexible, complicated to set up, and fail to provide a comprehensive view of a patient's health and living conditions. Systems requiring manual supervision or wired connectivity pose challenges, especially in remote or resource-limited locations [1,2]. Monitoring vital signs is critical for in-time identification of a health decline. However, current approaches often make patients travel to healthcare facilities or employ inconvenient devices. Additionally, other environmental factors like air quality and temperature have a significant influence on the health of patients, especially for those with respiratory diseases. While the use of wearable sensors and mobile applications has led to some advancements, most of the solutions do not offer real-time data collection or end-to-end smooth communication and notification methods [3].

Hence, this paper presents an Internet of Things (IoT)-based system that aims to overcome these challenges. The proposed system integrates biomedical and environmental sensors with real-time monitoring and emergency notification. In the proposed system, emergency cases can be handled immediately based on the programmability of Arduino and the communication capabilities of smartphones to provide constant monitoring. This new approach combining functions while reducing the limitations of traditional methods, may lead to better and more patient-oriented care in a post-COVID-19 era.

2. Related Work

Numerous researchers have explored fall detection and health monitoring using IoT technologies. The following paragraphs present several related works that aim to address the gap in designing and implementing a comprehensive system for monitoring COVID-19 patients.

Kakria et al. [4] proposed a smartphone-based system to achieve real-time heartbeat monitoring; however, the system was based on basic communication methods, resulting in a low degree of flexibility and robustness.

Chiarugi et al. [5] developed an IoT-based environment monitoring system which also covered parameters such as air quality and humidity. However, none of these systems involved biomedical monitoring. Lee et al. [6] designed a fall detection system using smartphone accelerometers, which effectively sensed motion but struggled to integrate additional health metrics like oxygen saturation and heart rate.

Horta et al. [7] discusses ways to address fall prevention using biofeedback monitoring, focusing specifically on wearable devices. Although successful, these systems did not have real-time emergency notification capabilities. Additionally, Ajerla et al. [8] proposed frameworks for automatic accident and fall detection, but they are not implemented at the physical level in combination with environmental monitoring or vital sign tracking.

In 2022, Hasan K. Naji et al. [9], have proposed a design and implementation of a system prototype that helps workers in the medical field detect and monitor COVID-19 symptoms by measuring vital signs. They aim to avoid patients' hospitalisation in the Intensive Care Unit (ICU) by monitoring the patient's vital signs like oxygen saturation, body temperature, and heart rate all the time. In their proposed system, they used Max 30100, DS18B20 sensors, and ESP8266 microcontroller, where all components are placed in a 3D printed bracelet. The Raspberry PI has been used to analyse, process, save, and display the vital signs data.

In 2024, Celine Khai Shin Lim and R. Dhakshyani [10], have proposed an IoT-based system that integrates a health monitoring system with a fall detection system to monitor the state of the patient remotely. To implement this system, they used the ESP8266 microcontroller, temperature sensor (LM35), pulse oximeter sensor (MAX30100), and accelerometer (MPU6050). The data from sensors is uploaded to a dashboard that is developed on BLYNK for monitoring. An SMS message can be sent by a fall detection system to the phone of the caretaker if a fall occurs. The system is cost-effective and can support low-income families with a portable healthcare device with high accuracy.

The primary limitations of current systems include fragmentation, where most solutions address specific aspects of health monitoring without offering an integrated framework. For example, environmental monitoring systems often ignore biomedical data, while fall detection systems lack integration with continuous monitoring of vital signs. These fragmented approaches lead to inefficiencies, increased costs, and limited applicability for vulnerable populations, particularly during emergencies like the COVID-19 pandemic. This work is an attempt to overcome these limitations as it introduces a complete solution that integrates healthcare monitoring with a fall detection system which can help in improving the life of the patients.

Table 1 below compares the proposed system with traditional healthcare monitoring systems to highlight advantages and limitations.

Table (1) : Related Projects

Similar related work	Strengths	Weaknesses	How this work is different
A Real-Time Health Monitoring System for Remote Cardiac Patients Using Smartphone and Wearable Sensors [4]	- Tracking patient location is supported - Measuring blood pressure - Ability to diagnose diseases like bradycardia, tachycardia, hypertension, hypotension, fever, and hypothermia	- High (hundreds to thousands of dollars per device) depending on the devices used - System sends alerts but are not fully automated - No SpO2 level measurement - No environmental sensors	- Very low (under $50 for the full system) - Instant alerts via IoT and mobile networks - SpO2 level measurement - Use environmental sensors
Measurement of heart rate and respiratory rate using a textile-based wearable device in heart failure patients [5]	- Measure heart rate, respiratory rate, SpO2 level, blood pressure, and body weight at home - Ability to detect early decompensation episodes	- Requires complex installation and regular maintenance - No alerts - No temperature measurement - No fall detection - No environmental sensors	- Easy to install, wireless, requires minimal maintenance - Instant alerts via IoT and mobile networks - Temperature measurement - Fall detection - Environmental sensors
A real-time fall detection system based on the acceleration sensor of smartphone [6]	- Tracking patient location is supported with 3D information	- No temperature measurement - No SpO2 level measurement	- Temperature measurement - Environmental sensors

		- No environmental sensors	
Ubiquitous mHealth Approach for Biofeedback Monitoring with Falls Detection Techniques and Falls Prevention Methodologies [7]	- Fall detection and fall prevention system	- No environmental sensors - No SpO2 level measurement	- Environmental sensors
A Real-Time Patient Monitoring Framework for Fall Detection [8]	- Fall detection using sensors	- No temperature measurement - No SpO2 level measurement - No environmental sensors	- Temperature measurement - SpO2 level measurement - Environmental sensors
Software Implementation of a Smart Bracelet Prototype to Monitor Vital Signs, Locate, and Track COVID-19 Patients in Quarantine Zone [9]	- Tracking patient location is supported - Components are encapsulated in a wearable smart bracelet	- No environmental sensors - No fall detection	- Remote, real-time monitoring via smartphones - Fall detection
IoT-based health monitoring system for COVID-19 patients incorporate with fall detection system [10]	- Using MPU6050 accelerometer	- No environmental sensors	- Environmental sensors

3. System Design and Architecture

The proposed system comprises four key elements:

a) Hardware Components : The MAX30100 (heart rate and SpO2), MLX90614 (body temperature), DHT11 (air temperature and humidity), and MQ135 (gas and air quality) sensors are integrated to provide comprehensive monitoring of biomedical and environmental parameters. The Arduino NodeMCU microcontroller connects to the server via Wi-Fi modules to ensure real-time data transmission.

b) **Android Operating System (OS)**: An accelerometer in smartphones is employed to implement data to detect falls. The application sends emergency alerts through SMS and visualises sensor data in real-time with an IE-friendly user interface for caregivers and medical personnel [11].

c) **Database Server**: The MySQL database is maintenance-free via XAMPP, where all the data received from the sensors is stored. The server plays an essential role in storing a copy of all historical data, which allows for analysis and monitoring from different geolocations. This architecture allows scalable and safe patient information storage.

d) **Webserver (PHP, HTML)**: The project has a web-based dashboard based on PHP and HTML. It is an interface designed to grant authorised users access to both real-time and historical patient data, enabling live visualisation and remote decision-making.

3.1 System Architecture

The system architecture is designed to integrate multiple subsystems seamlessly. The biomedical and environmental sensors are connected to the Arduino NodeMCU microcontroller, which processes the data and transmits it to the server via Wi-Fi. The Android application interfaces with the server to retrieve and display real-time data. Emergency notifications are triggered by predefined thresholds or detected falls, ensuring timely alerts. Figure 1 illustrates the flowchart of the proposed system emphasising the interaction between hardware components, the database server, and user interfaces, and Figures 2 and 3 show the connection of sensors with the NodeMCU microcontroller.

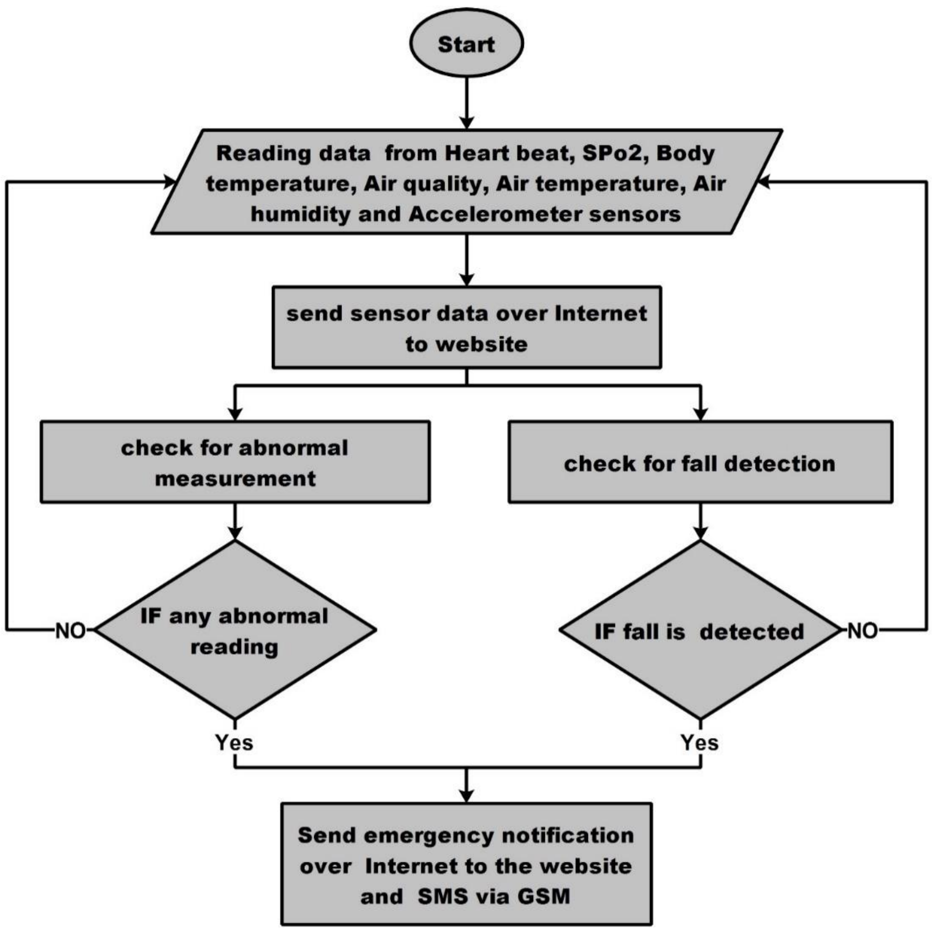

Figure (1): Flowchart of the proposed system

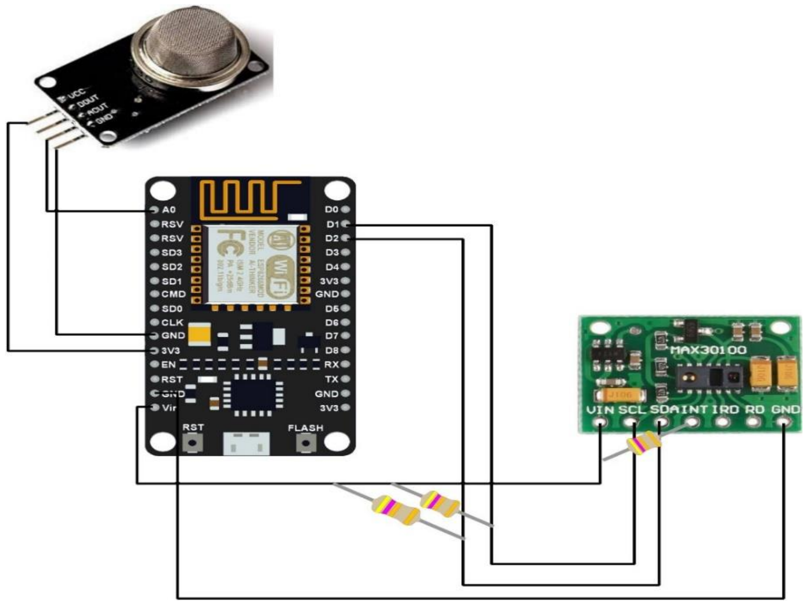

Figure (2) : NodeMCU with Heartbeat, SpO2, and air quality sensors

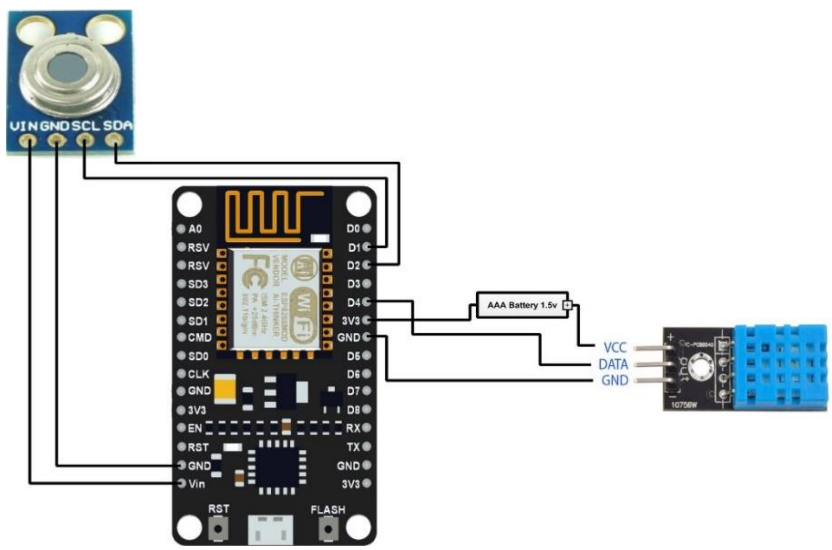

Figure (3) : NodeMCU with body temperature, air temperature and air humidity sensors

The architecture is highly modular, allowing for easy addition or replacement of sensors. It incorporates redundant communication paths to ensure reliability. For example, GSM communication acts as a backup for Wi-Fi, guaranteeing uninterrupted service during network outages. The system also supports bidirectional communication, enabling remote updates and configurations.

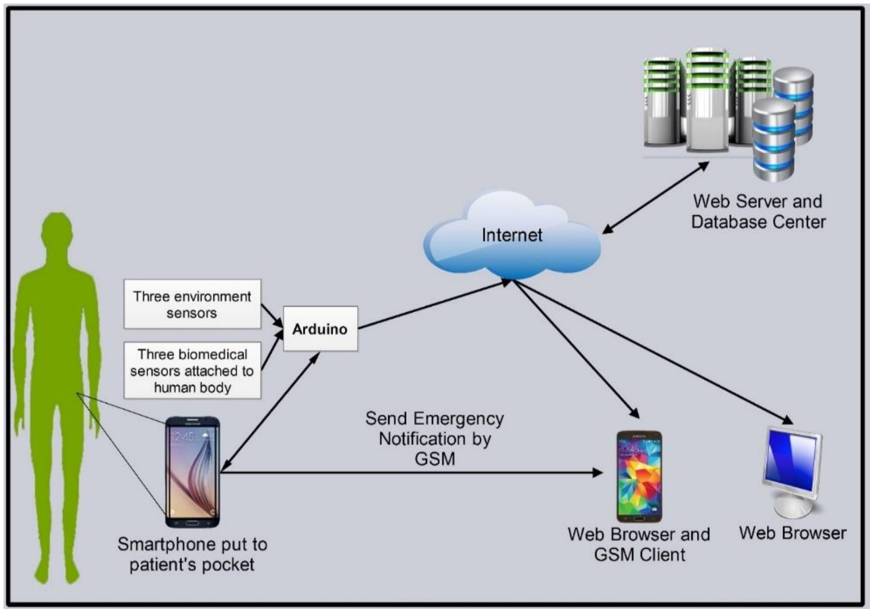

Figure (4) : Overall proposed system architecture

4. Implementation

4.1 Programming Tools

The system was developed across multiple programming environments to ensure robust functionality of all components. Data collected from the sensors was transmitted wirelessly to other system components through programming the NodeMCU using the Arduino IDE. An exclusive smartphone application was developed using Android Studio to receive real-time information from the NodeMCU. Using accelerometer data, a fall can be determined when it has happened and an emergency notification is sent through SMS. The database and web server environment, XAMPP, a lightweight and versatile server solution, was used to configure the system for seamless data storage and retrieval.

4.2 Integration Process

The hardware connections design process: connecting the NodeMCU with the sensors to make sure it collects data accurately and transmits it. The Maximum30100 sensor module is calibrated with other MLX90614, DH11 and MQ135 modules. Wi-Fi was used to wirelessly transmit the data from these sensors to the database server. The Android application was used for monitoring, displaying the live data and sends notifications to emergency contacts on error detection. A web interface designed in PHP and HTML has been developed displaying sensor readings and enabling caregivers to access patient information remotely. This system does not deal with sensitive data like in Protected Health Information (PHI), where it focuses on real-time monitoring and fall detection for elders and patients. Anyhow, the system provides a decent level of privacy, where information from sensors is securely stored in the database with proper encryption and backups.

5. Results and Discussion

Testing was conducted to ensure the system's reliability under various conditions. Each sensor was tested in a controlled environment to evaluate accuracy and response time. Simulated falls were used to assess the reliability of the fall detection algorithm, ensuring no false positives. The network stability was also assessed to ensure that communication between the hardware, the database and the smartphone application was uninterrupted. Analysis of the results showed that the system accurately detected all the required parameters and could be deployed for real-time healthcare monitoring applications.

Using a controlled setting that mimicked real-world scenarios, the proposed system was evaluated for its effectiveness in monitoring and responding to emergencies. The assessment centred around the precision, dependability, and usability of the system. The system architecture shown in Figure 4 integrates the biomedical and environmental sensors with the IoT communication and shows descriptions of the data flow among components, emphasizing the real-time processing of data.

The biomedical sensors were validated against medical-grade devices and were found to be accurate. For instance, heart rate readings had a 98% correlation and SpO2 levels, with an average error below 2%. Environmental sensors monitored changes in air quality and humidity and issued those alerts when it detected them (see Figure 5). For instance, Figure 6 shows a case in which air quality suffered anomalies and our system successfully generated an emergency notification.

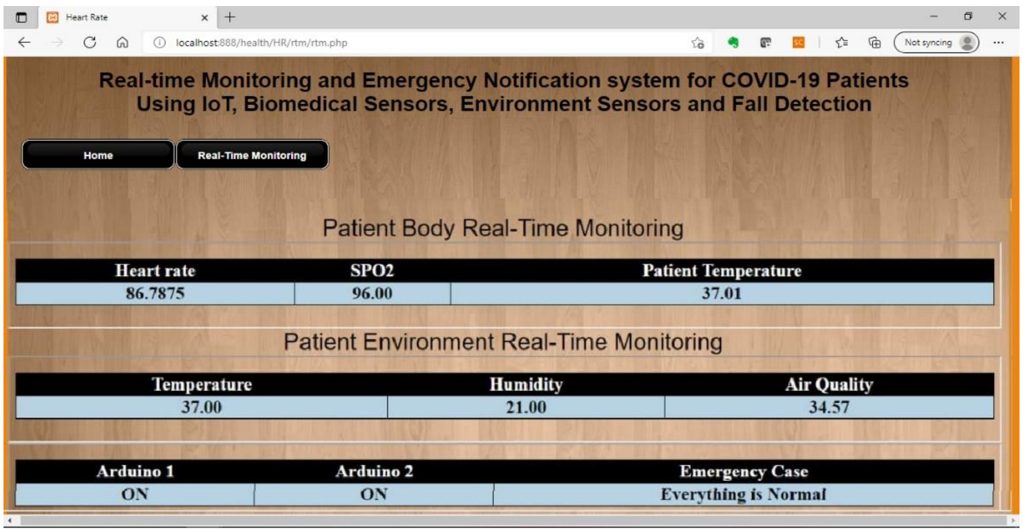

Figure (5) : Real-time monitoring and emergency notification system at normal state

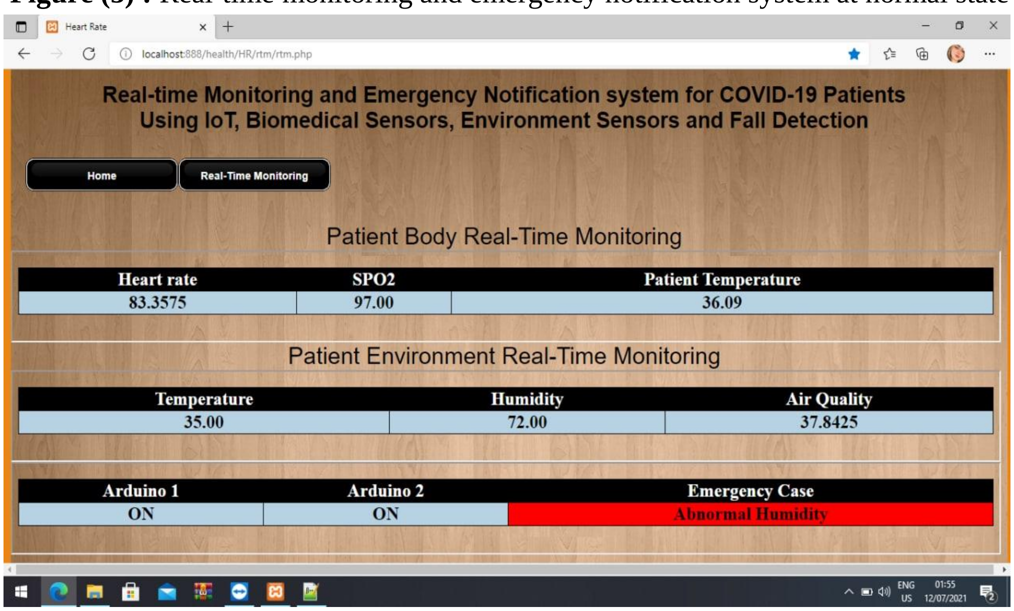

Figure (6) : Real-time monitoring and emergency notification system at abnormal humidity

5.1 Fall Detection

As shown in Figure 7, the fall detection mechanism reached a detection accuracy of 96% out of 50 tests. It correctly distinguished between genuine falls and jarring but harmless motions, reducing the number of false positives.

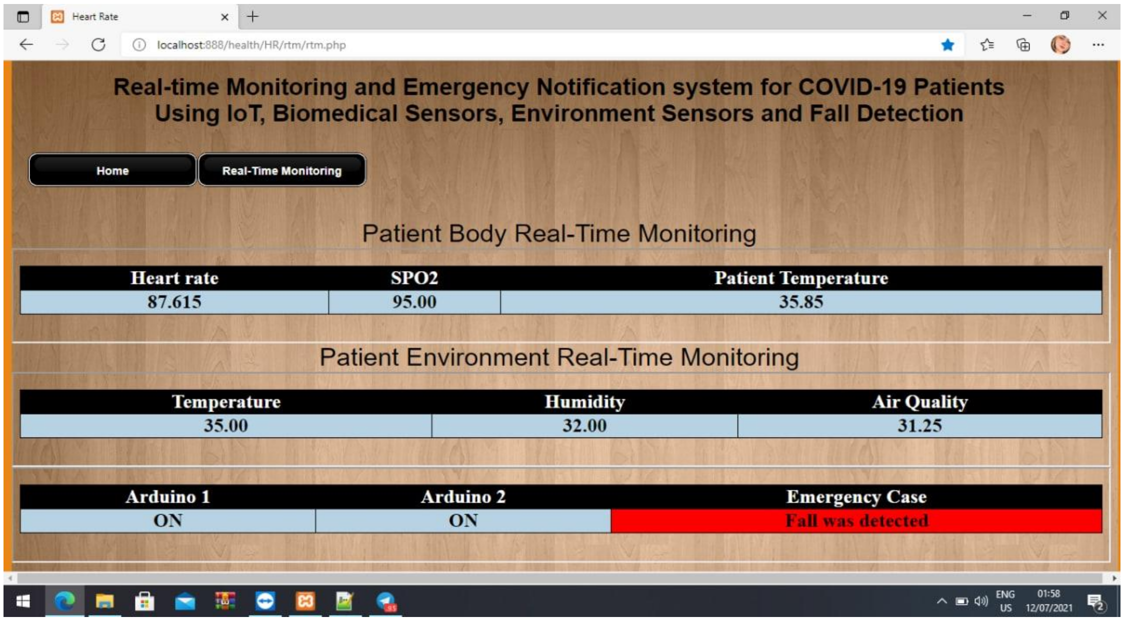

Figure (7) : Real-time monitoring and emergency notification system when fall was detected

5.2 Response Time

Emergency notifications sent in response to threshold breaches or fall events were received in an average of 4.3 seconds (see Figures 8, 9, 10), where the application was shown with an emergency alert in pass-through mode.

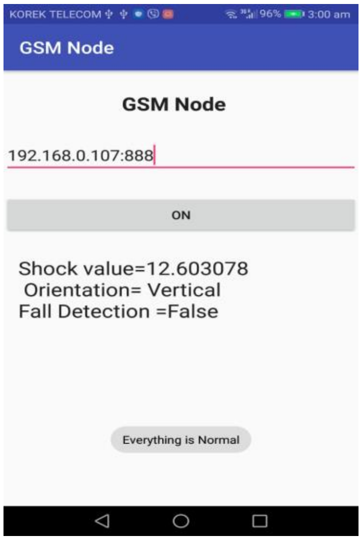

Figure (8) : Android smartphone application at normal state

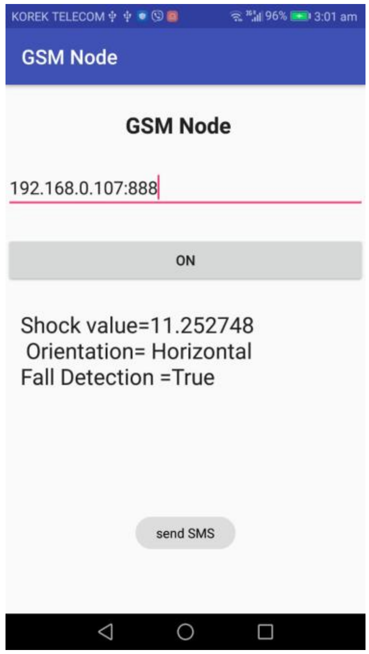

Figure (9) : Android smartphone application when fall was detected

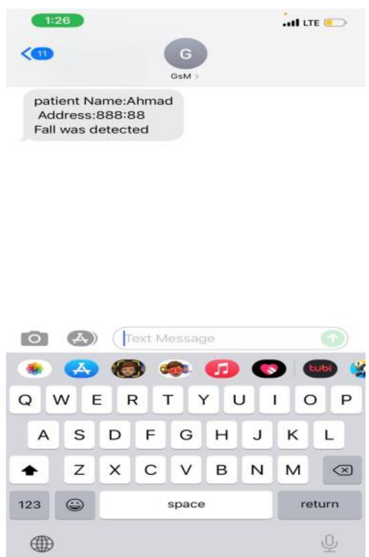

Figure (10) : Emergency contact when receiving the emergency notification for fall detection

5.3 User Experience

Both user interfaces of the system were evaluated for usability and include the smartphone application and the web dashboard. Caregivers reported that the interfaces were intuitive, and enabled real-time updates and access to historical data. Such a thorough evaluation confirms the robustness, reliability, and suitability of the proposed system during continuous healthcare monitoring in various scenarios.

6. Conclusion

The proposed system effectively addresses the limitations of traditional healthcare monitoring solutions by providing an affordable, scalable, and comprehensive alternative. Unlike conventional systems that rely on expensive standalone devices and necessitate frequent hospital visits, the proposed IoT-based solution significantly reduces costs by utilizing low-cost components, with the total hardware cost remaining under $50. Additionally, it eliminates the need for complex installations and maintenance expenses through wireless operation. Beyond cost efficiency, the system enhances healthcare delivery by integrating biomedical sensors for vital sign monitoring and environmental sensors for tracking air quality and humidity. Real-time alerts via IoT-enabled notification systems improve patient safety, particularly benefiting elderly and disabled individuals who require continuous monitoring. Furthermore, its modular design allows for future expansion, supporting additional sensors such as ECG and GPS tracking. This adaptability not only enhances healthcare accessibility but also reduces operational costs, making quality healthcare more affordable and accessible, especially for underserved communities.

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