An inventive and innovative system to detect fall of old aged persons – a novel attempt with IoT, sensors and data analytics to prevent the post fall effects

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Abstract: According to the statistics of national council on aging (NCOA), these days rate of deaths in the old aged people has reached a critical state that for every 11 seconds an older adult is being treated for a fall and for every 19 minutes a death is taking place. Statistics by north eastern Ohio state reveals that, the rate of emergency room treatment of fall related injuries in persons aged 75 and older approached 80 per 1,000 per year in women and 60 per 1,000 per year in men. Falls in elders vary from that of the falls in kids, as the healing power in the old people slackens with their age. We present a frugal and affordable system that could monitor the motion of the old people and can detect their fall. We use IoT, sensors and data analytics to build this system. The system is tested for its functioning and is fool proof.

Keywords: fall detection; old age support; IoT; IoT for medicine; old aged tracking system.

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1 Introduction

These days' falls have become major health problem, particularly in the old aged ones. According to the statistics of WHO (http://www.who.int/mediacentre/factsheets/fs344/en/), 646,000 fatal falls are being recorded and 37.3 million falls that are not so fatal but which needs medical treatment have occurred. It has been noticed that falls have been more fatal in men than in women. But, the cases where falls resulting in fractures or injuries is more in women than in men. Either ways, the numbers are really not encouraging and are a certain threat to the life. Among people aged 65 to 69, one out of every 200 falls, result in a hip fracture. That number increases to one out of every ten for those aged 85 and older (http://www.comfortkeepers.com/home/info-center/senior-independent-living/seniors-and-falls-statistics-and-prevention). One-fourth of old people who get their hip fractured are dying within six months of the injury. The statistics cited in Table 1 are the records of the adults that are being followed up for six months.

Table 1 shows the statistics of the falls in both the men and women for a follow up duration of six years.

Table 1 Fall statistics

	Three-year-follow-up		*Six-year-follow-up*	
	n, faller/total	*%*	*n, faller/total*	*%*
All	106/555	19.1	205/1542	13.3
Age in decades				
60	-	-	106/979	10.8
70	21/159	13.2	40/303	13.2
80	68/343	20.0	47/230	20.4
90	17/53	32.1	12/30	40.0
Sex				
Men	34/230	14.8	68/716	9.5
Women	72/325	22.2	137/826	16.6

Source: https://bmcgeriatr.biomedcentral.com/articles/10.1186/1471-2318-13-81

From Table 1, it can be inferred that, women are falling more than men and people of age group 80 are facing more falls the other age groups. The mortality rate in elderly due to falls has increased by 55% within a span of nine years. It has risen from 29 per 100,000 to 45 per 100,000. It is also noted that, it has increased by 44% for those aged 45–64 years. Here are some of the reasons why and how falls occur frequently in elderly (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3314071/).

1 Endocrine problems: endocrine disorders can cause leg weakness. For example, diabetes often causes nerve damage in the legs and feet, called diabetic neuropathy. The result is pain or numbness and weakness in the legs. Overweight diabetics and those with poor blood sugar control are more likely to have these problems. Endocrine disorders with US prevalence estimates of at least 5% in adults included diabetes mellitus, impaired fasting glucose, impaired glucose tolerance, obesity, metabolic syndrome, osteoporosis, osteopenia, mild-moderate hypovitaminosis D, erectile dysfunction, dyslipidaemia, and thyroiditis (Sivaraman et al., 2013).

2 Spine and back problems: in sciatica, spinal disk or a muscle in the buttock causes pressure on the nerves, resulting in pain and weakness in one or both legs. Spinal stenosis, a narrowing of the channel in the spinal cord, also can cause pressure on the spinal cord and weakness in the legs which could result in fall. Experts estimate that as much as the 80% of the population experience back pain. Americans spend at least $50 billion each year on back pain – and that's just for the more easily identified costs. Most cases of back pain are mechanical or non-organic – meaning they are not caused by serious conditions, such as inflammatory arthritis, infection, fracture or cancer (https://www.acatoday.org/Patients/Health-Wellness-Information/Back-Pain-Facts-and-Statistics).

3 Parkinson's disease: Parkinson's disease (PD) is a long-term degenerative disorder of the central nervous system that mainly affects the motor system which further troubles the movement where there is more risk in falling. Parkinson's strikes 50% more men than women. Doctors diagnose as many as 60,000 new cases each year. The average age of onset is 60 (https://www.floridahospital.com/parkinsons-disease-pd/statistics-parkinsons-disease-pd).

4 Environmental factors: poor lighting, strolling on slippery or uneven surfaces, alcoholism, medications, strokes, and injuries are some of the minor causes that may result in falling of the person (https://www.healthdirect.gov.au/what-causes-falls).

All the above statements conclude that during the old ages of the adults there will be more tendencies towards fall and procrastination of the treatment may even cause death of the person. If the treatment to these type of injuries are delayed it may lead to the laceration of the soft tissues causing blood loss and resulting in the coma state and sometimes even lead to the death of the person. If the person only faces bleeding due to a fall it takes approximately 4–6 hours to a healthy individual to recover. Inflammation starts within the first hour or two after injury, peaks within 1–3 days but lasts at least a couple of weeks. This phase is when you will experience swelling and some heat around your injury. After the person falls body starts preparing a proliferated scar tissue to heal the injury, this process will be going on for 4–6 months from the fall in elders. The above recovery process can prolong up to two years of time which is a very huge time to recover. In medical terminology, golden hour is defined as the to a time period lasting for one hour, or less, following traumatic injury being sustained by a casualty or medical emergency, during which there is the highest likelihood that prompt medical treatment will prevent death, It is well established that the patient's chances of survival are greatest if they receive care within a short period of time after a severe injury. The impact on the old people can be as following,

- 20–30% who fall suffers moderate to severe physical injuries like breaks, cuts, etc.
- Falls involving a hip fracture lead to 10–15% reduction in life expectancy.
- Loss of self-esteem and mobility leads to decreased activity and eventually inability to perform activities of daily living and shows embarrassment when they fall.
- Lacerations and fractures are some of most prominent impacts in adults.
- Intracranial bleeding in adults could lead them to death.

2 Existing solutions

There are many fall detection systems available in the market which can detect falls using the accelerometer sensors in the devices which people carry like mobile phones, wallets, etc. But we have designed a system that is more efficient in monitoring the old people.

The system proposed by Rougier et al. (2007) works based on the video analysis of the person using 3D head trajectory. In this project fall detection has been done using networked video cameras. At first this method views the head of the person as 3D ellipsoid and is projected onto an 2D plane and tracked through video sequence using an particle filter but later it is developed so as to directly track the 3D ellipsoid instead of the projecting it (Dai et al., 2010). Although tracking the person's head for detecting a fall is an amiable idea ,it has some disadvantages to be cited like , this system cannot detect the falls if the person is not in the vicinity of the camera, i.e., if the fall occurs inside the bathroom it becomes very hard to detect the fall. So, it can be regarded as major drawback in the fall detecting system and hence it is less efficient in detecting the falls of the elderly people.

Zhang et al. (2006) designed a system that is comprised of an accelerometer sensor embedded in a cell phone and connected to internet via internet using I-class support vector machine (SVM) algorithm for pre-processing and Kernel Fisher Discriminant (KFD) algorithm for precise calculations. The experiment system consists of a cell phone affixed with a box which contains accelerometer sensor and a micro controller unit that sends an UDP packet to the server via internet service. This is an effective system as per the technical perspective but in real time implementation it is not a preferable idea that to carry a mobile phone along with the accelerometer sensor and microcontroller elements. It causes discomfort to the old people (Zhang et al., 2006).

PerFallD system is designed by Dai et al. (2010). It is a design integrating phone, accelerometer and an apk file running in a mobile phone so that when the fall is detected the corresponding sensor values will be sent to the application using Bluetooth interface. The problem with these type of solutions is that it should be kept in a pockets of the clothes the person wears which will be a problem for elderly people as they wear a different dressings and a major problem is that, if the old people falls inside a place where the mobile phone cannot be carried like bathrooms, etc. this system will fail to detect the fall and rescue the person.

Sixsmith and Johnson (2004) has designed a button tapping fall detection system. In this system the person who falls has to trigger the alarm by tapping a button that is present in the form of a wearable. The main problem with this solution is that, falls of the person not only occurs due to environmental factors but also the health issues come into play. For an instance if the person falls onto the floor due to hypoglycaemia (reduced glucose levels in the body) then the person might be going into a trance like state where the person will barely able to move and in this type of situation we cannot expect the victim to tap the button and urge for a help.

Table 2 is presented with comparison of features from the existing system with the proposed one.

Table 2 A comparative views of features

Authors	*Wireless communication*	*Senses vibrations when falls*	*Video analysis*	*Used peripheral devices*	*Sends SMS or calls*	*Global monitoring*
Rougier et al. (2007)	✓	X	✓	X	X	X
Zhang et al. (2006)	✓	X	X	✓	X	✓
Dai et al. (2010)	✓	X	X	X	X	✓
Sixsmith and Johnson (2004)	✓	X	X	✓	X	✓
Proposed architecture	✓	✓	X	✓	✓	✓

3 Problem statement

We intend to build an affordable and frugal solution towards tracking the old aged people for their fall and to alert the concerned well in time.

4 Proposed architecture

4.1 Information about the hardware components

The accelerometer (GY-61) sensor and gyro (MPU-6050) sensor are attached to the proposed wearable's which must be used on both the hands at comfortable place. We have measured the rate of change of angle of GY-61 and MPU-6050 during various falls, multiple times and arrived at a Threshold value for each of the sensors respectively. The data from these sensors are acquired and is sent to the server via Bluetooth (HC-05) connected to the microcontroller (Arduino UNO R3).The server receives the data and plots it on a graph for analysing the data. If this data from the sensors reaches the predetermined Threshold value, then it makes a call for duration of 25 seconds and triggering an alert message as well to the concerned. Not taking chance, a buzzer sound is also raised in the home to alert the concerned, if he is at home. People have the tendency to leave behind the gadgets when they use the bathroom, if the elderly one who wears our system removes it before using bathroom and if he/she falls inside the bathroom, it would become troublesome. Many old people fall mostly inside the bathrooms because of the wet nature. Henceforth, we have got a method to catch this aspect of falling as well.

Table 3 Components cost

S. no	*Component name*	*Quantity*	*Cost*
1	Arduino UNO	2	$7
2	GSM module (SIM900A)	1	$15
3	Accelerometer sensor (GY-61)	1	$5
4	Gyroscope sensor (MPU-6050)	1	$10
5	IR sensor	2	$2
6	Bluetooth module (HC-05)	2	$5
7	Piezoelectric plate	1	$1

Two IR sensors are placed at the entrance of the bathroom and piezoelectric plates at different places of the bathroom. Both these components do not cost much and would certainly be beneficial. This data is also sent to the server via Bluetooth. When the person enters the bathroom both of these sensors detects the entry and stops the incoming data from wearable and starts transmitting data from the piezoelectric plates via Bluetooth. The moment when person falls on the floor where piezo is implanted, it would get the same alert signal triggered and thereby fall inside the toilets or bathrooms can also be tracked, without giving a chance for failure of the proposed system. The schematic of the proposed system with and transmitter and receiver aspect is presented in Figure 1 and Figure 2. The workflow of the proposed system is presented as Figure 3.

Figure 1 Schematic of the proposed system – transmitter (see online version for colours)

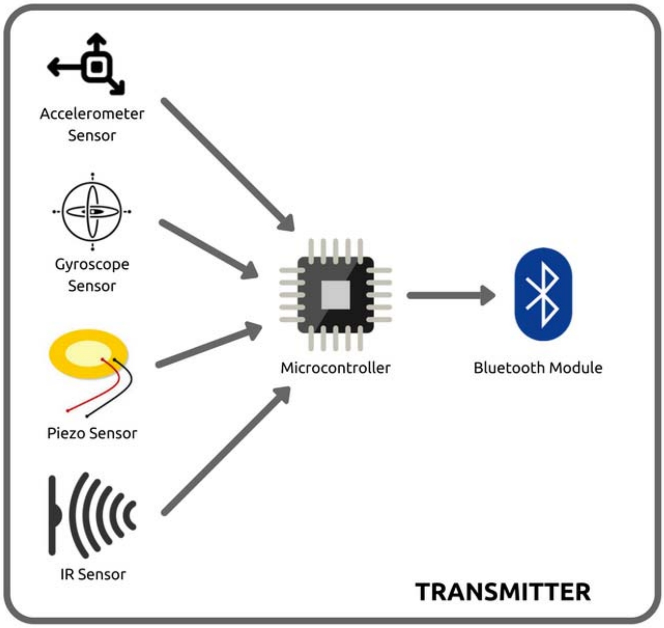
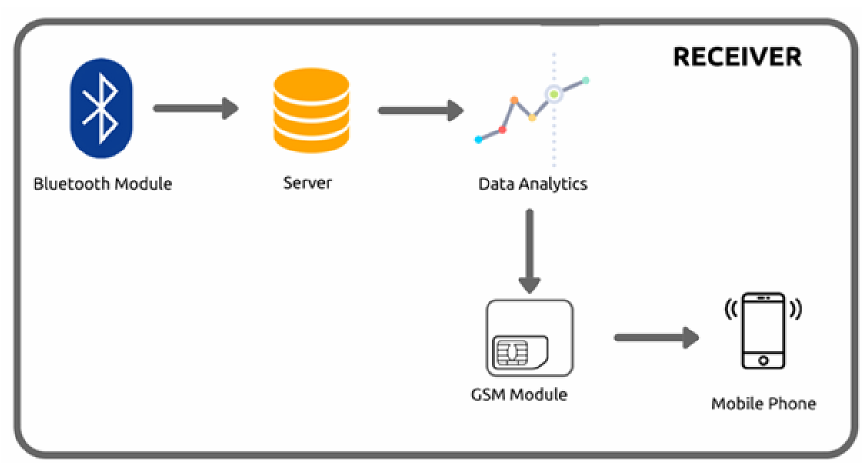
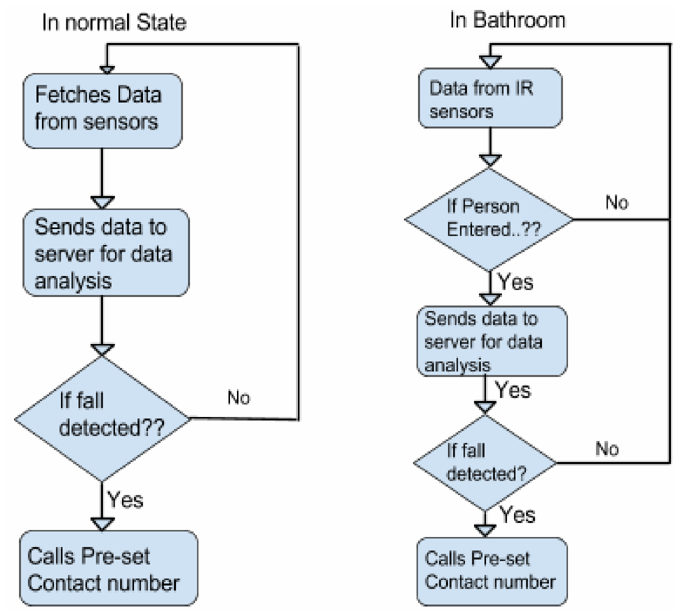


Figure 2 Schematic of the proposed system – receiver (see online version for colours)



The server receives the data and plots a 2D graph for analysing it. After getting the data, server calculates the change of analogy value from the sensor and if the change reaches the Threshold value, the alert will be raised. If not, the system shall keep monitoring the values from the sensors in real time. To get an idea about the prototyping cost, Table 3 is framed with the cost factors. It did not cross USD 60 to make the prototype.

Figure 3 Proposed workflow (see online version for colours)



4.2 Information about the software and data analytics

Data received from MPU-6050 and GY-61 is stored in two different arrays in the server which are analysed together when the person is outside the bathroom. Data from Piezoelectric plate is stored in another array which is analysed when the person enters the bathroom.

To analyse and draw the graph from the data obtained from different sensors, we used a python script. The following code a snippet does the work, as mentioned above the respective snippets.

Module for analysing the data from MPU-6050 & GY-61:

```
if i == 0:
   val_1.append(myData_bt)
   val_1 = val_1[-100:]
   x_diff=abs(val_1[99] - val_1[98])
else :
   val_1.append(val_1[99])
   val_1 = val_1[-100:]
if i == 1 :
   val_2.append(myData_bt)
   val_2 = val_2[-100:]
   y_diff = abs(val_2[99] - val_2[98])
else :
   val_2.append(val_2[99])
```

```
    val_2 = val_2[-100:]
  if i == 2:
    val_3.append(myData_bt)
    val_3 = val_3[-100:]
    z_diff = abs(val_3[99] - val_3[98])
    i = -1
  else :
    val_3.append(val_3[99])
    val_3 = val_3[-100:]
```

Module for analysing data from piezoelectric plate:

```
if (myData_ard != '' and char != 'x') :
  val_acc.append(myData_ard)
  val_acc = val_acc[-100:]
  diff_acc = abs(val_acc[99]-val_acc[98])
if (char == 'x') :
  if (val_piezo == [None]*100) :
    val_piezo.append(myData_ard)
    val_piezo = val_piezo[-100:]
  else:
    val_piezo.append(myData_ard)
    val_piezo = val_piezo[-100:]
    diff_piezo=abs(val_piezo[99]-val_piezo[98])
    val_acc.append(0)
    val_acc = val_acc[-100:]
```

After getting the data from both sets, the below code snippet is used for plotting the graph.

Module for plotting the graph:

```
def makeFig():
  if (char != 'x') :
    plt.plot(time_1, val_1, colour = 'r', label = 'x_angle',
    linewidth = 0.5)
    plt.plot(time_1, val_2, colour = '#67C117', label =
    'y_angle', linewidth = 0.5)
    plt.plot(time_1, val_3, colour = '#1735C1', label =
    'z_angle', linewidth = 0.5)
    plt.plot(time_1, val_acc, colour = 'k', label =
    'acc_angle', linewidth = 1.5)
  if (char == 'x') :
    plt.plot(time_1, val_piezo, colour = 'c', label =
    'Piezo_angle', linewidth = 1)
```

```
plt.grid(True)
plt.legend(loc = ‘upper centre’ , bbox_to_anchor = (0.5,
1.1) , ncol = 4)
```

When the threshold value is reached the below code snippet is used for sending message and a missed call to the concerned.

Module for sending message and call with GSM:

```
def gsm_func():
   print “Help...!!”
   winsound.Beep(800,500)
   gsm_data.write(‘ATZ\r’)
   time.sleep(0.5)
   gsm_data.write(‘AT+CMGF=1\r’)
   time.sleep(0.5)
   gsm_data.write(‘‘‘AT+CMGS=“‘‘‘+”+918919029787” + ‘‘‘“\r’’’)
   gsm_data.write(“ATD+918919029787;\r”)
   time.sleep(30)
   gsm_data.write(“ATH\r”)
   time.sleep(0.5)
   gsm_data.write(“Message from GSM I need your Help” + “\r”)
   time.sleep(0.5)
   gsm_data.write(chr(26))
   time.sleep(1)
```

5 Experimental setup

The proposed system is experimentally tested for its working with the components listed in Table. 3. The software is written by us to enable the hardware to function. The representation shown in Figure 4 reveals the setup.

Figure 5 represents the setup used towards acquiring data from the gyro sensor with the help of Bluetooth module. This is fixed in one of the hands of the person using this system.

Figure 6 shows the integration of the accelerometer to the system. We have also highlighted the piezo and IR sensors in same setup for the want of resource and experimental purpose. If implemented, IR and piezo combo and the control unit shall be framed as different unit and they are to be in the bathrooms for fall detection in the bathroom.

Figure 7 has captured the setup of the GSM unit which holds the responsibility of sending SMS and making calls during the fall detection.

Figure 4 Schematic of the experimental setup used with labels (see online version for colours)

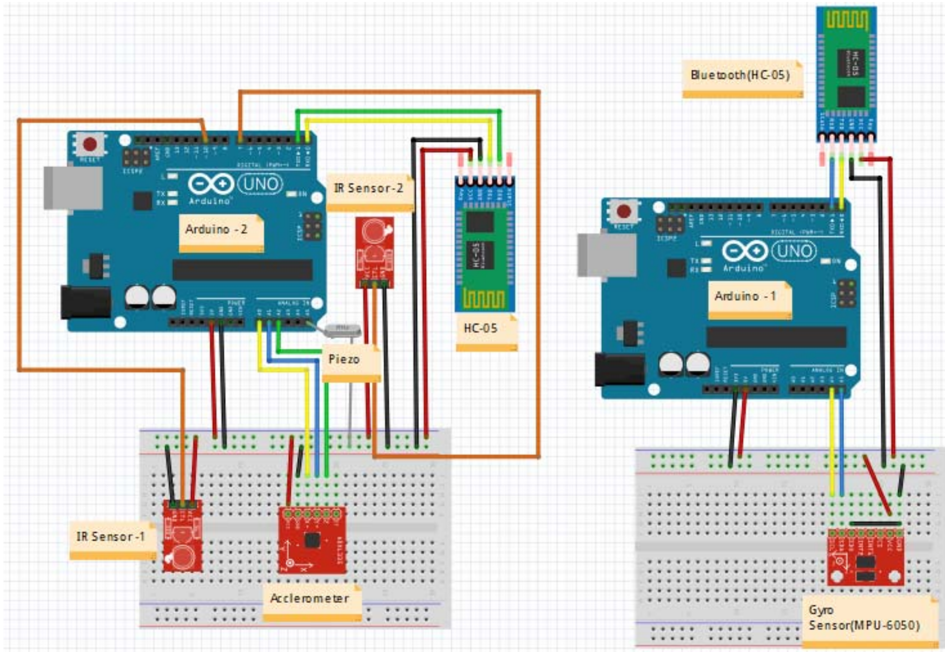


Figure 5 Sending data from the gyro sensor using Bluetooth module (see online version for colours)

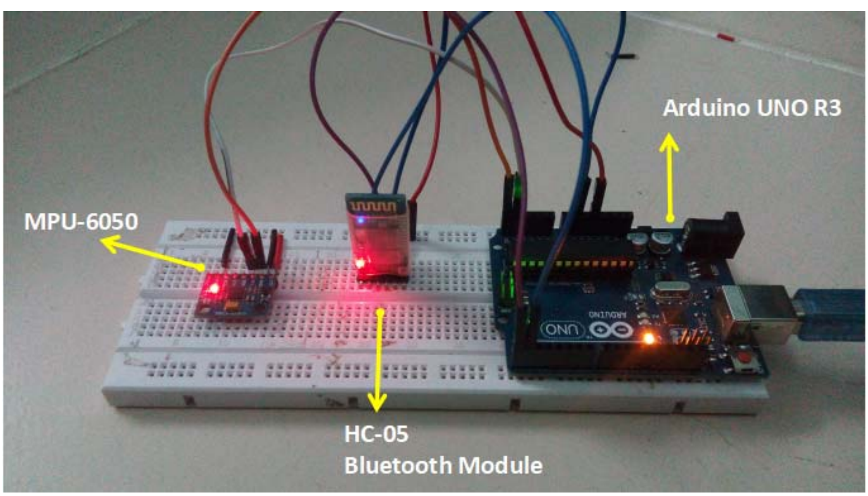


Figure 6 Sensing the fall of person using IR sensor and piezoelectric plate (see online version for colours)

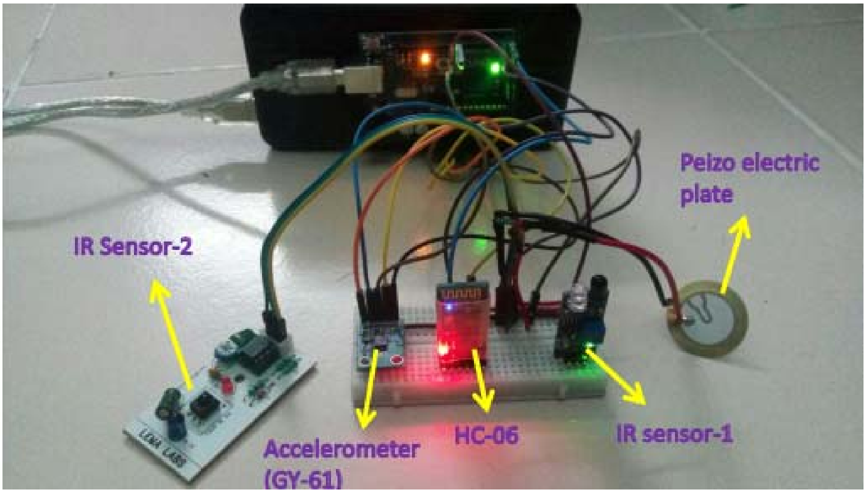
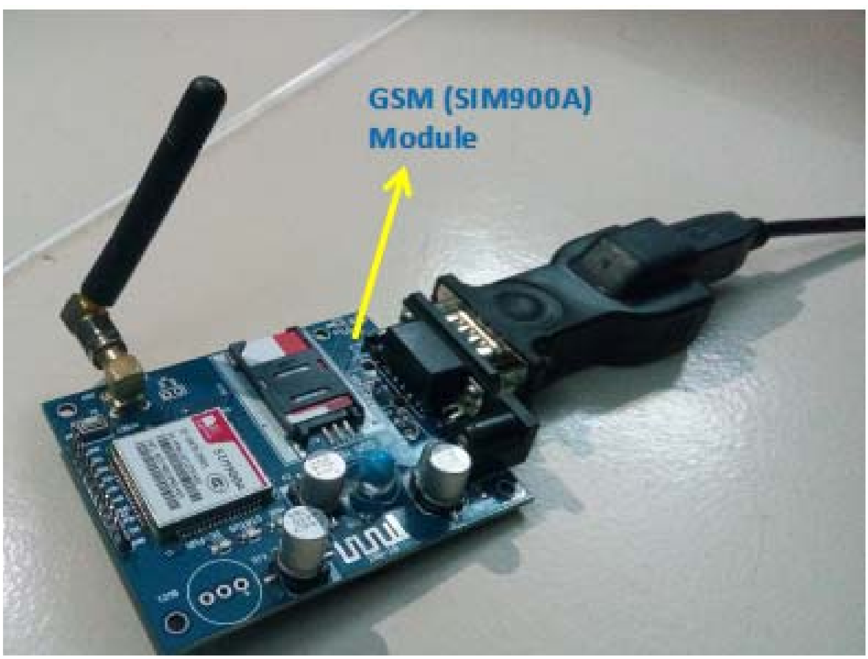


Figure 7 GSM module for sending the SMS and calling the concerned persons (see online version for colours)



6 Analysing the data from the experimental setup

The data received is to be analysed for getting some inference with which the entire system functions.

The MPU-6050 and GY-61 data is shown in Figure 8, which has been recorded real-time.

Figure 8 Data from MPU-6050 and GY-61 when the person is in normal state (see online version for colours)

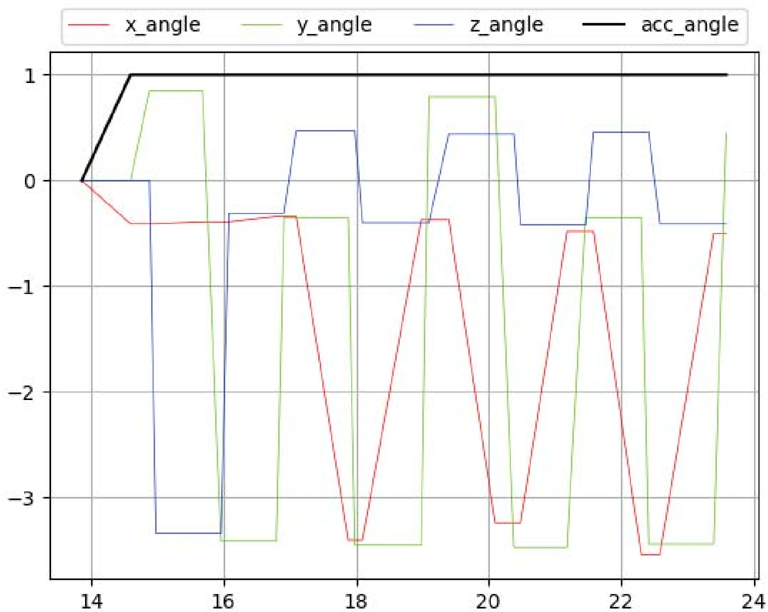
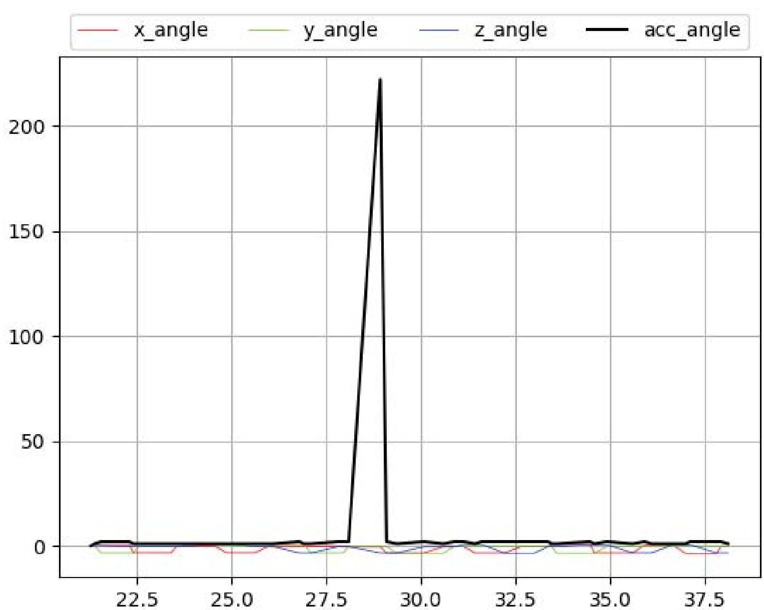


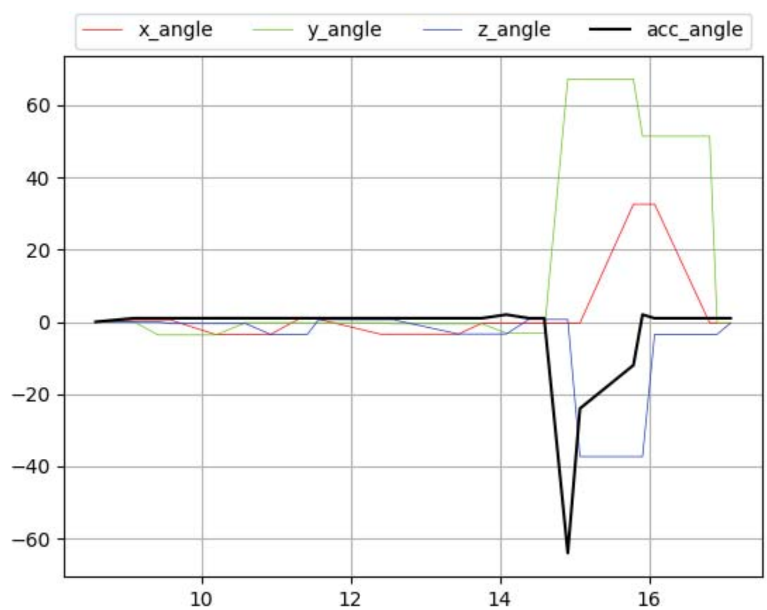
Figure 9 Data from MPU-6050 and GY-61 when only accelerometer data reaches the threshold value (see online version for colours)



From Figure 8, it has to be inferred that black line represents the data from accelerometer (GY-61). The data from the gyroscope is presented in three different axes as recorded. X, Y and Z axes are presented in the figure as red, green and blue respectively. The alert will not be triggered when only one of these two, i.e., GY-61 or MPU-6050 reaches threshold value. Both of these should reach the threshold to make the alert for fall. We made it in such a way that, if one of the hands alone swings or moves, it is not considered a fall. When both the hands face the impact of fall, the threshold is measured and appropriate action if initiated. Conditions like taking the food plate in hand or folding the clothes with two hands in action shall not generate as much threshold to initiate an alert and the system is trained appropriately to handle this case. Figure 9 represents the threshold being reached by only accelerometer (GY-61) alone whereas MPU6050 remains calm without generating the output. This case would not generate an alert as it would be an inappropriate alert.

Figure 10 makes it clear that, when the threshold is reached by both the sensors, as shown, the alert shall be generated which represents an identification of the fall.

Figure 10 Data from MPU-6050 and GY-61 when a fall is detected (see online version for colours)



Once the fall is identified, the message and the call shall be triggered to the registered user to take the necessary action. Figure 11 shown represents the message received, on the alert being generated. Also, the call which is made is also presented as a screenshot in Figure 12.

Figure 11 Alert message during the fall (see online version for colours)

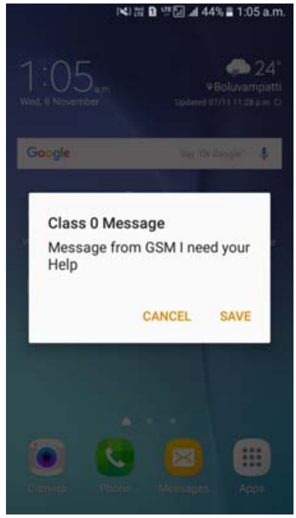


Figure 12 Alert call during the fall (see online version for colours)

When the piezo mode is enabled, i.e., when the user goes to the toilet or bathrooms, the sensors GY-61 and MPU6050 will be made inactive and its output is not of the interest to the system. If a fall is recorded in the bathroom, with the impact on the floor where we have planted the piezo plates, we shall be able to get the output voltage. Here, we have considered the trivial output voltages generated during the walk, bucket or component placement in the floor, etc. The impact generated on the fall would be much higher than the above mentioned scenarios. Figure 13 represent the data recorded during the normalcy state of the user.

The piezoelectric plate data is shown in Figure 13 during no fall state followed by the fall detection in the bathroom (ref. Figure 14).

Figure 13 Data from piezoelectric plate when the person is in normal state (see online version for colours)

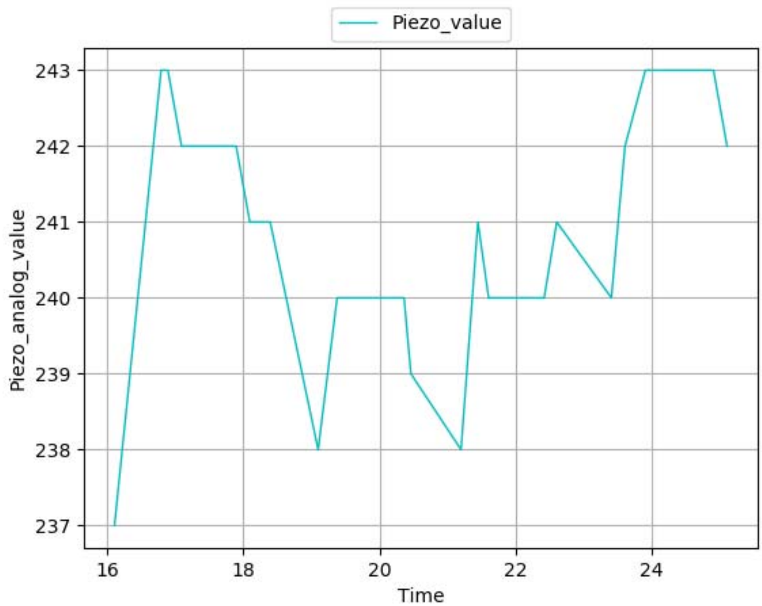
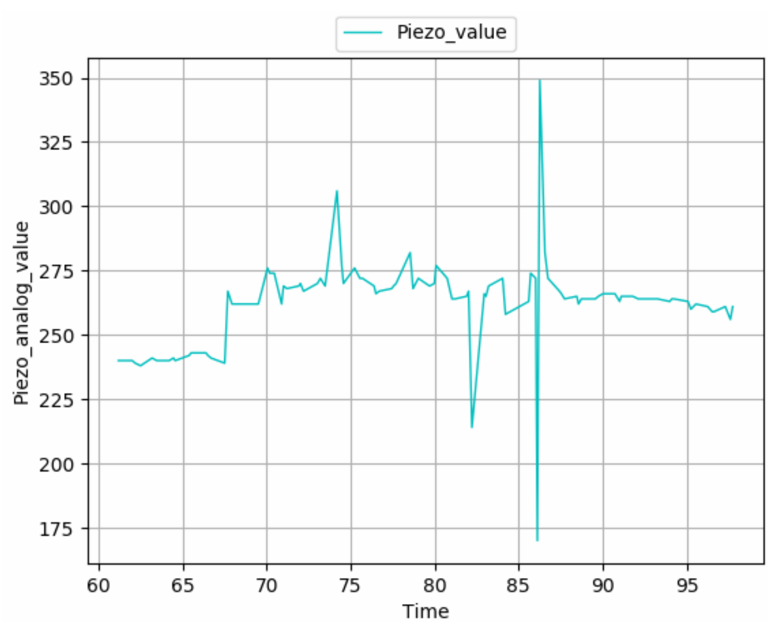


Figure 14 Data from piezoelectric plate when a fall is detected (see online version for colours)



7 Conclusions and future scopes

The way the technology has progressed tremendously in the past few years [4, 5]. From the literature and the personal experiences with friends and family one would definitely appreciate the need for this system. The system does the following tasks flawlessly:

1 Monitors the stability of the users (old aged).

2 In case of a fall, an alert shall be made to the registered user followed by an SMS.

3 In case the user is in the toilet or bathrooms, we have an alternate set up to track their fall inside bathrooms with piezo plates in place. The entry to the bathroom is well detected and the sensory data is disabled from the GY-61 and MPU-6050 sensors.

4 The data is recorded and is analysed real-time and the alert is generated.

5 The data can also be stored to understand the fall pattern of elders and can be used for research purposes as well.

6 IoT, sensors, data analytics – all these together have contributed to bring up a fully functional system.

7 The system would approximately cost a price ranging between 100 to 130 USD when made as a product.

8 The whole testing of the system is done in real time and the prototype is working as expected for the identified test cases.

From the improvement perspective, usage of Bluetooth can be averted with replacement of Wi-Fi. Machine learning can be made a major component in this system since it has a lot of scope. The location tracking and information about the location can be shared with the care taker and would be of a greater usage. Calling the ambulance based on heart rate monitoring can be done as an added feature.

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