Development of an SMS-Based Wearable Fall Detection System

Blessing Olatunde Abisoye, Jonathan Gana Kolo, Nafisa Opemi Jimoh, Opeyemi Aderiike Abisoye, Lukman Adewale Ajao
Computer Engineering
Federal University of Technology
Minna, Nigeria
b.abisoye@futminna.edu.ng, jgkolo@futminna.edu.ng, jbleenah@gmail.com, o.abisoye@futminna.edu.ng, ajao.wale@futminna.edu.ng

Abstract—**Fall occurs as a result of lack of physical fitness or loses of stability. Many lives have been shortened or deformed due to the problem of fall. The morbidity and mortality resulted from this problem is very rampant among the age group of 65 and above.Many fall detection devices have poor notification mechanisms in terms of message alertness and position.This device will assist to decrease the danger linked with fall and improves the living of an individual by reducing anxiety and disquiet before a fall. It also helps the user to be more buoyancy in living on-one self and continue with normal life activities. The device also gives fast communication between the fallen patient and the caretakers for speedy medical attention. This work developedan SMS based wearablefall detection system with good notification mechanism to ensure that fall victims receive instant medical attention when a fall occurs. The system employed the use of accelerometer and gyroscope sensors to sense the orientation of the victim. To get the geographical location of the user of the device a GPS module was deployed and to send SMS alert when fall occurs a GSM modules was employed. Fall detection algorithm was developed based on threshold technique. Threshold value was set to distinguish between normal body movement and actualfall. At the completion of the design, some tests were carried out. The device was able to detect daily dynamic movement activities, back fall and side fall whether to the right or left of the user. The device is worn around the waist of the user.**

Keywords- Fall, detection, gyroscope, accelerometer, SMS, Wearable

I. INTRODUCTION

Most permanent deformities and death experienced today can be averted if proper preventive measures are considered. The second leading cause of death by accidental or unintentional injuries is a fall [1]. When fall occurs the victim may be unconscious, which implies that the victim needs the assistance of someone or medical attention. Most old people prefer to stay alone without any physical contact with relatives and loved ones. Some of the aged people with critical health conditions are at risk when there is no care when fall occurs [2]. Dehydration, low body temperature (hypothermia), Pneumonia, muscle breakdown that can lead to kidney damage and failure known as Rhabdomyolysis and Pressure sores are all medical problems that can arise when a person who has experienced a fall stays longer on the floor without immediate medical attention[3].

Wearable computing originated in the mid of 1990 [4], this technology deals with the application of hardware and software to develop devices worn on the body. They are designed to be handy, less expensive, and comfortable with the capability of functioning without human interference [5]. Wearable computing technology has established itself cutting across various disciplines, which includes development of hand-worn terminals and smart clothing for military and industrial use. They perform related task with mobile phones and other hand-held systems and are seen to even outperform some of these devices [6]. This technology cuts across the medical field, which includes devices as blood pressure monitors, ECG monitoring and hearing aids. They are employed in life-threatening scenario like the pressure bandage system for monitoring scorpion sting [7]. Wearable computing is growing speedily and has become a pronounced area of application of embedded systems and tele-medicine to resolve critical health matters.

According to study, the researches indicated that not only detecting a fall is important but also the location, the time-to-fall, the direction, lying fall period and also the fall condition of the victim matters a lot [8].Researches on fall recognition and detection are still valid today [9]. Literaturesuggests that that, there are three methods applied when detecting a fall. These methods are wearable-based method, video-based method, and ambient-based method. Video-based methods were seen to be more accurate than ambient and wearable-based methods but the system suffers from high risk of privacy and high cost when implementing the cameras [4].

Afall detection system worn as a pendant was proposed. It was divided into two segments: a wearable device acting as a pendant and an application on the cell phone. The wearable device establishes a communication with the application on the mobile phone by the use of a wireless device known as Bluetooth device. Fall was detected by the use of a threshold value for both accelerometer and gyroscope embedded on the pendant. This pendant was worn around the neck. The pendant sends an alert message to the mobile application whenever a fall was detected. The limitation of this system is that the user location cannot be ascertained and Bluetooth has a lower range compared to GSM module and it did not include any form of sending the location user to the caregivers [1].

An autonomic fall detection system was proposed in [10]. The system focuses on how to use an Autonomic Healthcare Management System (AHMS) to detect fall based on IoT wearable devices and cloud computing system technology. The AHMS receives information from a local server which is connected to wearable devices, the system continuously monitors and analyzes the information gotten from the wearable device including other information contained in a Personal Health Record (PHR), a fall can be detected or other life-threatening events by creating a datasheet and training on the datasheet using k-NN algorithm. AHMS approach has a low cost and consumes less power with a wireless wearable device placed on the body. The limitation of this system is that any delay in detecting a fall by the local server can lead to death of the elderly.

A system based on smart button for long-term fall detection was proposed in [11]; this system accurately monitored the falling behavior of the patient, and sent a warning message online to the caregivers. The system comprised of three parts: data collection done by the accelerometer sensor attached to the human's body at the chest, data transmission using a Bluetooth device to transfer the received signal, data processing carried out by the mobile phone to detect if a fall has occurred. Support Vector Machine (SVM) classifier is used to judge a fall and non-fall from the data gotten, the SVM algorithm is adopted on an android phone. The system looks at eliminating the inconvenience brought by several sensors worn on multi-parts of the body. The limitation of this system is that Bluetooth is seen to have a lower range compared to GSM communication and the location was not sent.

A highly portable sensor-based system for human fall monitoring that uses three sensors (magnetometer, accelerometer and gyroscope) was developed. Using only accelerometer was found to be imprecise because of determining some activities of daily living as a fall. The sensor data are sent to the mobile phone via a Bluetooth communication. An android application is developed for receiving the signal from the sensors to processes the raw data to calculate the acceleration and orientation to detect whether a fall has occurred or not based on a fall detection algorithm. If a fall has occurred, the mobile phone sends out an alarm as a call automatically to the emergency contact. Seven fall activities and nine ADLs designed were to determine the threshold of acceleration for accurate fall detection and to verify the best body location. The limitation of this system is the use of a cellphone, without the cellphone, the caregivers cannot be contacted [12].

A fall detection system that uses adaptive Neuro-Fuzzy Inference System was proposed. This system was set to tackle the difficulty that comes with distinguishing a fall from other daily activities. Falls are detected using accelerometer and gyroscope embedded in a smartphone, which is used to collect the data from the person. The system could detect four different types of falls and nine daily activities. The smart phone gets the motion data with its in-built motion sensors and transfers the data to a computer which does the computations by differentiating a fall from a normal daily activity and sends an alarm message if a fall is detected. Communication between the smartphone and computer incurs time wastage, another limitation is that the computer has to call the caregivers and not the smartphone [13].

A fall detection system based on IoT with energy efficient sensor nodes was proposed. The device was to address the challenges that associate a fall.An IoT- based system was developed which takes advantage of wireless sensor networks, fog and cloud computing including wearable devices. Energy consumption of sensor nodes was also investigated in an IoT-based fall detection system. Also, a design of a customized sensor node was carried out. The fall detection system comprises of three parts: sensor nodes (3D accelerometer sensor, microcontroller sensor and wireless communication module), a gateway and a back-end system. The system focuses on energy consumption than detection a fall [14].

A fall detection system was introduced [15] using accelerometer and gyroscope based on smartphone with android operating system software, the system embedded the gyroscope and accelerometer sensors inside the smartphone. The smartphone technology used was to relieve the stress of the elderly being monitored 24 hours a day by people and thereby providing indirect monitoring. A call is generated and sent to the family members of the system when a fall is detected. No location was sent and a fall cannot be detected without a fall.

A system based on the evaluation of human activity and fall detection system was proposed using an android phone. The system uses an android phone with built-in sensors which include accelerometer and magnetometer with alarm notification system; these sensors were used to get proper and accurate recognition of falls and activities. Signal Magnitude Vector (SMV) algorithm was used to analyze the fall like events. Daily life activities like walking, standing and sitting were differentiated from a normal fall using different threshold values to solve the problem of false alarm activation. It observed that using external sensors give more accuracy than in-built sensors. The system requires a phone to be carried around and the study also focused on outdoor uses when the aged are going out for a longer period of time [16].

An enhanced fall detection system for the elderly person using consumer home networks that uses smart sensors to detect a fall was proposed. These sensors are worn on the body of the elderly person operating through consumer networks. The work was seen to have an accuracy of 97.5% and a sensitivity of 96.8% with a specificity of 98.1%. This system uses an accelerometer and smart sensors which includes humidity and temperature sensor which gets the signal from the user's body and sends the digital signal to the microcontroller for further processing. A customer interface is implemented in the system to monitor information in real-time, the system uses only accelerometer [9].

In summary, many researches have been done with respect to fall detection. The drawbacks of these researches are inability to differentiate between normal daily dynamic activities and actual fall of the user, delayin alerting the caregivers, problem of geographical location of the user and failure of wireless network. These cause delay in attending to a fall victim. When a fall victim is left unattended to, their condition can get worse and can result to a permanent damaged of body system or death. The aim of the proposed system thus focuses on developing an SMS-based wearable fall detection system thereby alerting their doctors and loved ones in time to receive immediate medical attention. The objectives of this work are; to design a fall detection system using sensors; to determine the geographical location at which a fall occurs by deploying GPS module and; to send fall detection notification alert to the caregiver by employing GSM module.

II. SYSTEMDESIGN

The system comprises of the following major components, a microcontroller (ATMEGA328), a combination of two sensors: accelerometer and gyroscope, a buzzer, false alarm button, GSM module (SIM 800L) and GPS module as depicted in fig. 1. The sensors get the input analog signals from the body of the user, the analog signals are converted to digital signals and sent to the microcontroller for further processing to distinguish a real fall from normal daily activities like sitting, jumping, running, sleeping using a fall detection algorithm based on a threshold technique. The input signals are compared with the threshold value to determine if a fall has occurred or not. If the threshold value is exceeded, the system waits for 5 seconds and activates the buzzer to sound an alarm and waits for an addition of 5 seconds before the message is sent to enable a deactivation button in case of a false alarm. When the deactivation button is pressed, the device restarts itself, if no deactivation button is pressed after 10 seconds the system considers it as a fall and the GSM and GPS module is activated to send an alert message and the location to the caregivers of the user. When the message and location are sent, the buzzer is activated to continue sounding an alarm in the environment in case there is a passerby that can easily assist and to assure the user that a message for help has been sent.

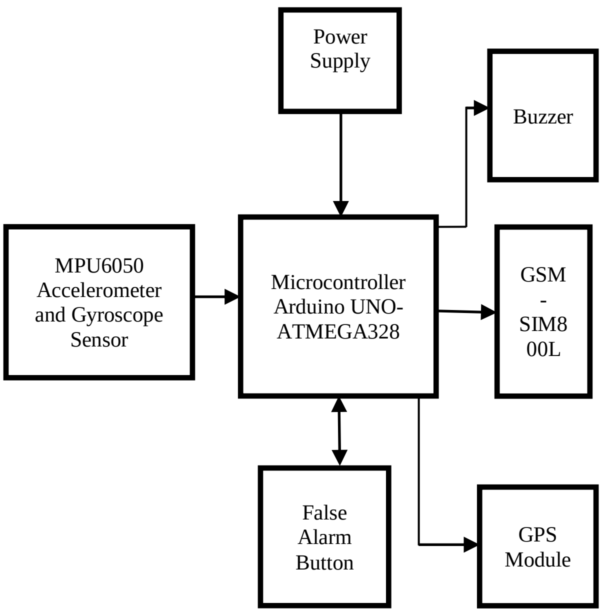
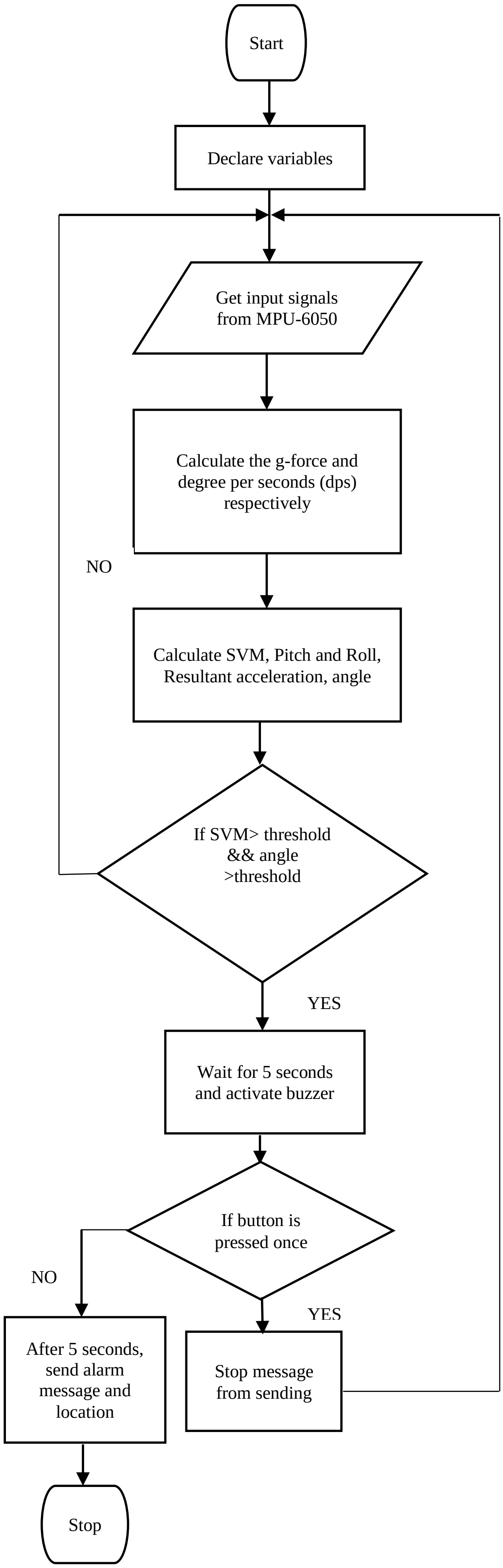


Figure 1: Block Diagram of the System

1. System Flowchart



2. System Algorithm

1. *Initialize*
2. *Measure Accelerometer and gyroscope*
3. *Compute the signal vector magnitude*
4. *Compute pitch and roll*
5. *Measure the angles (pitch and roll)*
   a. ***While** signal vector magnitude > threshold **and** Angle > threshold then*
      i. *Indicate a fall*
6. *Wait for 5 secs*
7. *Activate buzzer*
8. *Wait for 5secs*
9. ***If** !(deactivation button pressed) then*
10. *Send alarm message and location*
    i. *Continue alarm sound*
11. *End **if***
12. *End*

3. Computation of SVM and Angles

The angular velocity measured using gyroscope is given in degree per sec (dps), to convert the x, y and z axes raw values being measured to dps equation 1 is used.

$$\text{Angular velocity} = \frac{\boldsymbol{axes}}{\mathbf{131}} \quad (1)$$

For the accelerometer, the raw values for x, y and z-axis is divided each by the sensitivity scale factor as shown in the Equation 2, this is done to get the required acceleration in g.

$$\text{Acceleration} = \frac{\text{axes}}{16384} \quad (2)$$

Where;

Axes = x, y and z

Sensitivity scale factor = 16384 LSB/g

Sum vector magnitude (SVM) of the acceleration along x, y and z-axis, Equation 3 is used.

$$\text{SVM} = \sqrt{\text{Ax}^2 + \text{Ay}^2 + \text{Az}^2} \quad (3)$$

Where:

Ax = acceleration about x axes

Ay = acceleration about y axes

Az = acceleration about y axes.

4. Pitch and Roll Determination

To measure tilt using three axes of the accelerometer, changes in orientation are described by rotation in roll, pitch and yaw about the x, y and z axes respectively. The roll is the rotation along the x-axis of the accelerometer; the pitch is the rotation along the y-axes, which is the horizontal plane. The orientation with respect to gravity is calculated using Equation 4 and 5 these equations give the roll and pitch values of the accelerometer.

$$\text{roll} = \arctan\left(\frac{\text{ay}}{\sqrt{\text{ax}^2+\text{az}^2}}\right) \quad (4)$$

$$\text{pitch} = \arctan\left(\frac{\mathbf{-ax}}{\sqrt{\mathbf{ay}^2+\mathbf{az}^2}}\right) \quad (5)$$

The angles are summed up to get the resultant acceleration in equation 6.

$$\text{Accel\_R} = \sqrt{\text{pitch}^2 + \text{roll}^2} \quad (6)$$

5. Rotation Angles Using Complementary Filters

The values obtained from the accelerometer and gyroscope are used to calculate the rotational angles. Due to the noise and drift, that accompanies the use of accelerometer and gyroscope over short and long-term use, a complementary filter is used to achieve results that are more accurate and precise. It combines the data from the two sensors to give accurate orientation estimation. Gyroscopes are seen to drift away when they are in stationary position and are not reliable on short term while accelerometer contains noise. Equation 7 and 8 are the implementation of the complementary filters, the dT is the time between the iterations and roll/pitch equations gotten from the accelerometer. The orientation of the body is determined in the roll and pitch. The complementary filtercombines the angular velocity from the gyroscope and the orientation from the accelerometer.

$$\text{Roll} = b * (gX * dT + Roll) + (1 - b) * roll * \frac{180}{\pi} \quad (7)$$

$$\text{Pitch} = b * (gY * dT + Pitch) + (1 - b) * pitch * \frac{180}{\pi} \quad (8)$$

Where:

b – the filter parameter which is between 0 and 1

Roll – roll angle acquired from the accelerometer

Pitch – pitch angle acquired from the accelerometer

gX and gY are the angular velocity gotten from the x and y axes of the gyroscope.

The resultant of the roll and pitch obtained from Equation 7 and 8 is employed in Equation 9; this was done to get the threshold value for the angle.

$$R\_angle = \sqrt{Pitch^2 + Roll^2} \quad (9)$$

The first prototype of the system is shown in fig 2. The prototype was performed on an electronic board. It comprises of the Arduino, which is the microcontroller, MPU6050, buzzer and the GPS for sending the location.

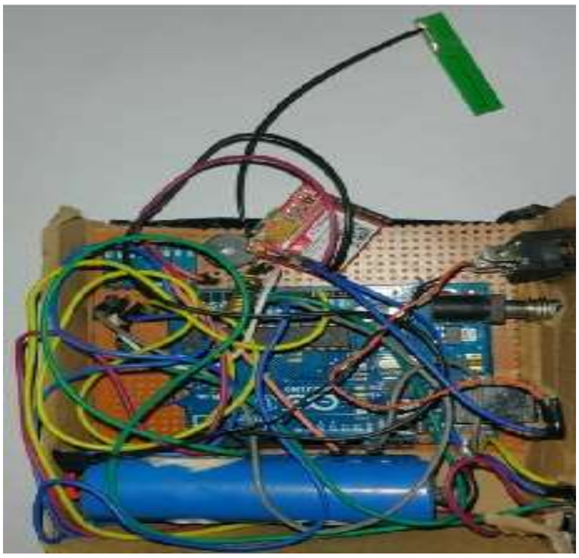


Fig. 2. Pictorial representation of the developed device

III. RESULTS AND DISCUSSION

The dynamic movement of the person is shown in Table I. The data was recorded for 15 seconds and it shows the inconsistency of the values in SVM. The data is seen to change as the patient engages in different activities and moves around, so the alarm is not triggered. Fig. 3 is graphically illustration of Table I. that depicts the range of the value and how the SVM changes. The dynamic movement can also be seen as the patient performing ADL (activities of daily living).

Table II shows the data gotten when the patient has encountered a fall and lies on his back, the patient is in a stationary position, the values gotten when the signal vector magnitude does not vary, the values are within the range of 1.06 to 1.08, after this observation, a threshold was set as proposed in [1] which was 1.06 for this work. Fig. 5 is graphical representation of Table 2, when the patient is in a standing position; the SVM is within the range of 0.98 to 0.99g, and the resultant angle increases until it becomes constant at around 80 dps. Before a fall occurred backwards, the SVM and angle reached a high peak of 1.87 although the values may change and was seen to settle at the range of 1.06 to 1.08g. The angle decreases till it was lesser than 25 dps and remained stable. With this observation, the threshold value was set. A fall usually occurs after there is a high peak in the SVM value.

To detect fall at the right or left side, the static state of the patient after experiencing a fall at both sides was used, the signal vector magnitude and the angle are considered. The threshold value set for the SVM is 1.02 to 1.04. Before a fall occurs in fig. 6, the user was standing; the range of values is from 1.02 to 1.04 like the threshold that was set,when the user falls sideways. The value went higher because a sudden movement occurred after being in a static position for some time.

Complementary filters are used to decrease the errors that come with accelerometer and gyroscope; the angles gotten were used to set the threshold for fall. After a fall is detected, an alert message including the location of where the fall occurred is generated and sent to the caregiver’sphone, which is shown in fig. 7.

TABLE I. DYNAMIC MOVEMENT OF THE USER

Times (s)	SVM (g)
1	1.07
2	0.85
3	1.06
4	1.16
5	1.01
6	0.9
7	1.13
8	1.02
9	0.9
10	1.06
11	1.03
12	1.06
13	0.98
14	1.00
15	1.28

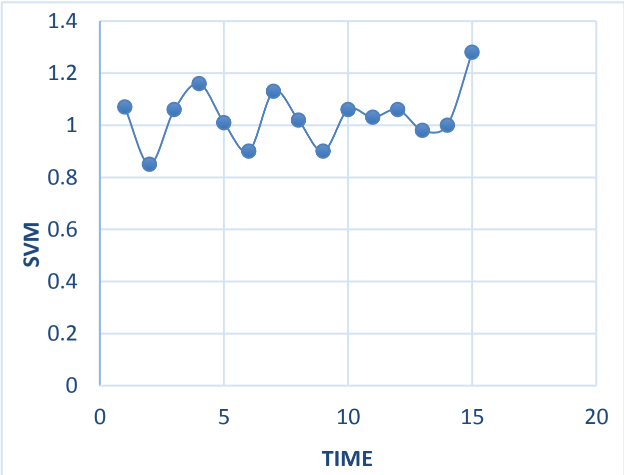


Fig. 3. Dynamic position of the user

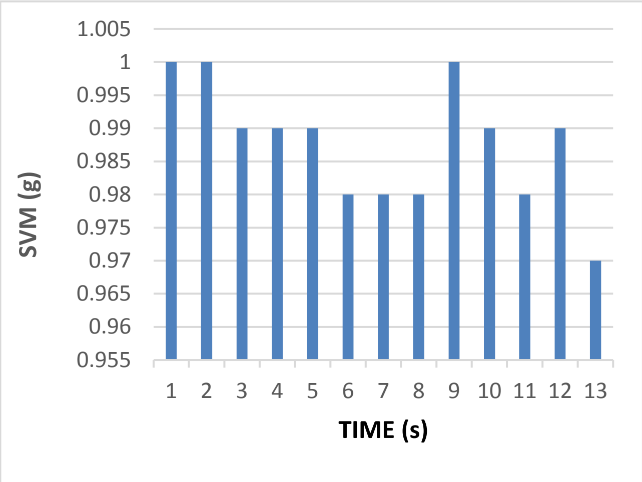


Fig. 4. User in standing position

TABLE II: THE SVM, RESULTANT ANGLE

Time (s)	SVM (g)	Resultant Angle(dps)
1	1.00	65.11
2	0.99	66.70
3	0.99	67.99
4	0.97	71.36
5	0.99	73.14
6	0.99	73.86
7	0.99	76.28
8	0.99	79.83
9	1.00	79.24
10	0.98	80.06
11	0.98	86.73
12	0.99	87.89
13	0.99	87.81
14	1.04	87.81
15	1.87	87.15
16	1.06	112.21
17	1.02	71.94
18	1.06	62.72
19	1.06	45.91
20	1.07	38.95
21	1.06	33.43
22	1.08	31.94
23	1.08	29.16
24	1.07	26.73
25	1.06	25.66

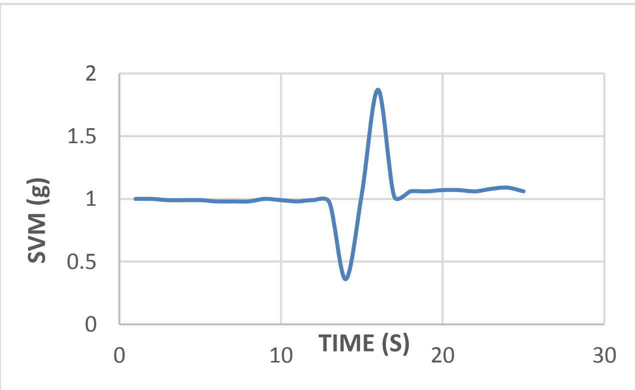


Fig. 5. Graph showing when a backward fall is detected

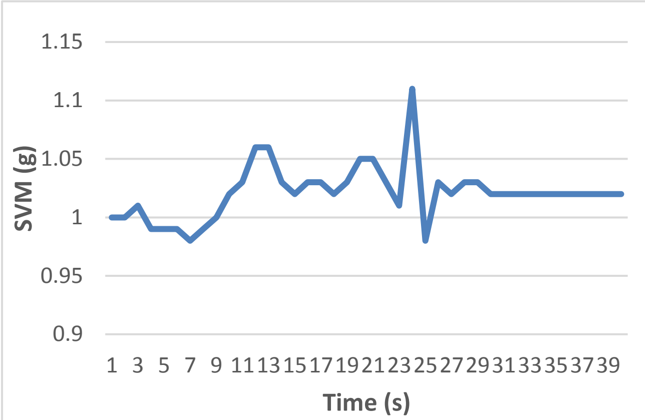


Fig.6. Sideways Fall Detected

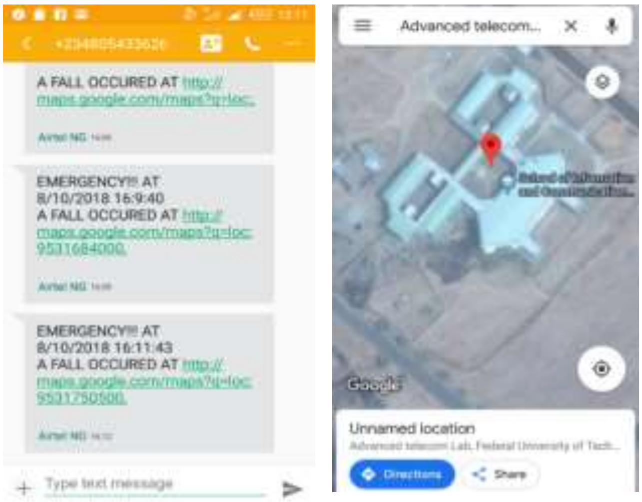


Fig. 7. SMS display on mobile phone

IV. CONCLUSION

In this paper, an SMS-Based fall detection system was developed, the system is worn around the waist the waist of the user, it detected both sideways and backward fall. The fall detection was based on the use of threshold algorithm, which included both Sum Vector Magnitude (SVM) and angles gotten using complementary filters.

The research gap bridged by this development is that at the time a fall was detected, the system was seen to get the geographical location of the user using the GPS instead of Bluetooth proposed in [1, 11, 12]and also send the required alert SMS to the caregivers via the GSM module instead of placing a call on the caregiver cell phone as proposed in [9, 11] which may result to difficulty in locating the user.However,further work needs to be done to improve the efficiency of the system in the case of detecting fall. A better way to eliminate the drift and inaccuracies accompanied with accelerometer and gyroscope should be taken into consideration

REFERENCES

[1] J. Santiago, E. Cotto, L. G. Jaimes, & I. Vergara-Laurens. Fall detection system for the elderly. *2017 IEEE 7th Annual Computing and Communication Workshop and Conference, CCWC 2017*, 1–4.

[2] N. Noury, "A smart sensor for the remote follow up of activity and fall detection of the elderly," 2002, pp. 314-317.

[3] S. C.Chavan& A. Chavan. Smart wearable system for fall detection in elderly people using Internet of Things platform. In *Intelligent Computing and Control Systems (ICICCS), 2017 International Conference on* (pp. 1135-1140).IEEE

[4] C. Randell. Wearable Computing : A Review Wearable Computing : A Review, May 2014.

[5] A. K. Singh& D. Agarwal. Wearable Computing: It's Application and Devices. *International Journal of Scientific & Engineering Research*, 2013, *4*(7), 568–572.

[6] S. Jhajharia, S. K. Pal,&S. Verma. Wearable Computing and its Application. *International Journal of Computer Science and Information Technologies*, 2014,*5*(4), 5700–5704.

[7] E. Olaye,M. A. Abiodun, O. M. Olaniyi, S. T. Apehn&U. U. Buhari. Development of a wearable pressure bandage system for scorpion sting. *Journal of Engineering Science & Technology*. *School of Engineering, Taylor's Univeristy*, 2018,*13*(7), 2195–2210.

[8] N. Pannurat., S. Thiemjarus., &E. Nantajeewarawat. Automatic Fall Monitoring: A Review, 2014 12900–12936.

[9] W. Jin, Z. Zhongqi, L. Bin, L. Sungyoung,, & S. R Simon. An enhanced fall detection system for elderly person monitoring using consumer home networks. *IEEE Transactions on Consumer Electronics*, *60*(1), 23–29 2014.

[10] A. T. Ozdemir, C. Tunc, &S. Hariri. Autonomic fall detection system. *Proceedings - 2017 IEEE 2nd International Workshops on Foundations and Applications of Self* Systems, FAS*W 2017*, 166–170.

[11] W. Zhuang, X. Sun, Y. Zhi, Y. Han, &H. Mao. A novel wearable smart button system for fall detection. In *AIP Conference Proceedings* (Vol. 1839, No. 1, p. 020075). AIP Publishing.

[12] A. Mao, X. Ma, Y. He,& Luo. Highly portable, sensor-based system for *Sensors* 17, no. 9 (2017): 2096.

[13] F. Abdali-Mohammadi, M. Rashidpour, &A. Fathi. Fall detection using adaptive neuro-fuzzy inference system. *International Journal of Multimedia and Ubiquitous Engineering*, 2016,*11*(4), 91–106.

[14] T. N. Gia, I. Tcarenko, V. K. Sarker, A. M. Rahmani, T. Westerlund, P. Liljeberg, & H. Tenhunen. IoT-based fall detection system with energy efficient sensor nodes. *NORCAS 2016 - 2nd IEEE NORCAS Conference*, (October).

[15] A. Z. Rakhman, L. E. Nugroho, Widyawan, & Kurnianingsih. Fall detection system using accelerometer and gyroscope based on smartphone. *2014 1st International Conference on Information Technology, Computer, and Electrical Engineering: Green Technology and Its Applications for a Better Future, ICITACEE 2014 - Proceedings*, 99–104.

[16] M. B. Rasheed, N. Javaid, T. A. Alghamdi, S. Mukhtar, U. Qasim, Z. A. Khan, &M. H. B. Raja,. Evaluation of Human Activity Recognition and Fall Detection Using Android Phone. *2015 IEEE 29th International Conference on Advanced Information Networking and Applications*, (January), 163–170.