A COMPARATIVE STUDY OF WEARABLE SENSORS FOR RELIABLE FALL DETECTION APPROACHES

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ABSTRACT:

Aged people are seldom prone to fall, due to their age and health condition. Unintentional fall can cause severe injuries which enhances medical care cost. Fall detection, notification and management have always posed a major challenge to the scientific community. Many advanced technologies are in use for fall detection, notification & management with different approaches like Video based, Acoustic/Ambiance based and Wearable sensor based with GPS & GSM enabled Tri-axial Accelerometers (MEMS), Gyroscopes and Magnetometers etc. This paper takes a detailed look into the different aspects of fall detection sensors, fall angles, sensitivity and reliability of wearable sensor based approach. Here we have conducted two experiments to detect and notify the fall based on two different wearable sensors. One MEMS accelerometer based approach and the other is inexpensive approach of Liquid based Fall Detection System (LFDS) along with GSM and GPS. The paper also compares the minimum fall angle which is required to happen at the event of fall. The use of GSM architecture is for information transformation (status of fall) through SMS and GPS is for location awareness. Certainly, accumulation of these technologies like location awareness, GSM and different fall detection techniques fulfils the requirements of delivering critical information to concerned people.

Keywords: Liquid Sensor Based Fall Detection System (LSBFDS), MEMS accelerometer, Dual Band GSM Modem, GPS Receiver, Bi-axial Mechanical inclinometer.

[1] INTRODUCTION

The event of fall is a very peculiar physical phenomenon that occurs frequently & causes dangerous injuries to the elderly people. It is most surprising & challenging task for scientific community to understand & manage. The risk of tolerating heavy injuries due to accidental falls creates major medical problems. When a fall occurs, the subject undergoes a large change in the position of the body starting of the fall to end of fall. The ability to differentiate these positions of the human body is very critical to the reliable fall detection system. The cause of factors that influences a fall can be put in two types. The internal factors like Gait, impairment of balance, central nervous system, vestibular
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dysfunction, weakness of muscles, impairment of vision, medical illness, ageing, orthostasis and influence of drugs etc are responsible for a fall. The external factors like environment hazards, low quality foot wares, & detrainment due to which slips occurs, syncope and drowsiness can also contributes to the event of fall. Broadly falls can be categorized in two types. Real fall and Virtual fall. A real/unintentional fall is one when actual body touches horizontally to the plane of the ground with high impact due to which injuries will be created. In virtual/intentional fall which refers to simply bending of the body where no injuries can occur. For a reliable fall detection system, identification/notification of the event of fall itself is a critical aspect. Such fall detection systems should not miss the identification of real fall and also must minimize the recognition of virtual fall. Generally fall detection systems are classified in to three types. 1) Vision/Camera based fall detection system: In which a video camera is used to monitor the real movement of the subject & an algorithm is applied to identify the body posture of the subject.2) Acoustic/Ambiance based fall detection system, here the identification of fall is based on the frequency component of vibrations produced by fall. 3) Kinematics/wearable sensor based fall detection system, in which accelerometers, gyroscopes or magnetometers are used for fall detection. The sensors are small & compact in size hence wearable. Such systems don’t require human involvement as they can be mounted wirelessly on the subject’s body. In this paper we have adapted this wearable sensor based fall detection method. Two different sensors i.e. tri axial accelerometer and liquid based sensors have been used. Separately we have identified the event of fall in the two approaches. We also tried to identify the minimum angle that is required for an event of fall to happen. Finally we have compared the results of two approaches for low cost, reliable fall detection method.

[2] RELATED WORK

Multi category human recognition system based on MEMS 3-axis accelerometer for very short distance communication through blue tooth [1]. For little larger distance, The Zigbee with different MEMS for physical activity monitoring have been reported in literature [2,3,4]. Farelle et al [5] have suggested the use of body area sensor network for body posture recognition. Yu-Jin Hong et al [6] reports the use of RFID reader as iGrabber with Bluetooth for fall detection system. MEM with Zig-bee wireless communication is well suited for indoor activity monitoring the adults is reported [7]. Some more realistic approach for Monitoring & controlling of physiological parameters by using SMS techniques with the aid of GSM & GPS network is also available in literature [8-10]. Certain occasion only location awareness of the patient/people becomes a vital tool using GPS network [11]. The use of such kind of technologies does not restricts to only medical care quality improvement but also facilitates other applications like plane optical tracking & measurement, train arrival detection system and some multiple message display systems [12-14]. But the fact that the fascinating uses of these technologies are really best suited for blind people whose daily life activity is quite different from normal people [15]. Networks of fixed motes are used in the home environment and location awareness based on MEMS accelerometer for fall detection [16]. Authors have reviewed this kind of tri-axial accelerometer for fall detection along with different sensors and systems [17]. Researchers have also conducted a survey of the various techniques and methods proposed for fall detection and also they have proposed their own technique for different body posters [18]. Vigneswara Rao et al [19] reports a new design smart fall detection which is known as e-SAFE which incorporated many technologies like Zigbee for indoor notification, SMS & e-Mail for outdoor notification along with GPS for location awareness. Raymond et al [20] presents the study of sensitivity and specificity of fall detection using mobile phone technology in which
accelerometer transmits signals to cell phone directly. A researcher reports the use of multiple accelerometers attached to different part of the body for sensing the fall and amount of acceleration change is calculated and simulated for different types of falls [21]. Olukunle Ojetola et al [22] says the machine learning, particularly decision tree to identify 4 types of falls in which accelerometer & gyroscope sensors have been used for differentiating between activities of daily living and falls with precision of 81% & recall of 92% best suitable for this type of application. The adaptation of multilayer perception neural network to capture movement signals of human body based on accelerometer was suggested for fall detection system [23]. Nicolas Thome et al [24] finds another new fall detection system that uses video sequences, in which a multi view approach adopted to detect the fall where human motion is modelled using layered hidden markov model (LHMM), the posture classification is performed by a fusion unit. Anastasios Doulamis et al [25] proposed a real-time computer vision based system which is capable of detecting the falls of aged people in rooms, using a single camera. A very inexpensive, new version of fall detection system using liquid sensor is also reported. The GSM & GPS technologies facilitate not only an alert SMS but also the information about location awareness. The paper also describes the identification & measurement of minimum fall angle [26]. This paper presents design and development of MEMS accelerometer based fall detection and notification system built on simple low cost 51 architecture microcontroller that uses GSM & GPS network to transmit the vital information such as status of fall & location awareness. It also describes identification & measurement of minimum fall angle that is required in the event of fall & is calibrated around the plane of ground & perpendicular to it.

[3] THE SYSTEM OUTLINE

Here, we have distinctly proposed two different reliable fall detection approaches based on two different fall detection sensor. One, a low cost GSM & GPS enabled MEMS accelerometer sensor based fall detection system and the other is very inexpensive GSM & GPS enabled liquid sensor based fall detection system. We have also attempted to measure the minimum fall angle that is required for the human body to occur the event of fall. Both systems make use of GSM architecture/network & its ability for mobile communication to transmit the fall status of the person to an authorized person’s cell phone. The systems also uses GPS technology for identification of location by taking Longitudinal & Latitudinal values of the geographical location of the GPS receiver and sends information in the form of SMS. The system also responds to SMS messages sent by the caretaker, verifies the authenticity and then sends a reply to SMS with which one can know the fall status of the elderly person. The two systems are built on 51 architecture family of microcontroller.

[4] METHODS AND MATERIALS

[Figure-1] shows the functional block diagram of the two proposed systems side by side. The hardware is built on 51-architecture. The other components are display unit, GPS modem, GSM modem, ADC, 3-axis accelerometer, Liquid fall Sensor etc. Many of the components are common for both systems. The details of sensors used for the fall detection are discussed as follows:
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Figure: 1. Functional Block Diagrams of two systems

1. 8051- Microcontroller.
2. Dual Band GSM Modem.
3. GPS Receiver
4. MEMS accelerometer fall sensor
5. Liquid fall detection sensor
6. Analog to Digital Converter (ADC)
7. LCD Display unit.
8. Emergency Switches

MEMS Accelerometer: (ADXL335) this is an electromechanical device, it will measure acceleration forces. There are two types of forces static, like the constant force of gravity pulling at your feet, or the other is dynamic - caused by moving/vibrating the accelerometer. By measuring the amount of static acceleration due to gravity, we can find out the angle of tilt with respect to the earth. By sensing the amount of dynamic acceleration, one can analyze the way the device is tilting.

Liquid Fall Detection System: It consists of a small glass bottle filled with a conductive fluid and two electrodes, inner and outer. The outer electrode is in the form of a wire mesh and the inner electrode is a straight wire. The inner electrode is longer than outer electrode and is always in contact with the fluid. The fluid level in the bottle is so adjusted that it touches both electrodes only when it is considerably tilted. The following dimensions have been obtained after the calibration to detect the fall. Bottle length = 5.7cm, Outer diameter = 3.2cm, Total volume of the conductive liquid = 25ml & volume of the liquid at the sensor level = 14ml as in [Figure-2]

Figure: 2. Shows design & development of an bi-axial mechanical inclinometer for fall angle measurement manually.
Mechanism of fall and its types:- Fall is a very peculiar physical phenomenon and it can occur while sitting, standing, walking & sleeping. Fall is of two types i.e., REAL FALL & VIRTUAL FALL. According to human body posture, the real/unintentional fall is one when the body impacts horizontally to the plane of the ground causing injuries. The virtual fall is simple bending of the body can also called as intentional fall.

Fall Angle Measurement: Fall angle is the minimum angle to which a fall occurs and this angle is with respect to the plane of the ground. The tilt sensors which are used to sense fall, in this proposed system are 3-axis accelerometer and Liquid based sensor. To identify the fall angle an apparatus which is known as bi axial mechanical inclinometer is designed & developed in our laboratory as shown in [Figure-2] & it is discussed as below. For experimentation, the accelerometer/liquid sensor is placed on the inclinometer horizontally with respect to the plane of the ground. Slowly, the inclinometer knob is rotated in clockwise or anticlockwise. In steps of $2^0$, the status of fall sensor is observed as shown in [Figure-3].

![Figure: Shows comparison of position of two sensors at which fall is detected](image)

The apparatus discussed above is used to find minimum fall angle. The results are tabulated in table (A) & table (B) for both type of sensors with fall status FS=0 or FS=1. The table 1 shows the MEMS sensor status for different angles from 0 deg to 30 deg in steps of 2 deg. Note the fall angle 20 deg for which the sensor status is 1 i.e., the sensor is identified the fall angle & this fall angle is same to all directions around the circular plane. The table (B) shown Liquid based sensor status for different angles from 0 deg to 45 deg in steps of 5 deg. At an angle of 24 deg, the fall is identified.

| TABLE 1. COMPARISON OF READINGS OF FALL SENSOR STATUS FOR DIFFERENT ANGLES |
|------------------|------------------|
| **TABLE (A)**    | **TABLE (B)**    |
| Angle of Fall    | Fall Sensor Show | Angle of Fall | Fall Sensor Show |
| 0 deg            | NO (FS=0)        | 0 deg        | NO (FS=0)        |
| 2 deg            | NO (FS=0)        | 5 deg        | NO (FS=0)        |
| 4 deg            | NO (FS=0)        | 10 deg       | NO (FS=0)        |
| 6 deg            | NO (FS=0)        | 15 deg       | NO (FS=0)        |
| 8 deg            | NO (FS=0)        | 20 deg       | NO (FS=0)        |
| 10 deg           | NO (FS=0)        | 25 deg       | YES (FS=1)       |
| 12 deg           | NO (FS=0)        | 30 deg       | YES (FS=1)       |
| 14 deg           | NO (FS=0)        | 35 deg       | YES (FS=1)       |
| 16 deg           | NO (FS=0)        | 40 deg       | YES (FS=1)       |
| 18 deg           | NO (FS=0)        | 45 deg       | YES (FS=1)       |
| 20 deg           | YES (FS=1)       |              |                |
| 22 deg           | YES (FS=1)       |              |                |
| 24 deg           | YES (FS=1)       |              |                |
| 26 deg           | YES (FS=1)       |              |                |
| 28 deg           | YES (FS=1)       |              |                |
| 30 deg           | YES (FS=1)       |              |                |
The geometrical representations of fall angle of two approaches are as shown in [Figure-4]. Whenever the event of fall occurs, the both systems sends SMS with FS=0 or FS=1 with the help of GSM network.

![Figure:4. Graphical representation of fall angle for MEMS & Liquid Sensor](image)

[5] SOFTWARE IMPLEMENTATION

The designed & developed systems are dedicated embedded systems; software was written in assembly language & stored in the memory of the controller. When power is switched ON the system comes to ON condition from RESET position then the program is executed and with respect to fall sensor status it displays the message locally on the LCD and also sends SMS to caretakers.

[6] EXPERIMENTAL RESULTS & DISCUSSIONS

The requirement of fall detection/monitoring systems has increased in the health care industry for aged people as their population is increasing day by day. For reliable fall detection system, the system must not miss the event of fall and identification of virtual fall must be minimized. This work is the extension of our earlier two works based on two different sensors. The experiments are conducted in the laboratory; the main aim was not only to identify the fall but also to find the minimum fall angle to which the sensor responds & the event of fall occurs and also to compare the results of two approaches. Hence, a 3-axis accelerometer ADXL-335 fall sensor and Liquid based fall sensor was used. The fall angle is measured on specially laboratory designed bi-axial mechanical inclinometer. The results are shown in table 1. The accelerometer is kept horizontally with respect to the plane of the ground on the inclinometer (below the feet of the doll). Tilt is given in the order of 2 deg in steps from 0 to 30 deg. From 0 to 18 deg the fall status which is denoted by FS = 0. At 20 deg of tilt, the fall status FS becomes 1 while it remained 1 up to 30deg. In case of liquid based sensor, the bottle filled with liquid is kept vertically up on the inclinometer, tilt was given in steps of 2 deg. From 0 deg to 20 deg, the fall status FS=0 i.e. no fall is detected. At 24 deg, the fall status FS = 1 i.e. fall is detected. Now if we compare the fall status (FS) of both sensors i.e accelerometer & liquid bottle it is 20 deg & 24 deg respectively. And the difference is 4 deg. For a any type of fall 4 deg would be negligible as compared to large fall angle. The system has expressed its ability with GSM network for fall monitoring and notification in case of medical emergencies along with location identification. It was also aimed to identify the fall status automatically from anywhere without any limitation of distance and make use of GSM mobile technology for communication and GPS for location identification & thus to enhance the communication range to unlimited. If the fall occurs, the system gets the geographical locations from GPS receiver to calculate the latitude and longitude of the place/location and prepares a concise SMS and sends the information through the GSM modem to the mobile phone of the doctor/care taker as in [Figure-5].
From the above discussions it is clear that the system is automatic, wireless, portable and communicates status of fall of a elderly people along with GPS position for location identification to the caretaker’s/doctor’s cell phone as shown in [Figure-6].

Figure: 5. Photographs of both experimental setup

Figure: 6. Photo of Cell phone with SMS sent by the Wearable unit

The details of this SMS are as follows:

- $FS=0$ (Fall is not detected)
- $FS=1$ (Fall is detected)

The GPS locations are:

- LAT=1718.8014.N (Latitude North)
- LON=07652.6666.E (Longitude East)

[7] CONCLUSION

This paper describes a comparative study of wearable sensors for reliable fall detection approaches designed & developed on 51 architecture, with GSM/GPS technologies. From the above discussion, it is clear that MEMS accelerometer fall detection approach has shown 20 deg minimum fall angle that is required for an event of fall and liquid bottle based sensor approach has given 24 deg minimum fall angle. For reliable fall detection approach, there is a difference of 4 deg minimum fall angle. But as far as a large fall angle of 20 deg is concern, the 4 deg difference would be negligible. Under only one exceptional case i.e. forward bending of the body, the body has tendency to bend forward but not to fall. This 20 deg of minimum fall angle can be applied to all directions except forward or front. The error factor is +/- 1 deg we considered for this purpose. Without loosing accuracy and sensitivity of sensors, thus, we felt that, the low cost liquid bottle approach suitable for this particular application. The cost of MEMS accelerometer is very high when compared to liquid bottle. The design & implementation of two approaches is done to sense, send, display and store the physical activity such as fall of elders. The system is simple, low cost and portable. The final ambition of the work is to reduce the cost of hospitalization & assistance and to increase patient’s quality of life. The system has functioned satisfactorily and can be used by elderly people or people...
suffering from variety of medical ailments & thus to improve medical care quality of adult people.

REFERENCES


Author[s] brief Introduction
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Sudhindra F. Received his B.E (E&CE) from Gulbarga University, Gulbarga and Master’s degree from KSOU, Mysore. He is working as Technical Officer-I in University Science Instrumentation Centre, Gulbarga University, Gulbarga since 1995. He has completed his M.Phil from Gulbarga University, Gulbarga. He has attended many seminars, workshops and conferences. His areas of interest are digital electronics, Embedded Controllers and Wireless communication. He has serviced and repaired more than 500 laboratory instruments.

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