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A Mobile IoT-based Elderly Monitoring System for Senior Safety

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Abstract. Traditional elderly monitoring systems may misdiagnose and treat senior citizens due to inaccurate results, resulting in higher care costs and poorer health outcomes. Thus, the Internet of Things (IoT) was introduced to provide accurate, real-time monitoring data to improve overall performance. The IoT health system connects devices wirelessly to collect and analyze health data, monitor vital signs and physical activity, and provide real-time insights to improve health management. This paper aims to monitor real-time conditions as well as ensure the safety of senior citizens by developing a low-cost wearable prototype device to measure heart pulses, detect falls, and determine their actual location in an indoor space. The data is uploaded to IoT platforms like Blynk, Firebase, and Google Assistant, providing frequent updates on the elderly's health status and conditions and sending emergency messages, if necessary, to an Android application. A home control system is also developed to control the home appliances using mobile phones or voice control. A demonstration has been conducted to showcase the operation and functionality of the prototype. The proposed system has the capability to simplify the daily routines of the elderly while also granting caregivers greater control over their health and well-being.

Keywords: Elderly monitoring; Fall detection; Indoor positioning; Internet of Things

1. Introduction

Health monitoring has evolved significantly throughout history, from ancient Chinese pulse reading and Greek urine analysis to the modern concept of a healthy city (Whulanza and Kusrini, 2023). For example, the development of wearable devices, such as smartwatches, that track different health metrics, like their heart rate and how well they sleep, has made health monitoring simpler. The advancement of the Internet of Things (IoT) technology and other forms of remote systems, such as telemedicine, have also allowed healthcare professionals to monitor patients remotely (Irianto *et al.*, 2023), which is helpful for patients with mobility difficulties or who live in rural areas. Besides that, Electronic Health Records (EHRs) allow storing and sharing information about a patient's health, which helps improve the accuracy and efficiency of health monitoring. Biomarkers are also used in modern health monitoring systems to measure signs of a particular disease or condition, such as the amount of blood sugar for diabetes. Recent developments in genomic testing have allowed for the identification of genetic risk factors for various diseases, which has important implications for the early diagnosis and prevention of many

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conditions (Junaid *et al.,* 2022).

Meanwhile, this paper focuses on a health monitoring system based on IoT technology. An IoT-based monitoring system is a system that collects and transmits data about an individual's health using connected devices and sensors. These data can track and monitor multiple health parameters in real-time, such as heart rate, and body temperature (Sangeethalakshmi *et al.,* 2021; Chaudhary *et al.,* 2018). Similar work has been extended to include sending the real-time location of the patients to family members and doctors via email and Twitter notification (Taştan, 2018). Furthermore, an IoT-based system has been reported to be capable of tracking eye movement and oxygen saturation percentage for coma sufferers (Tamilselvi *et al.,* 2020). In addition to these specific applications, IoT can also be used to monitor broader health indicators such as activity levels, sleep patterns, and nutrition (Saleem *et al.,* 2020). Once the data is collected, it can be analyzed to identify potential health issues and provide recommendations for their management.

Besides that, the IoT monitoring system offers numerous benefits, such as continuous tracking of an individual's health without frequent healthcare facility visits. This enables early detection of changes or abnormalities, ensuring appropriate care for patients, especially in underserved or isolated areas (Bharathi *et al.,* 2022; Chin *et al.,* 2022). The system provides valuable data, such as the health conditions of coronavirus disease (COVID)-19 patients (Abdullah *et al.,* 2022), for healthcare professionals to make informed treatment decisions and is particularly useful for seniors with multiple health issues or medications. This work has been extended by introducing Radio Frequency Identification (RFID) and Global Positioning System (GPS) tracking for the patients who were under quarantine (Chin *et al.,* 2022). Nevertheless, there are researchers who have constructed IoT-based wearable devices for health monitoring purposes (Cheng *et al.,* 2020; Taştan, 2018). In another paper (Cheng *et al.,* 2020), an accelerometer was used for elderly fall detection and connected to an IoT platform called ThingSpeakTM.

In summary, IoT-based health monitoring promotes a proactive approach to health management, reducing the burden on the healthcare system through continuous monitoring and personalized recommendations. Researchers have different priorities, such as latency, mobility, cost, and size, with the aim of achieving the best possible monitoring device. Therefore, the aim of this paper is to develop a low-cost and small wearable prototype device that has the advantages mentioned above for elderly monitoring using IoT technology and mobile applications. The pros and cons of the previous and proposed systems have been compared, as shown in Table 1. The overall system is designed based on the NodeMCU ESP8266 and Wemos D1 mini, as these microcontrollers are easier to use and fulfill all necessary requirements. The architecture of this research is divided into three parts: Sensing Device, Monitoring Device, and Home Control Device. The Sensing Device is a wearable device for elderly people that comprises multiple sensors to detect falls, sense heart rate, and perform indoor positioning. The Monitoring Device is used by the guardian to help monitor and assist the elderly at anytime and anywhere. The Home Control Device is able to control any home appliance. Multiple IoT platforms connect the three prototype devices to handle the data collected from each sensor in each prototype device, such as the Firebase platform for data collection and Blynk for the Android application interface. Nevertheless. If This Then That (IFTTT) is also programmed to take actions depending on the sensor's data input collected in the system.

The paper is organized in the following sections: The system architecture is first introduced and explained in the form of hardware and software descriptions. Flow charts of the prototype devices and all the implemented tools are also included here. A prototype demonstration and resultant discussion are then presented in the next section. The findings of the research are finally concluded with future recommendations.

Table 1 Comparisons of previous and proposed systems

Research Works	Micro-controller	Latency	Mobility	Size	Cost	Uniqueness
Sangeethalakshmi *et al.*, 2021	Arduino and ESP32	Low (30s to update data)	Not wearable	Big	Medium	Only send messages to the phone
Taştan, 2018	Arduino Pro mini	Low (long delay time)	Wearable	Big	Medium	Email and Twitter notification
Tamilselvi *et al.*, 2020	Arduino Uno	High (a few seconds to update data)	Not wearable	Big	High	Eye movement detection
Bharathi *et al.*, 2022	Arduino Uno	Low (reset needed to upload data)	Not wearable	Big	Low	Only SMS alert
Chin *et al.*, 2022	Arduino Mega and ESP32	Medium (time needed for GPS tracking)	Not wearable	Small	Medium (around $50)	RFID and GPS tracking, Google Map
Abdullah *et al.*, 2022	Arduino and ESP32	High (2s to update data)	Not wearable	Small	Low	Only display data on the phone
Cheng *et al.*, 2020	Arduino Uno	Medium (15s to update data)	Wearable	Big	High	Fall detection using an accelerometer
Proposed system	NodeMCU ESP8266 and Wemos D1 mini	High (less than 10s to update data)	Wearable	Small	Low (less than $30)	Fall detection, indoor positioning, voice control, Google notification, email and phone alert

2. System Architecture

2.1. Hardware Description

The overall architecture is designed to remotely monitor the elderly's health conditions and assist the guardian in managing their conditions easily using mobile phones. It consists of Sensing, Monitoring, and Home Control Devices, as explained in the next section.

2.1.1. Sensing device

The first prototype, as shown in Figure 1(a), is equipped with a Wemos D1 mini microcontroller. The device is frequently updated on the elderly person's state by using the fall detection sensor to determine if there is a fall or not, the heart rate sensor to determine the heart rate pulses, the internal Wi-Fi module to determine the location of the elderly person inside the home, and the push button to send an emergency message. The Wemos D1 is chosen because of its ability to provide more power efficiency in a small package and its low cost. The system uses only a 3.7 V rechargeable Lithium Polymer (LiPo) battery.

The fall detection sensor detects the fall by comparing the threshold value with the acceleration magnitude. If there is a change, it will take action. Both "Blynk" and "IFTTT", which are "IoT platform" and "If This Then That" services, respectively, are making the action process (Blnyk, 2023; IFTTT, 2021). Blynk is an online platform that shares all the data collected from the sensors and stores it in the Firebase database (Firebase, 2023). IFTTT is a service that provides multiple options for taking action if something is triggered. The advantage of using IFTTT is that you can send a warning message to a specific number, send an email, etc. For this sensor, the output is chosen to be an emergency email message to the guardian. Meanwhile, the heart rate sensor senses the pulse of the heart whenever an elderly person holds it. The LED is used to blink simultaneously with the pulses. The heart rate sensor readings are shown in the mobile application, which will be discussed later. Lastly, the push button is programmed as an emergency button to send an emergency message if pressed. This method is done through the use of the "IFTTT" service.

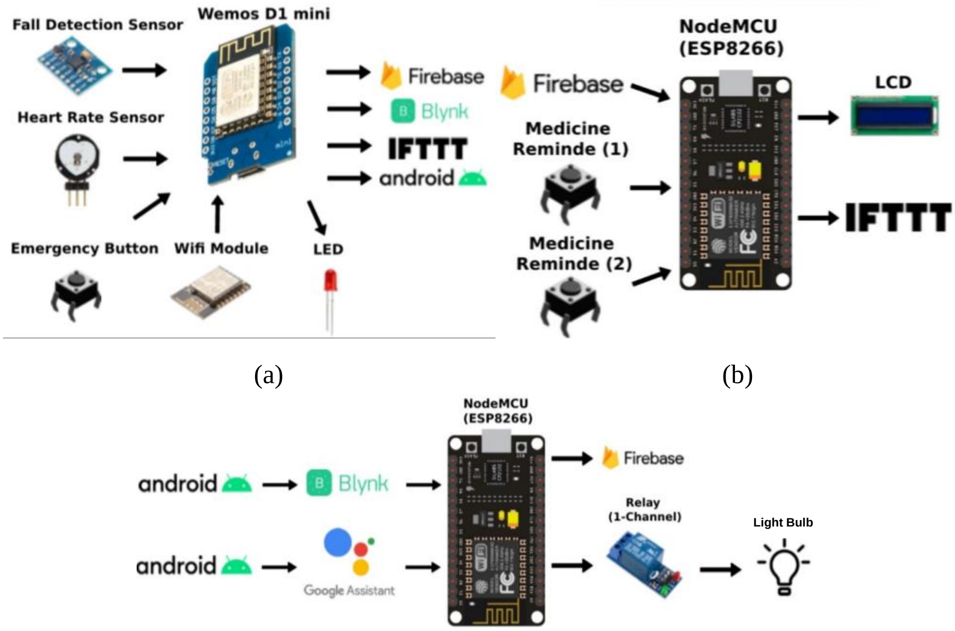

Figure 1 (a) Sensing device, (b) Monitoring device, and (c) Home control device

By using the internal Wi-Fi module, the location of the elderly person can be detected via the Received Signal Strength Indicator (RSSI) measurement between the fixed-place router in the house and the Wi-Fi module inside the Wemos D1 mini (Kawęcki, Hausman, and Korbel, 2022). After the location is determined, it is frequently updated in Firebase and represented in the mobile Android application via Blynk. The power consumption is low compared to systems mentioned in the literature review because of the use of a small number of communication modules, like Wi-Fi and Bluetooth modules, and because no logic gates are used to power some sensors that depend on a specific turn-on voltage.

2.1.2. Monitoring device

The second prototype, as shown in Figure 1(b), describes the ability to send and receive data under the guardian's control. This device is equipped with a NodeMCU (ESP8266) microcontroller. It has two buttons to set a quick reminder on Google Calendar to take medicine (1) and medicine (2), respectively. The same methodology is applied here to send a message using the IFTTT service to make an event on Google Calendar if the button is pressed. Also, this device will have an implementation of a Liquid Crystal Display (LCD) with a size of 16 x 2 to update data (heart rate reading, elderly person's current location, and status of home appliances) from the Firebase via the IoT platform regarding the status of the elderly person and the interaction with the guardian if the button is pressed.

2.1.3. Home control device

Voice control is utilized to operate home appliances like light bulbs. Google Assistant, a mobile virtual assistant software program developed by Google, is programmed by the IFTTT service to execute specific voice commands for controlling home appliances. There is also an implementation of a virtual button on the Blynk mobile application to control the home appliances manually. The connection of the prototype is shown in Figure 1(c), in which the NodeMCU is used with a one-channel relay. Relay is the link between home appliances and the microcontroller. These two methods of controlling the home appliances, either by voice control (Google Assistant) or manual control (Blynk), are provided to the elderly to ensure there will be no difficulties in controlling the appliances. Firebase is used to update the status of the light bulb.

2.2. Software Description

Mobile phones play an important role in this research. It is used to monitor the elderly person's health by showing the readings of the sensors in the Blynk application, as shown in Figure 2. It first uses the light bulb virtual button to control the light in the elderly's home. Second, the location detection label is frequently updated with the home location changes of the elderly. Finally, the heart rate label shows the pulse readings of the heart rate sensor whenever it is handled. Moreover, the phone has a voice control feature to control the home appliances using Google Assistant. It controls the light status in the home by saying specific words, as shown in Figure 3. The voice control will also update the light virtual button status in Blynk using the IFTTT service. The Firebase is the prime link among all the devices in this research. The Sensing Device depends on it to send data to be viewed by the Monitoring Device. The Home Control Device also depends on Firebase to control the data.

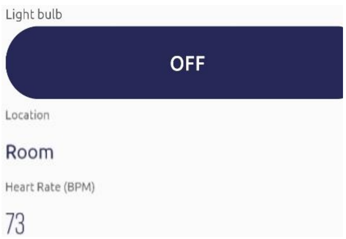

Figure 2 Blynk application

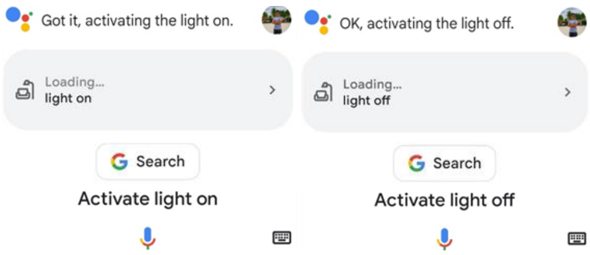

Figure 3 Google Assistant service

2.3. Algorithm and Flow Charts

The system's algorithm operates within the interactions among the devices mentioned earlier and the IoT platforms. It provides a systematic process flow for collecting health data and monitoring the conditions of the elderly, including fall detection and location tracking, all while enabling remote monitoring by caregivers. The devices serve as the front end of the system, while the IoT platforms are used as the back end to process, store, and manage the information received, as shown in the following flowcharts.

The flowchart of the first prototype is shown in Figure 4. The system will check whether the button is pressed or not. If it is pressed, it will request a web request from IFTTT to send an emergency email to the guardian. The second function is to measure the heart rate pulses if an elderly person holds the sensor. The LED is blinking in synchrony with pulses. Then, the measurement data will be uploaded continuously to Blynk and Firebase. The third function is to detect a fall. After detection, it will send a web request to IFTTT to send another email to the guardian, warning him of fall detection. The flowchart of the second prototype, as shown in Figure 5, starts by reading the data uploaded and saved previously on the Blynk. These data are displayed on the LCD in a continuous loop. The data types shown are heart rate pulses, location detection, and home appliance status. Then, the system detects whether one of the buttons is pressed or not. If it is pressed, a web request will be sent to IFTTT to make a medicine reminder on the Google calendar. There are two reminders to set for each of the buttons, respectively. Both buttons have the same sequence for applying the same function, except for different message outputs.

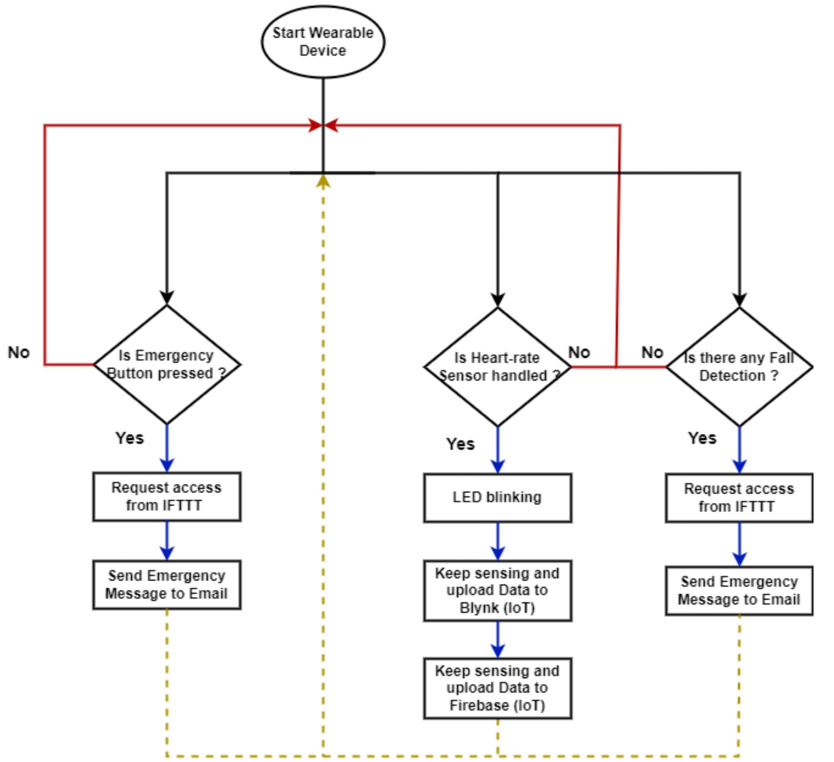

Figure 4 Sensing device flowchart

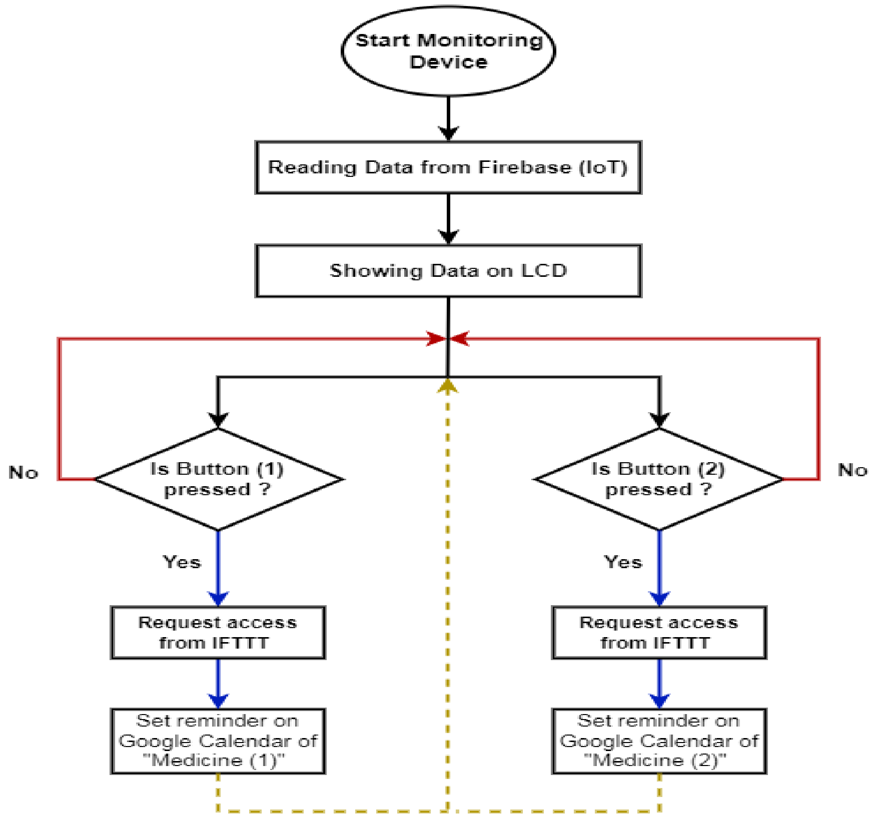

Figure 5 Monitoring device flowchart

The flowchart of the third prototype, as shown in Figure 6, has two functions. They are either voice-controlled or manually controlled by the mobile phone. Voice control starts by saying, "Hey, Google," then controlling the light by saying, "Activate light ON" or "Activate

Light OFF." Each method sends a web request to IFTTT to control the light's status. After sending it to IFTTT, the light's status is updated on Firebase and Blynk. The stored data is updated in Blynk to be controlled by the virtual button. Manual control is done by using the Blynk application with a virtual button to manually control the light by pressing the button to turn it on or off. Lastly, the manual control updates the data on the Firebase.

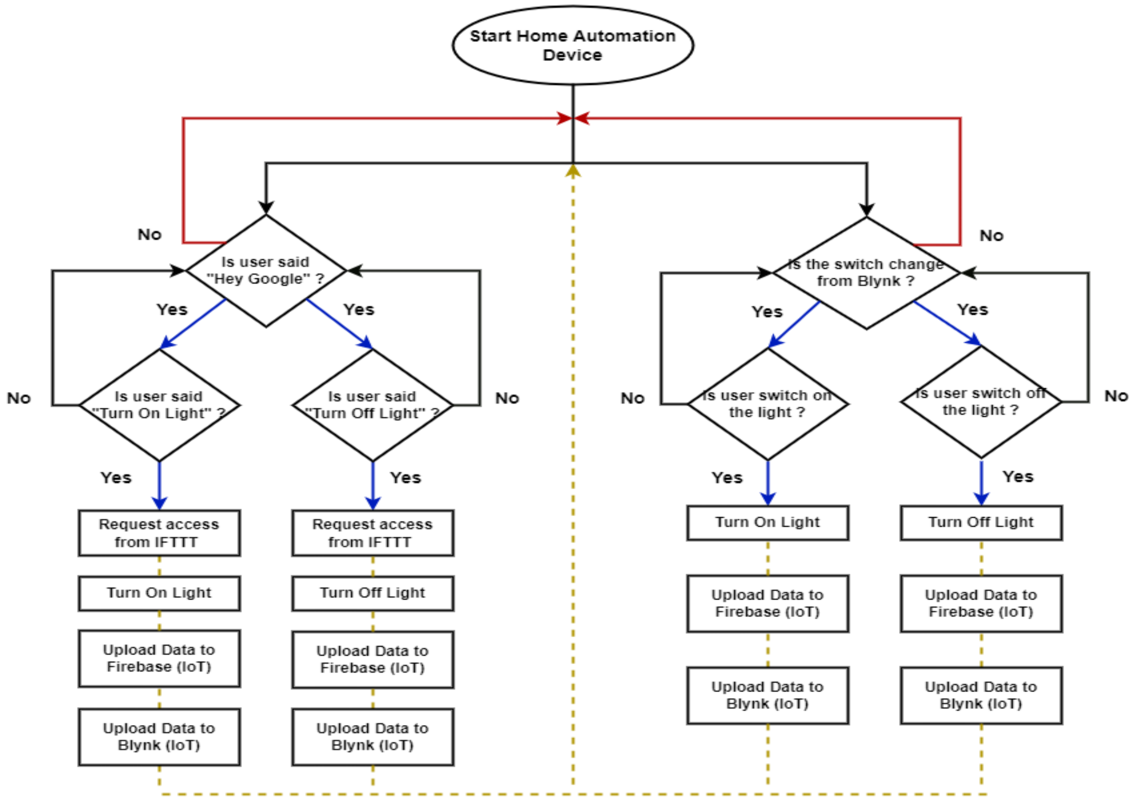

Figure 6 Home control device flowchart

3. Results and Discussion

In this section, a demonstration of the developed prototypes, as shown in Figure 7, will be performed. The interactions between these devices will also be explained.

Figure 7 Developed prototype

3.1. Sensing Device

The first prototype has multiple sensors to check the health of the elderly person. The software is coded to read data from each sensor and update it simultaneously on both the Blynk and Firebase IoT platforms. The hardware is designed to fit all the sensors in one small prototype device, and it is supported with the battery shield to have a stand-alone system with a rechargeable small battery, which will not affect the weight. The output of the heart rate sensor is blinking the LED synchronously with the heart pulses, saving the latest readings in the Firebase platform to be represented on the monitor device later on and uploading the data to the Blynk IoT platform to be presented in the mobile application. To validate the heart rate sensor's measurement values, it has been tested along with the Mi Band 6 smart watch. Table 2 compares the readings from the heart rate sensor and the smart watch Mi Band 6. These readings are calculated after measuring at different times and in different situations. It's important to mention that the heart rate sensor implemented inside the smartwatch is more advanced than the one used in our prototype system and costs much more than our sensor, but the readings are mostly the same, with a maximum relative difference of less than 3%.

Table 2 Comparison between the heart rate sensor and MI Band 6 smartwatch

	Heart Rate Sensor	Mi Band 6	Relative Difference
BPM (Beat Per Minute)	71	71	0%
	73	71	2.78%
	73	73	0%
	74	72	2.74%
	72	72	0%

The MPU-6050 fall detection sensor accurately detects falls and triggers a rapid response: sending an emergency email to the guardian for assistance, as depicted in Figure 8. This email-sending function is facilitated through the IFTTT service, as it is no longer supported by other IoT platforms. It has the flexibility to modify the message or even the action itself after programming the microcontroller and has a fast response if the action is triggered, like falling. A quick response is necessary to help the elderly as soon as possible. So, the time spent sending the email is only 1 second. On the other hand, the emergency button is provided to contact the guardian via email and ask for help with a single press, which results in a fast response without any delay or limitations. The email notification is shown in Figure 9.

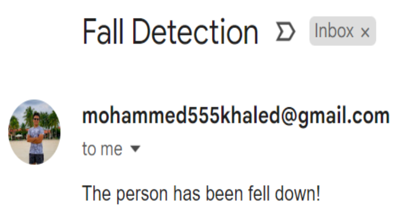

Figure 8 Email notification on fall detection

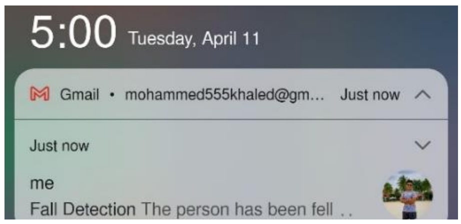

Figure 9 Emergency notification

With the aid of the RSSI technique and Wi-Fi, the location of the elderly person inside the home can be easily determined, and the data will be uploaded to Firebase and Blynk simultaneously. If it is not repeated, it will save the microcontroller's memory and prevent the system from failing and stopping. Table 3 shows the ranges of the RSSI preserved for the specific home location. These data are measured by calculating the distance between the home router and the internal Wi-Fi module inside the Wemos. Since the prototype is placed in the living room, the nearest detected location is the living room space that has the highest RSSI range value. Where else the furthest place is room, which has the lowest range RSSI value. The internal Wi-Fi module also helps decrease the prototype device's size.

Table 3 RSSI definition for specific home location

RSSI Range (dB)	Home Location
-52 to -27	Living room
-67 to -53	Kitchen
-81 to -68	Room

3.2. Monitoring Device

The second prototype is developed for internal home use only. It has two functions: presenting the data saved from Firebase and setting a medicine reminder on Google Calendar by using the IFTTT service. The LCD shows the data in a looped sequence of location, heart rate, and light status all the time, as shown in Figure 10. These data are updated simultaneously with the latest values in the Firebase. The loop design of presenting the data gives the guardian person the smoothness of monitoring the health of the elderly person without any manual control on the screen. On the other hand, the two reminder buttons result in making a reminder on the Google Calendar, as shown in Figure 11. The first and second buttons send the first and second medicines' names, respectively. The result will be shown on the computer or mobile phone to remind the elderly to take a specific medicine at a particular time. The medicine's time and name can be modified from the mobile device or the computer by using the IFTTT service at any time. the computer by using the IFTTT service at any time.

Figure 10 Data loop on LCD

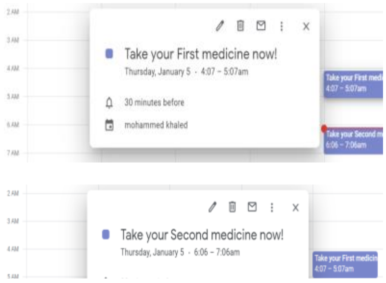

Figure 11 Reminders on Google Calendar

3.3. Home Control Device

The third prototype is designed to control home appliances with either voice control or manual control from the mobile phone. The connection between the mobile phone and the microcontroller is made using Blynk. The connection between the Google Assistant on the mobile phone and the microcontroller is made using the IFTTT service. The connection between these services and IoT platforms is shown in Table 4. It goes for the sequence started by either Google Assistant (voice control) or a mobile application (manual control). In Google Assistant, it is controlled by saying, "Hey Google, Activate Light ON" or "Hey Google, Activate Light OFF" in order to send to the microcontroller either "0" or "1", respectively. The manual control in the mobile application is done by a virtual button in the mobile app. This virtual button sends "0" or "1" if the button is switched to be turned "ON" or "OFF," respectively. Then, all of these states use the relay to control the light bulb. The type of relay used is an "active low" relay, which means the relay will switch on the light bulb if it receives "0" and vice versa. At the last stage, the light status will be updated in Firebase and shown on the Monitor Device.

Table 4 Home appliances control sequence

Google Assistant (Voice Control)	Mobile Application (Manual Control)	Relay (Active Low)	Light Status
"Activate Light ON"	Turn ON	0	ON
"Activate Light OFF"	Turn OFF	1	OFF

3.4. Comparisons with Existing Systems

After showcasing the functionality of the developed prototypes, it can be concluded that the system is practically feasible to implement in the real world. Compared with some of the previous systems, as shown in Table 1, the developed system has a lower cost and a smaller size. The choice of using the NodeMCU ESP8266 and Wemos D1 mini rather than Arduino successfully reduces the size of the hardware. Furthermore, the Sensor Device is wearable, which is portable and convenient for the elderly. All the sensors and units are also tested and validated with high accuracy, as are the existing works. The mobile and web applications are user-friendly and yet add useful functions such as indoor positioning, voice control, etc., which are not introduced in the other existing systems.

4. Conclusions

The main contribution of this paper is successfully developing a health monitoring system for elderly people using IoT technology and mobile applications. The prototype is low-cost and low-power, and it can be easily implemented in real-life applications such as medical systems. The system uses an Arduino microcontroller incorporated with multiple sensors to measure heart pulses, detect falls, and provide location data through an Android application. The application also controls home appliances, sends emergency emails, and provides medicine reminders. The wearable device is placed on the hand to easily access emergency buttons and simulate a real smartwatch. The significant of this work is that the system successfully provides real-time health data to carers and improves the daily lives of the elderly. The advantages of the system developed for the health monitoring industry, such as hospitals, are that it saves doctors time and effort in monitoring their patients' health status. In emergencies, fast contact between the patient and the doctor is also achieved. As the prototype device delivers real-time data, the sensors' readings are updated second by second. Also, patients will not face difficulties wearing the prototype device because of its small size. The limitations of this prototype device can be found in the packaging part. For future development, sensors can be covered; since this device is designed for the elderly, the risks of getting these sensors damaged are increasing. The mobile application can be improved by adding a user profile for each patient. It will keep their information secure and only accessible to authorized doctors. That will also make it easier for a medical specialist to monitor multiple patients simultaneously.

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