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Internet of things based fall detection and heart rate monitoring system for senior citizens

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ABSTRACT

Falls cause the maximum number of injuries, deaths, and hospitalizations due to injury for senior citizens worldwide. So, fall detection is essential in the health care of senior citizens. Present methods lack either accuracy or comfortability. The design of fall detection and heart rate monitoring system for senior citizens has been presented in this paper. The hardware interface includes wearable monitoring devices based on a tri-axial accelerometer and Bluetooth module that makes a wireless connection by software interface (mobile application) to the caregiver. Global positioning system (GPS) can also track the location of the elder. For detecting falls accurately, an effective fall detection algorithm is developed and used. The performance parameters of the fall detection system are accuracy (97.6%), sensitivity (92.8%), and specificity (100%). A pulse sensor is used for monitoring the heart rate of the elder. The device is put on the hips to increase comfortability. Whenever the elder's fall is detected, the device can send information on fall data and heart rate with location to the respective caregiver successfully. So, this device can minimize the injury and health cost of a fallen person as a victim can get help within a short time.

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1. INTRODUCTION

Approximately one-third of the older adults in Europe having a lifespan of more than 65 years live alone [1], and remarkable growth of the older adults is expected in the next twenty years. In 2025, the growth rate of senior citizens over 65 years old can climb to 20% in Taiwan [2]. China has entered an associate aging society as early as 1999. The sixth national census in 2010 [3] shows that the population of individuals over sixty in China is 1777.6487 million, 13.26% of the entire population. The National census [4] claimed that the senior citizen expansion rate is moderately increasing during the timeline of 1974 to 2011. In the year 1974, the number of elders between the ages of 60 to 64 years was 1,682,629, and the numbers were 3,218,974 in 2011. The report shows that the rate of elder age between 60 to 64, 65 to 69, 70 to 75, and over 70 years were 37%, 21% 20%, and 22% severally.

The danger of falling is highly noticeable among the most common issues looked at by older people. The falling percentage of older adults is high as the human body becomes weak and physical strength decreases with age. Falling can bring about severe injury that may even result in death. World Health Organization (WHO) stated that 28% to 35% of individuals over the age of 65 years suffer a minimum of one fall every year. This figure surges to 42% for older adults living more than 70 years [5]. WHO also reckons that more than 50% of senior citizens require hospitalizations, and roughly 40% of the senior citizens are inside the mortality hazard. According to the centers for disease control and prevention (CDC) statistics, in the United States, one-third of people being more than 65 years old fall every year, and approximately 61% of the falling events occur in living places causing approximately 10,000 demises. Yet, the hospitalization and death rate can be decreased by 26% and 80% if fast service is provided immediately after a fall [6]. According to the chief Yuan Department of Health, Bureau of Health Statistics [2], the falling rate of the older peoples in Taiwan is 10.7% to 20.1%. The home environment is considered as commonplace that the elders are most likely to face accidental injuries. According to the analysis "Risk factors of home injury among older peoples in Malaysia", among 4842 informants having lived over 60 years, a total of 279 (5.8%) had suffered a home injury of some sort during the year before. The most frequent types of injuries were falls (n=205), object-oriented (n=14) and, cuts (n=43) [7].

Most research on fall detection utilizes accelerometers, sometimes gyroscope-based detection system has also been used. Falls are distinguished either by applying edges to acceleration, speeds, and points or by utilizing machine learning to perceive activities of daily life (ADL) comparing to a fall. Depending on the sensor used, the fall detection system is classified into three categories. They are the wearable device method, ambiance device method, and camera-based method.

The wearable device strategy depends on sensors having on by the person to distinguish stance or movement of the patient's body for recognizing falls. Accidental fall's appraisal is troublesome because of the unpretentious and complex essence of body development that needs exact and dependable estimation procedures. The area of the fall-identified sensor is likewise primary since the site of flag identification, for example, hip, trunk, wrist, or head, will result in distinction pattern designs. A wide range of systems have been proposed to distinguish the falls. Degen *et al.* [8] decorated a wristwatch consisting of two accelerometers to differentiate three types of falling. Because of the intricacy of the arm motion, the achievement rate achieved 65% only. Yang and Hsu [9] utilized a triple-axis accelerometer set at the midsection level to identify everyday physical exercises, yet a fast take a seat or a rests stance would be mixed up as a falling event in this framework. Lindemann *et al.* [10] built an amplifier device based on two accelerometers and would have the capacity to recognize seven sorts of falling and five sorts of day-by-day exercises. It is not impressive to outline that the sensors placed at the head level cause discomfort for many users, and the affectability and exactness of falling event acknowledgment are low [11]. Gjoreski *et al.* [12] developed a multi accelerometer-based system. The accuracy for the three accelerometers was 96%. However, a single accelerometer was not able to detect falls accurately. A wearable device based on the acceleration threshold [13] was developed with sensitivity and specificity of 83.33% and 95.40%, respectively. This method was unable to avoid fall detection in case of going down/up the stairs. Nevertheless, their device was performing best for long-term heart rate monitoring.

The ambiance device method is based on sensors like video cameras, infrared cameras, floor pressure sensors, infrared sensors, and audio systems. Multiple sensors can be used to collect the data to detect falls. Vibration or force sensors [14] on the tiles can analyze the location using fall data. These sensors can determine where the elder is at home. A fall-detection method [15] was developed employing a pressure sensor and infrared camera. This method is not feasible because the sensor under each tile is not possible and is costly. Their accuracy and sensitivity were 98.3% and 96.7%, respectively. However, in the multi-direction, the accuracy was 91.1%.

A unique fall detector was developed by a group of researchers that mainly used cameras for detecting falls [16]. This device exhibits accuracy greater than 96%. But the light conditions greatly affect the performance of this device. Debard *et al.* [17] proved that the use of a particle filter for fall detection by vision enhances accuracy. This method failed to detect quick movements by 24%.

Many different approaches exist for the detection of the fall. However, the proficiency of fall recognition and stance acknowledgment are dependably challenging. The internet of things (IoT) has numerous utilization areas, among which health care is one of the most attractive and promising fields [18]. In this research project, we developed a wearable device that detects falls, monitors the heart rate, and gives the user a provision to contact the caregiver in an emergency using IoT. It is positioned on the hip to make it comfortable. We developed and implemented a fall detection algorithm in this device built up through practical experiments for falls. With the help of this algorithm, the fall detection accuracy of this device has become high (97.6%). After detecting a fall, the location and heart rate of the user is sent to the caregiver through the wireless network. This device can also monitor heart rate and alert the caregiver on the occurrence of stroke, and the user can send a notification to the caregiver if he/she requires emergency attention. Observing the heart rate of an elder before and after falling will reduce fall injury drastically. With a specific end goal to convey sufficient restorative help, a wearable device system is proposed here to affirm the steady-state condition more exact that includes a novel falling event recognition calculation that gives a reliable and accurate fall recognition.

2. RESEARCH METHOD

The system has been developed using a wearable device outfitted with an accelerometer to perceive body movement. During detecting body motion, the accelerometer detects linear acceleration on three perpendicular axes. If acceleration values of x, y, and z axes are found, the associate net value is calculated using the following formula. Net acceleration plays a vital role in detecting falls. The final and determining quantity of fall is body orientation. Pitch and roll determine body orientation. Pitch and roll give an understanding of the orientation of the user and ensure fall detection. The acceleration along each axis can be used, along with trigonometry, to find out the pitch and roll in terms of angles.

$$A_{net} = \sqrt{Ax^2 + Ay^2 + Az^2},\ \text{Pitch} = \tan^{-1}\left(\frac{Ax}{\sqrt{Ay^2+Az^2}}\right),\ \text{Roll} = \tan^{-1}\left(\frac{Ay}{\sqrt{Ax^2+Az^2}}\right)$$

This device is embedded with a delay after fall recognition to let the user decide if he wants the message sent or not. This methodology is adaptable in both indoor and outside situations. It is utilized in both fall detection techniques and heart rate monitoring with a global positioning system (GPS) module that gives a falling person's location. The location of the user is shown in Google Maps as a gateway from the developed android application. The system measures heart rate, and whenever a fall is detected, it sends heart rate data and fall data to the respective caregiver.

2.1. System architecture

The system methodology has been divided into three parts. The block diagrams of the proposed system are presented in Figures 1(a), 1(b), and 1(c). Figure 2 shows the flowchart for the proposed system. When the device is turned on, it begins its Bluetooth module to send data wirelessly. The user needs to install the android application to get complete services; otherwise, this device will only alert the surrounding people about the user's fall. After starting the Bluetooth module, the accelerometer is initialized. If the accelerometer is functional, then a tiny checking is done whether the user needs any attention from the caregiver or not. If he requires it, then a message is sent to the caregiver using the android application. A beats per minute (BPM) check is also done to monitor the user's heartbeat. Suppose it is in the range of stroke (heartbeat <45 or heartbeat >120) [19], then a message is sent to the caregiver about the user's stroke after observation of abnormal heart rate for 1 minute long. During this communication, a 5 s delay is provided to prevent any data communication problem in the device.

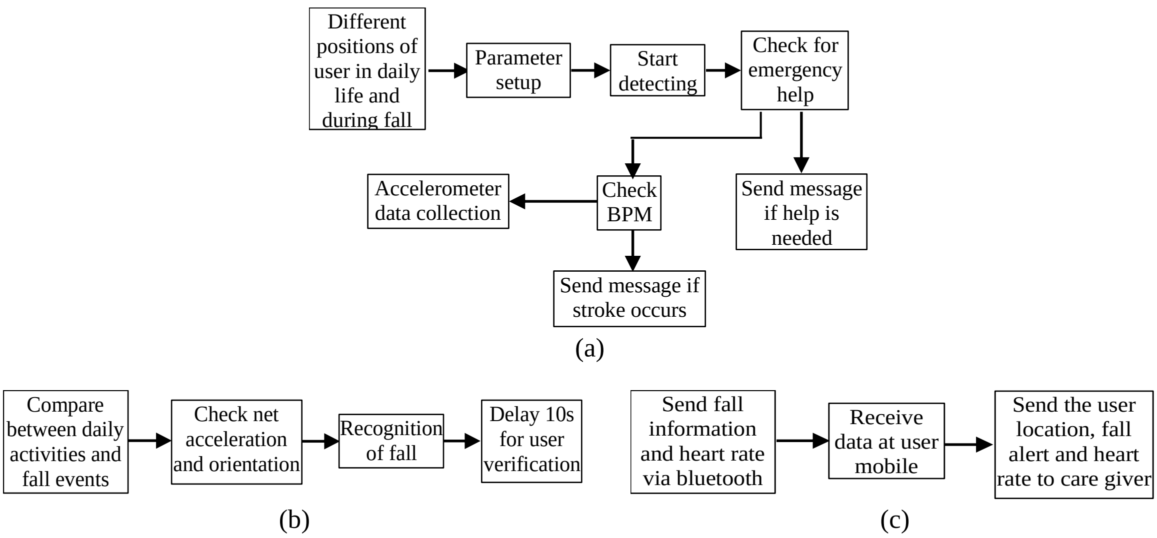


Figure 1. Block diagram of the proposed system (a) before falling, (b) fall detection process, and (c) after falling

After this, the collected data from the accelerometer is analyzed to detect falls. If acceleration and orientation's value satisfied all the preset conditions in the fall detection algorithm, then fall is detected. There is a ten-second window to let the user decide if he wants the attention of the caregiver. If attention is needed, then the buzzer on the device starts to alert nearby persons, and the application sends the caregiver a message of the user's fall. It also sends the BPM and location of the user using the GPS module on the user's mobile to the caregiver so that immediate help can be provided to the user. These communications between the user and the caregiver are done using the android application that we built for this device. This application connects the user and caregiver's mobile to a cloud server. This way, all the devices are connected to a server, and this server handles all the communication between them.

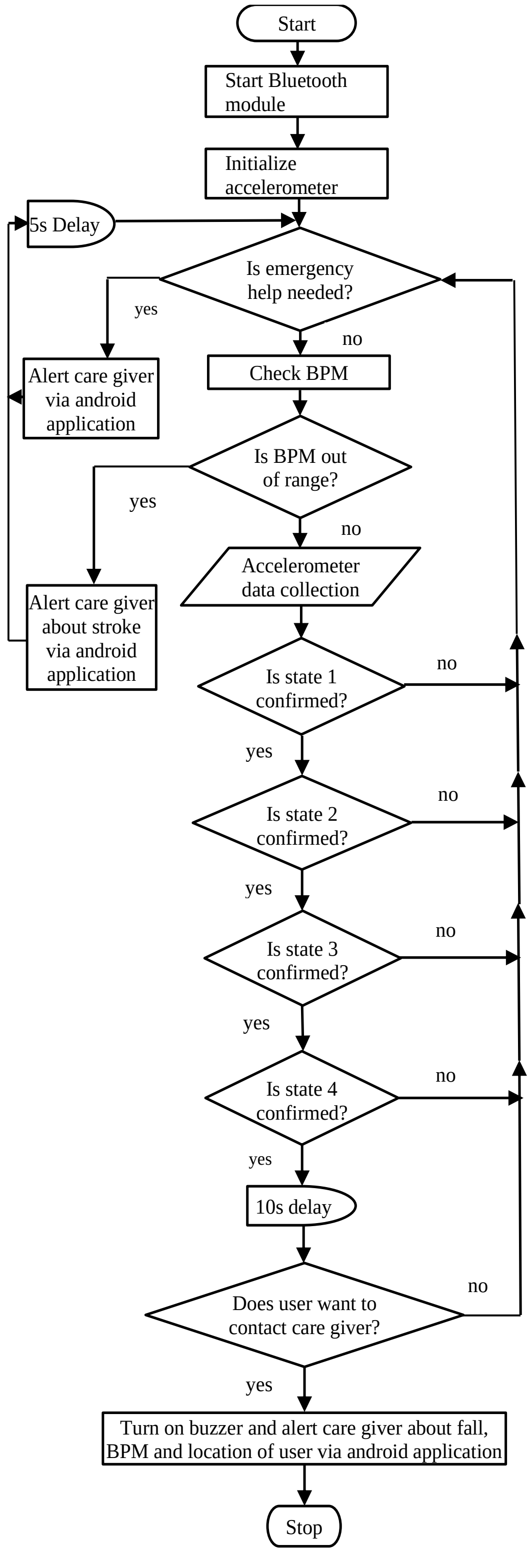
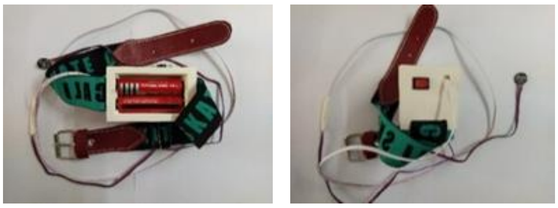


Figure 2. System flowchart

2.2. Hardware setup

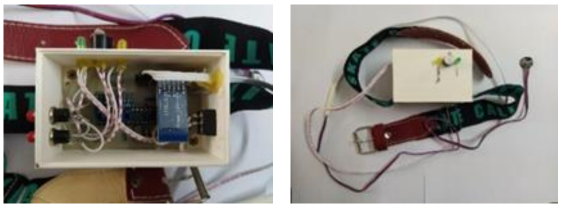
The hardware components used in this device are an accelerometer, Bluetooth module (HC-05), Atmega 328 p microcontroller, pulse sensor, resistors, LED, buzzer, rechargeable lithium-ion battery, 3.3 V regulators (ASME 1117), LM7805 voltage regulator, push-button switches, on-off switch, printed circuit board, box, and belt, connecting wires, nut, screw, hex connector and female to male headers. This device is powered by two 18650 Li-ion rechargeable batteries of approximately 2500 mAh, each shown in Figure 3(a). A switch is used to turn on and off the device, shown in Figure 3(b). LM 7805 voltage regulator provides 5 V and ASME 1117 for 3.3 V to the components that require it. Push-button switches are used to send a signal for different functions. All the components are set up on a printed circuit board mounted on a plastic box with the help of nuts, screws, and hex connectors depicted in Figure 4(a). The placement of the buzzer and led in this device is shown in Figure 4(b). Figure 5 depicts the placement of two push buttons for the provision of emergency care and deactivation of the communication process from device to user’s smartphone for messaging. This box has been designed in Solidworks software for mounting all the hardware components on it. The Solidworks design is shown in Figure 6. A three-dimensional (3D) printer from digital fabrication laboratory (Fab-Lab) of Chittagong University of Engineering and Technology, Bangladesh, was used to print this box. A plastic polymer named ABS has been used to print this box.

When powered up, accelerometer and pulse sensor work as input sensor, and Bluetooth module is used for providing output for wireless communication for this device. These sensors send their signals to the microcontroller, where a program is written based on the flowchart. I2C protocol has been used to connect the digital accelerometer and microcontroller rather than SPI as I2C is less complicated to implement and compatible with the microcontroller pins and matches the accelerometer. The hardware architecture of this device is shown in Figure 7. If a fall occurs or the user faces a stroke, the buzzer starts to notify surrounding people. When the user is in normal condition, then a led is continuously lit to indicate that the device is working, and the user is in a normal state. Another led is used to follow the rhythm of the user's heartbeat.



(a) (b)

Figure 3. Powering up the device (a) battery part and (b) power switch part



(a) (b)

Figure 4. Internal and output part (a) internal part and (b) output part

Figure 5. Input part of the device

2.3. Fall detection algorithm

The developed fall algorithms theoretically had to be converted from a systematic flowchart design to microcontroller programming. Figure 2 shows the flowchart, which includes the fall detection algorithm. In this fall detection system, four consequent states have been defined as the integer variable. The initial state will be "state zero". At first, the accelerometer starts to take the reading of x, y, z-axis acceleration data and input it to the Arduino. From the value of the three axes data, net acceleration, pitch, and roll are calculated using the formulas stated in the previous sub-section. The algorithm then checks whether the net acceleration A_{net} breaks the lower threshold. If this happens, the state value will be one and go to check the next state. "State one" will be "state 2" if A_{net} is greater than the second threshold value. Here algorithm will check the upper threshold to break for 300 ms. There is a transient state after the upper threshold. The next step is to check if the amplitude magnitude value is between this transient states for 200 ms and will make the state 2 to state 3. The final checkpoint is the orientation. After falling, the pitch or roll becomes more prominent than 60 degrees. If it occurs and orientation remains unchanged for 2s, state three will become state 4. State 4 confirms the fall. All these threshold values for fall detection have been collected from real-life experiment and sample curves of those experiments. Data from the experiments have been taken and plotted to get the waveforms of different activities for ADL and fall, as shown in Figures 8(a)-(c) and Figures 9(a)-(c). From these figures, there is a difference between the patterns of daily activities and free fall. The difference is in the threshold values of acceleration magnitude in different stages. For falling activities, pitch or roll becomes more than 60 degrees. For daily activities, pitch and roll are about to zero degrees. In the case of running and walking, net acceleration may rise above the upper threshold. However, it is not detected as fall as a change of orientation is considered. These figures give the net acceleration data. The pitch and roll data are also collected from the serial monitor in the Arduino platform from the actual experiment.

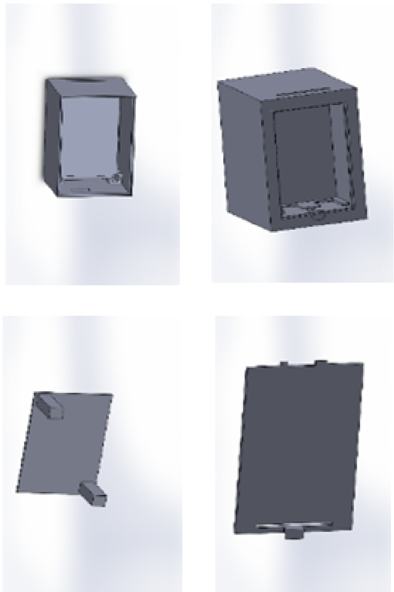


Figure 6. Design of the box in solidworks

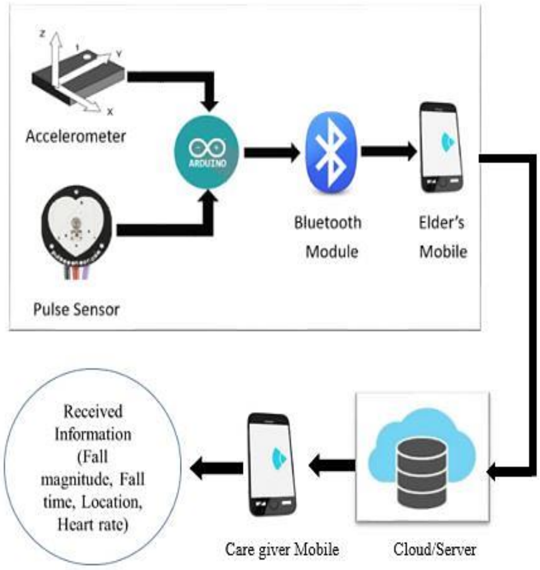
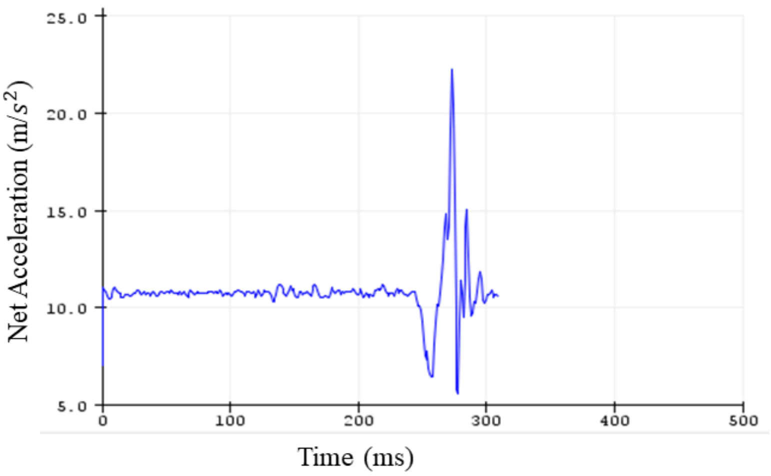


Figure 7. Hardware architecture

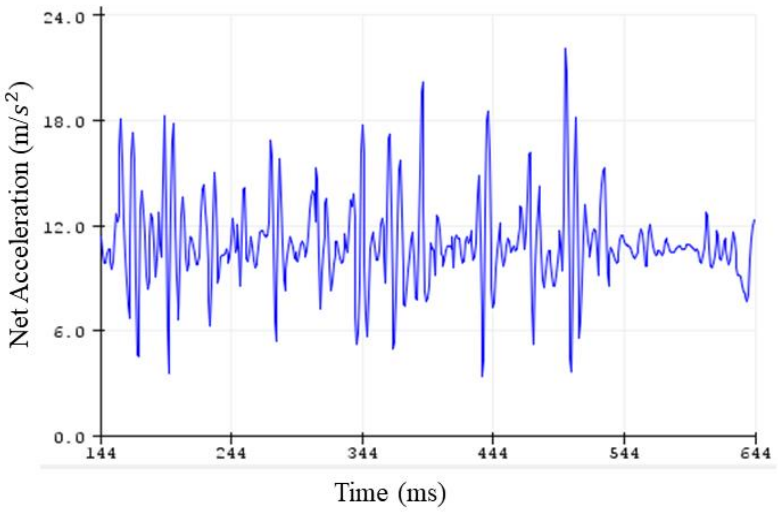
2.4. Android application

An android application named 'ElderCare' was developed on a java platform for establishing communication between the device and cloud server. The developed app has two interfaces. One is an elder interface, and the other is a caregiver interface. The user has to log in using email, and he has to provide the caregiver number and some other typical information. Users can update their caregiver's cell number anytime. The user needs to connect his smartphone with the device through Bluetooth. After falling, the app generates an automatic short message service (SMS) from the user's mobile to caregiver mobile and sends the information of fall occurrence, BPM, and fallen location of elder to the caregiver through the network. The time and date information are collected from the user's mobile. The location is collected from the GPS module placed in the user's mobile. So, for this communication, the mobile data and location feature should be turned on. Figures 10 shows some samples of the android application along with the message sent to the caregiver.

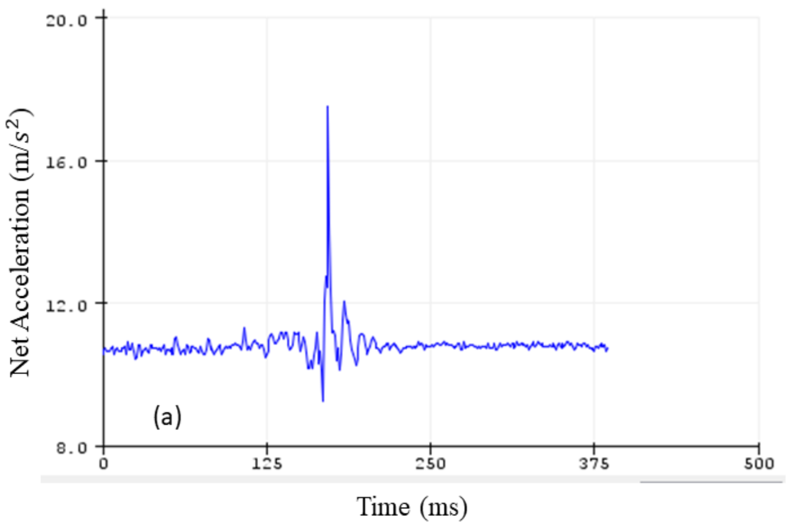
The data are sent via a real-time database. In this system, Google firebase has been used as a database. Figure 11 shows a sample of the real-time database. The user needs to register and log in using an email account as the patient in the application, and he has to provide the caregiver number and some other typical information. Users can update their caregiver's cell number anytime. The caregiver needs to register and log in as a caregiver in the application. During login, the caregiver must give the mobile number of the patient. This way, both the user and caregiver are paired up in the database. They only need to register one time. All the communication, registration, and login can be observed from the database. All the products will be communicating through this server.



(a)

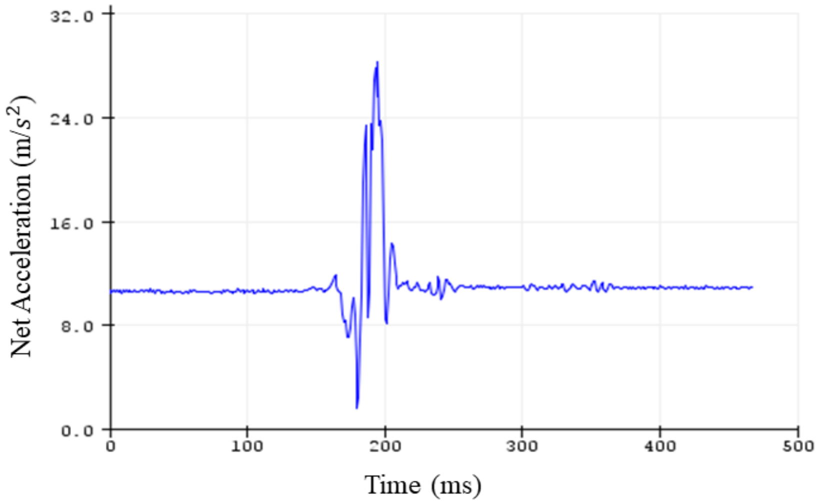


(b)

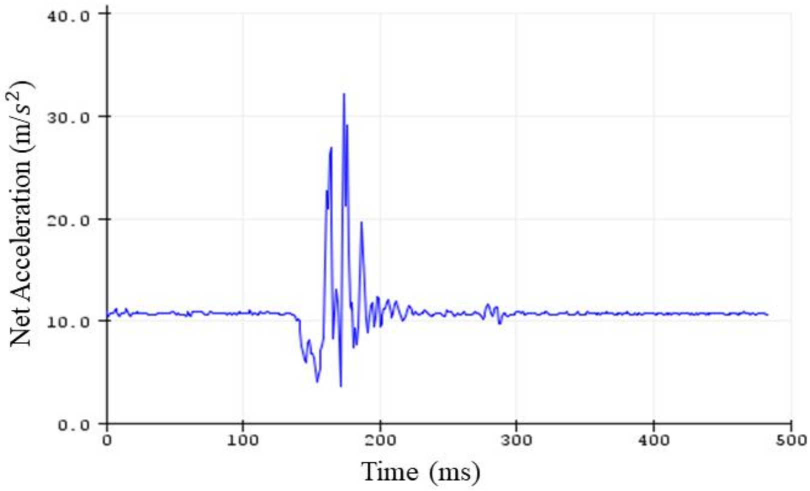


(c)

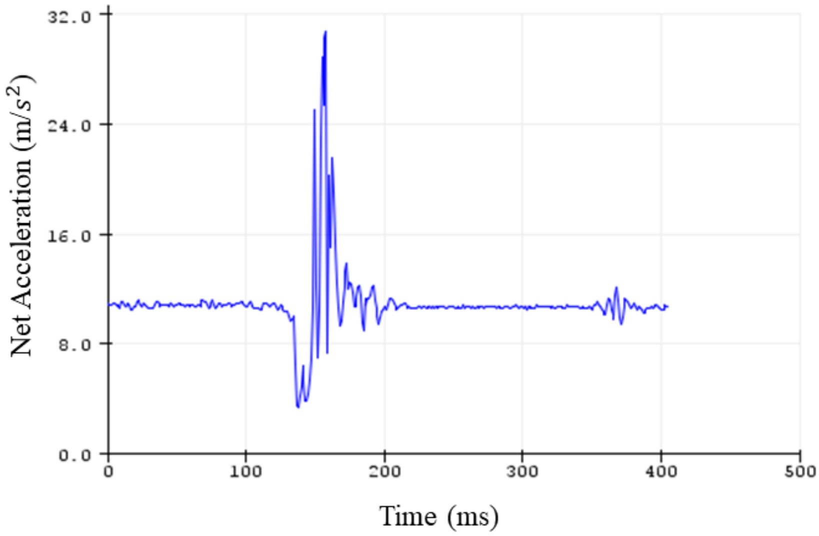
Figure 8. Net acceleration graph for ADL (a) stand to sit, (b) walking, and (c) sit to lying



(a)



(b)



(c)

Figure 9. Net acceleration graph for fall events (a) front fall, (b) right fall, and (c) left fall

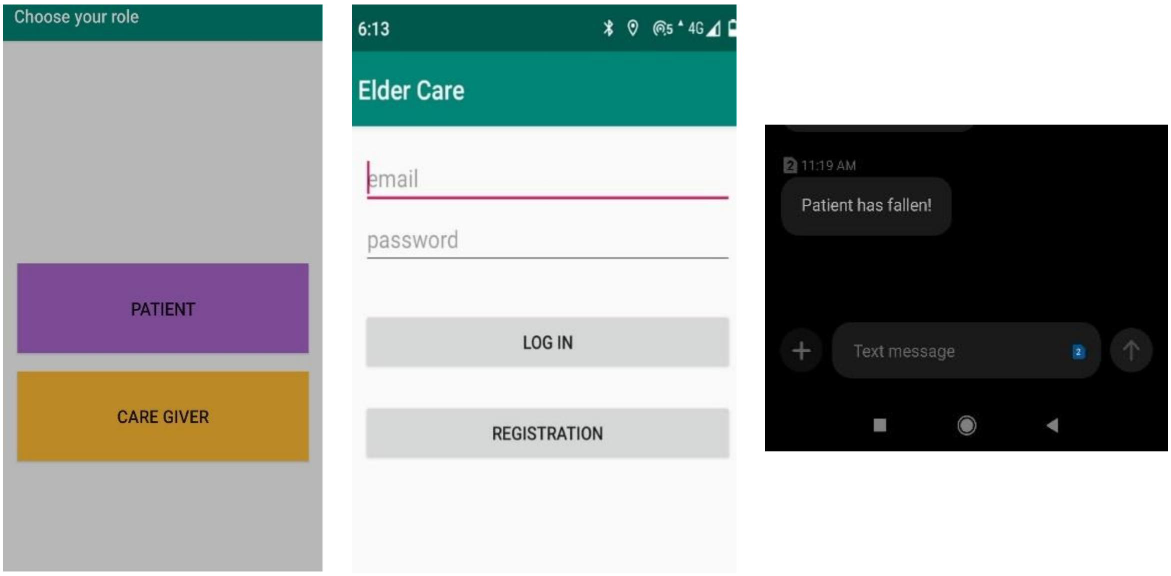


Figure 10. Android application

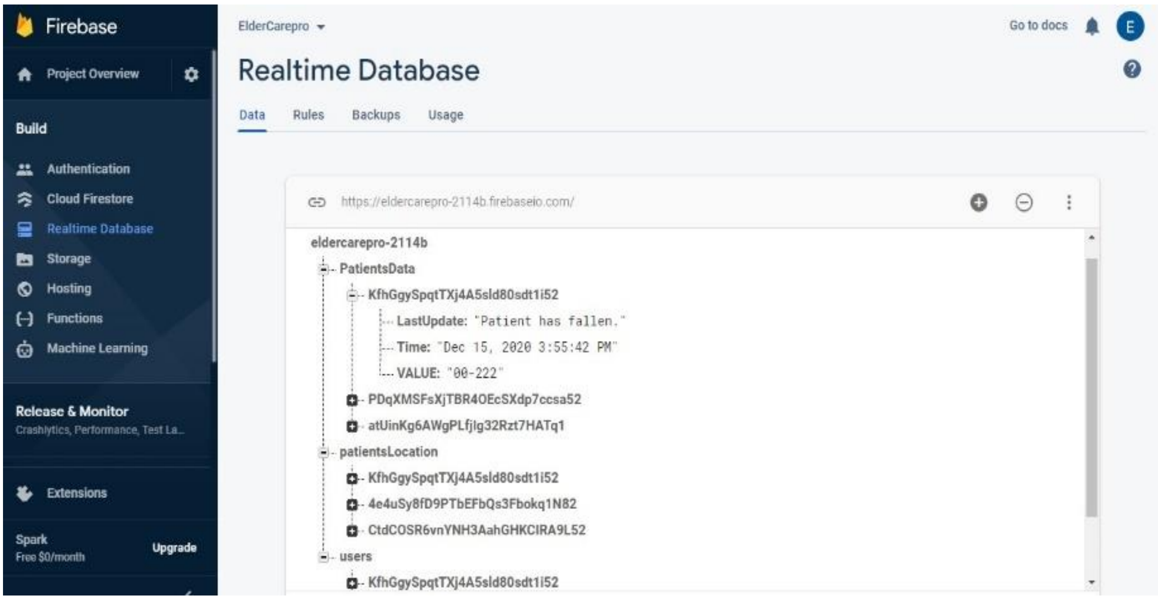


Figure 11. Real-time database

2.5. Heart rate measurement

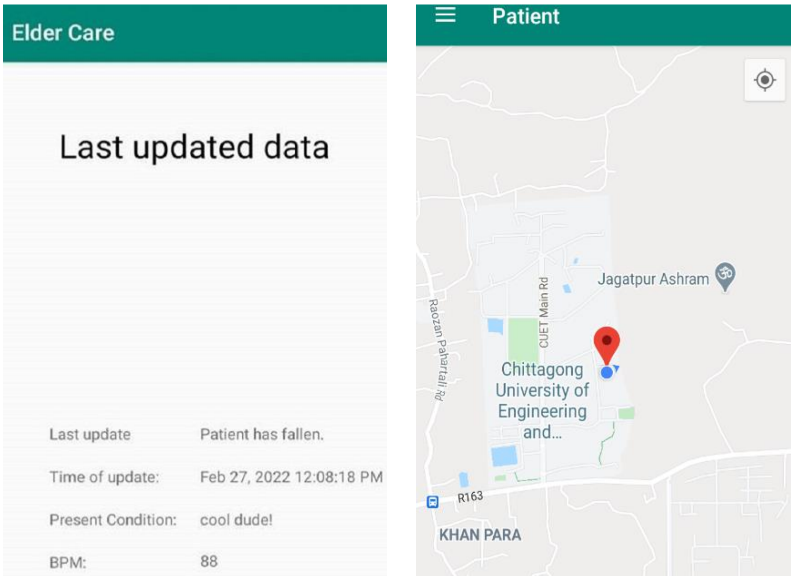
Heart rate, particularly the resting pulse, is a vital indicator factor for cardiovascular disease [20]; it is additionally concerning exaggerated mortality of coronary failure [21]. The heart pulse signal is an analog value. It fluctuates due to the circulating of blood in the body by the heart. It is measured based on photoplethysmography (PPG). Pulse Sensor has an amplifier. It amplifies the signal and converts the pulse signal into a voltage level. Pulse Sensor gives a response if the intensity of light changes. The analog signal value remains at or close to 512 if the amount of light incident on the sensor remains constant. The signal level increases when the intensity of light increases. In the case of low intensity of light, the signal level drops. Green color LED is used as its wavelength is suitable for this purpose. Light from the LED is back to the sensor's receiving end after reflecting and changes during each heartbeat. To find heartbeat inter beat interval (IBI) has to be measured. The program of the pulse sensor measures the IBI by counting the 50% crossing of two successive signals during the rising of the signal. Ten successive values of IBI are averaged. If IBI is measured in the unit of a millisecond, Heart Rate can be calculated from the following equation.

$$\text{HR} = \frac{60000}{\text{IBI}}$$

An average of 10 IBIs value is considered. The BPM is calculated from this average value. Here 1 minute has been converted into a millisecond. Whenever heart rate meets a particular condition, a signal is sent to the user mobile through Bluetooth communication. The data is sent to the cloud server using the android application. Then a message is sent to the caregiver from the server alerting him about the patient's stroke and location. A sample of the user's heart rate condition updated in the app is shown in Figure 12(a).

2.6. Emergency help

This device includes a feature that enables the user to get the caregiver's attention at any time through wireless communication. The user only needs to push a button which sends a signal to the microcontroller, sending another signal using Bluetooth to the android application. The application then sends this data to the cloud server, and a message "I need help" is sent to the caregiver from the server. The location of the user is also sent to the caregiver via the android application which is shown in Figure 12(b).



(a) (b)

Figure 12. Outputs in android application (a) heart rate data in android application and (b) user's location in android application

3. RESULTS

Fall detection performance can be described using three performance parameters which are accuracy, sensitivity, and specificity. These parameters depend on four fall detection cases. They are confirmed positive, false negative, true negative, false positive. Accuracy denotes the potentiality of the system to recognize any activity (Fall/ADL). Sensitivity specifies the capability of the system to recognize fall activity, and ADL recognizing ability is denoted by specificity.

$$\text{Accuracy} = \frac{\text{TP+TN}}{\text{TP+FN+TN+FP}}, \ \text{Sensitivity} = \frac{\text{TP}}{\text{TP+FN}}, \ \text{Specificity} = \frac{\text{TN}}{\text{TN+FP}}$$

For fall activities and ADL, data have been taken from five volunteers of age limit between 23-24 years. The total number of fall trials is 125 for five different types of falls in Table 1. True positive is 116, and false-positive is 9. Similarly, the ADL trial is 225 for nine types of ADL in Table 1. This device's measured accuracy, sensitivity, and specificity are 97.6%, 92.8%, and 100%. In the case of ADL, there is no false positive. The system can detect ADL successfully. There is zero probability of detecting ADL as a fall, ensuring that the elder can perform any regular activity without any problem. Table 2 shows a comparison between the performance of the proposed system and related works. The proposed system provides the most accurate fall detection.

Table 1. Performance parameters of the proposed system

Activity	No. of Trials	True Positive	False Negative	True Negative	False Positive	Accuracy (%)	Sensitivity (%)	Specificity (%)
Falling Forward	25	25	0	0	0	100	100	-
Falling Backward	25	25	0	0	0	100	100	-
Falling Right	25	23	2	0	0	92	92	-
Falling Left	25	22	3	0	0	88	88	-
Falling While Sitting	25	21	4	0	0	84	84	-
Standing to Sitting (Chair)	25	0	0	25	0	100	-	100
Standing to Sitting (floor)	25	0	0	25	0	100	-	100
Sitting (Chair) to Standing	25	0	0	25	0	100	-	100
Sitting (floor) to Standing	25	0	0	25	0	100	-	100
Sitting to Lying	25	0	0	25	0	100	-	100
Lying to Sitting	25	0	0	25	0	100	-	100
Walking	25	0	0	25	0	100	-	100
Walking on the Staircase	25	0	0	25	0	100	-	100
Running	25	0	0	25	0	100	-	100
Average						**97.6%**	**92.8%**	**100%**

Table 2. Comparison with related works

Name of the system	Sensor/Method	Accuracy (%)	Sensitivity (%)	Specificity (%)	Year
Bourke *et al.* [22]	Accelerometer	N/A	N/A	83.3	2007
Tzeng *et al.* [15]	Pressure and Infrared	91.1	93.3	88.9	2010
Fang *et al.* [23]	Accelerometer (Mobile)	N/A	72.22	73.78	2012
Zhou *et al.* [13]	Accelerometer	93.75	83.33	95.4	2014
Castillo *et al.* [24]	Accelerometer and camera	79.57	N/A	N/A	2014
Ma *et al.* [25]	Camera	86.83	N/A	N/A	2014
Chua *et al.* [26]	Video cameras	90.50	N/A	N/A	2015
Pierleoni *et al.* [27]	Accelerometer	95.19	N/A	N/A	2015
Kwolek and Kepski [28]	Camera and Accelerometer	95.77	N/A	N/A	2015
Daher *et al.* [29]	Force Sensor and Accelerometer	90	N/A	N/A	2017
Wang *et al.* [30]	Channel State Information	94	N/A	N/A	2017
Proposed System	**Accelerometer**	**97.6%**	**92.8%**	**100%**	**2020**

4. CONCLUSION

Portable fall detection and heart rate monitoring device for senior citizens have been proposed here, which can alert the caregiver through SMS service. The fall is detected by acceleration threshold determined through practical experiments and orientation-based detection techniques. The provision of heart rate monitoring is also provided in this device to reduce the health hazard. This system works based on IoT and so will work with any network such as GSM, Wi-Fi. Though the device is designed for senior citizens, experimental evaluation could not be done on the elderly as it would be hazardous for their health. However, almost all possible types of falls in the senior citizen have been considered here, and experimental evaluation was done on young and healthy subjects. The proposed system showed excellent accuracy when compared with other works in the literature. There is a scope to compact the device to become more user-friendly and add more biofeedback parameters. Observation of elders wearing this device should be done for a long time to evaluate this practical application.

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