



REVIEW ARTICLE

Technical Advances in Fall Detection System – A Review

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Abstract— Fall of patients and aged people is a serious issue. These kinds of falls may become fatal if unnoticed in time. The concept is to have a fall detection system which sends alarm to the concerned people or to the doctor, at the time of eventuality and helps to attend the patient in time. To minimize the fall and its related injuries continuous surveillance of patients and those who are prone to fall is necessary. Thus the requirement of a fall detector is increasing. In this paper we have reviewed history of fall detection system, different algorithms used to detect fall, different sensors used such as wearable sensor, combined sensors, ambient sensors and the application of each sensors is studied in detail. Image processing methods to detect fall are also studied.

Key Terms: - Fall detection system; Medical alarm; PERS

I. INTRODUCTION

Falls are common among elderly people. Day by day the number of falls is increasing in India; this is a result of change in the socio-economic status. According to survey done by Centers for Disease Control and Prevention (CDC), one out of three adults falls every year [1] [6]. Females have higher risk of falling than males [6]. Day by day the nursing cost is increasing because of falls. Based on data from 2000, total annual estimated costs were between \$16 billion and \$19 billion for nonfatal fall-related injuries and approximately \$170 million dollars [2]. Fall-related death rates in the United States increased between 1999 and 2004, from 29 to 41 per 100,000 population [2]. Falls do not only cause physical, but also severe psychological effects. History of falls can result in a higher probability of fall in future. The falls result in sustained psychological effects (fear, increasing dependence) [6]. The chances of unnoticed falls in the hospitals are more, when patients go to toilet. A low cost gadget which can detect unintentional falls can reduce this kind of complexities. All hospitals can buy the gadget and make the patients to wear it to reduce the injuries due to fall.

Organization of the paper: the section 2 discusses history and classification of technologies. Each type of technique is reviewed in the sections 3, 4, 5, 6, and 7. The references are listed in 8.

II. FALL DETECTOR

2.1 History

The fall detection system is popularly known as PERS (Personal Emergency Response system). The PERS was first designed and developed as “home alert systems” (Hausnotruf) in Germany in the early 1970s by Wilhelm Hormann [4]. It was programmed to send message when the remote transmitter button was pressed by the user. The transmitter was wearable and designed with the aim of helping elderly people staying alone. The cost of this gadget was \$795 [4]. The first prototype of a fall detection device was developed in 1998[5]. It had 90% success rate but specificity was very low.

2.2 General Block Diagram

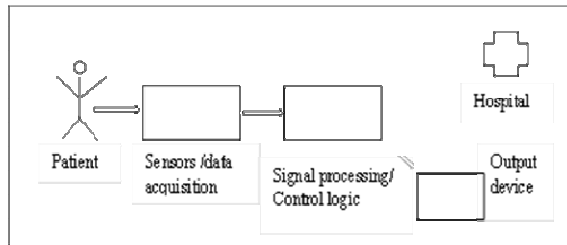


Fig.1. General Block diagram of fall detection system.

The general block diagram of fall detection system is shown in fig.1. The data acquisition includes collecting the signals from the sensors. The sensors may be wearable, floor sensors or camera. The signal processing unit compares the acquired signal to predefined threshold or runs image processing algorithms. The control logic makes decision and sends alarming signals. The output device may be computer monitor or LED or buzzer.

2.3 Different types of approaches

From the previous literatures existing technology for elderly care medical alarm systems can be broadly classified into five categories.

a. By using wearable sensors:

This approach is an application of embedded technology. Tri-axial accelerometer or gyroscopes or combination of both are used to access body posture of the subject. The sensors are placed on different places, such as waist, thigh, wrist, shoes. By using accelerometer of smart phones, unintentional falls are detected.

b. By using ambient sensors:

Ambient sensors are nothing but the sensors placed in the surroundings of subject. The floor sensors such as pressure sensors on mat, microphones, infrared sensors, microwave motion detectors are used to detect the fall. Neural network classifiers are used to classify daily activity and fall.

c. By image processing technique:

In this method camera is used to obtain the body postures. Various image processing techniques such as template matching, posture recognition, skeleton extraction, background subtraction, optical flow processing etc... are used to detect falls. The fig.2 shows general flow of image processing steps for fall detection [7].

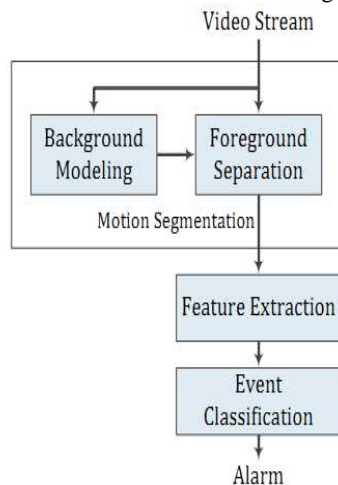


Fig.2 General Flow of visual fall detection [7]

d. Combined wearable sensor and ambient sensor:

Wearable sensor and camera/infrared sensors are used for data acquisition. The classifier algorithm fuses both the signals.

III. WEARABLE SENSOR FALL DETECTORS

Many of the researchers used tri-axial accelerometer as wearable sensor to derive the posture of subject. Gyroscopes, pressure sensors are other sensors. Thermistors, skin resistance sensor, ECG are also used to measure physiological parameters during fall [12]. The widely used wireless transmission protocols, to transmit alarm signals are zigbee [10] [12] and Bluetooth [9] [8], along with sms alert [14] [15]. The following paragraphs discuss works of a few authors. The common limitation of all experiments is the fall is simulated by healthy adults and soft mattresses are used to avoid injury. The impact and the acceleration values would be different during real scenario.

Qiang Li et al. [3] developed a fall detection system by using the combination of accelerometer (MMA7261QT) and gyroscope (IDG-300, ADXRS300) are used as sensor system. The sensors are controlled by a TI MSP430F1611 microcontroller. The different ranges of angles of body posture are measured by gyroscopes and accelerometer is used measure linear acceleration. The values measured by sensing system are compared with predefined values to decide whether there is a fall. The sensors are placed on thigh and chest region of subject. Several experiments are conducted to achieve accuracy of 92%.

Khalil Niazmand et al. [6] made a different approach by placing sensors on garment. The sensors are placed on a washable garment so that the patient can wear a fall detecting system without any discomfort. In its interior, there are eight acceleration sensors. The movements of the torso and the upper body can be detected by them. This data is read in the electronics unit and the fall occurrence is analyzed. If a fall is detected, an alarm is sent to a base station. The system is provided with energy by a rechargeable and removable battery. The electronics are installed within the garment in such a way that they can't be felt by the user. The sensors are encapsulated by washable material. The combination of sensors of the under arms provides the maximum of true-positive-rate (TP-rate) and the minimum of false-positive-rate (FP-rate). Threshold values are determined by taking consideration of several experiments. The algorithm developed had achieved a TP-rate of 97.50% (sensitivity) and a FP-rate of 3.08 %, which is equivalent to a specificity of 96.92 %.

S.Y.Sim et al. [8] placed accelerometer sensor in shoe. The change in acceleration is compared with threshold window for decision making. In order to determine correct location for placing sensor on shoes several experiments were done. Since different locations yield inconsistent accuracy, it was concluded that sensor at tongue of the shoe might yield good accuracy if sensing was fastened. The algorithm had a problem of detecting many fall like activities such as jogging, jumping etc... The achieved sensitivity was 81.5%.

A new algorithm was proposed by Ravi Narasimhan [9] to detect falls. The fall was considered as horizontal body posture. The acceleration values during walking and of lying posture were measured. The threshold window was computed by experimental values. The system was made to wait for some time, if the acceleration exceeded the threshold to detect fall. The specificity of 100% and sensitivity of 99% was achieved by placing the accelerometer on torso and by applying algorithm.

Chansik Park et al. [10] proposed fall detection and energy expenditure calculation scheme. The fall detection was done by determining body posture by accelerometer, gyroscope and two digital compasses. The direction of fall was determined by digital compasses. The energy expenditure was computed by regression between acceleration values and the energy consumed for the activity.

Marie Tolkiehn et al. [11] achieved 94.12% accuracy with their direction sensitive fall detection algorithm. The body posture was acquired by waist worn accelerometer and barometer pressure sensor. The angle and amplitude features were determined by keeping z axis of accelerometer aligned to body of the subject. The direction of fall was computed by measuring azimuth angle with respect to z axis.

Evaluation of autonomic nervous system for fall detection was proposed by Ronald Nocua et al. [12]. The data acquired from skin temperature, skin resistance and HRV are used for this purpose. By using SVM they managed to obtain sensibility=70.37%, specificity=80%, and positive predictor=73.8%. Many researchers worked to develop fall detecting system using built-in tri-axial accelerometer of mobile phone. Frank Sposaro et al. [13] developed an application for android phone. It asks the user to communicate when a fall is detected, messages are sent to social contacts if not replied. The emergency alarm is raised if both fail. Yi He et al. [14] considered smart phone as a waist worn device (as shown in fig.3) and developed an algorithm to send MMS (multimedia message service) to pre-selected contacts and the location is determined by GPS coordinate and Google map. Ying-Wen Bai et al. [15] made a similar approach to that of [14] by considering waist worn smart phone. The algorithm distinguishes daily activities from fall, by checking the change of acceleration in time intervals of two seconds. A novel system, tailored for smart phone, Fall-Down Detection based on Unrestricted Position (FDUP) was presented by Hsu-Yang Kung et al [16]. The FDUP algorithm monitors daily activity continuously and can detect whether the subject can get up or not.

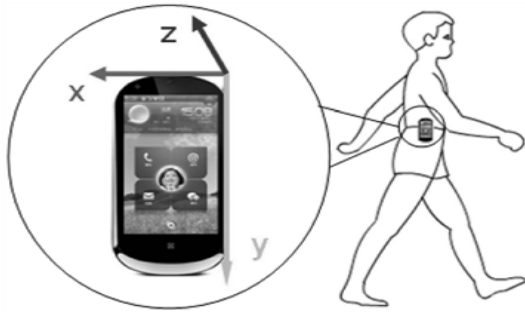


Fig.3 The position of waist worn smart phone according to [14]

Most of the research works on wearable sensor fall detector rely on tri-axial accelerometer and gyroscope as sensors. Yibin Hou *et al*. [17] developed a smartphone based classifier algorithm which detects the signal, transmitted via Bluetooth from waist/chest worn accelerometer. SVM (Signal Vector Magnitude) was employed to classify daily activities and unintentional fall with an accuracy of 92% and 6s of response time. A smart cane was designed by Mars LAN *Et Al*. [18] Contact pressure sensors and accelerometer embedded in the walking stick detect fall and signal transmission was done through Bluetooth.

Table.1 comparison of a few different approaches

Reference	Sensor	Sensor Placement	Measure of performance	Remarks
[3]	Accelerometer, gyroscope	Chest and upper thigh	Sensitivity: 91% Specificity: 92%	Inability to detect vertical fall
[6]	Accelerometer,	Washable jacket	Sensitivity: 97.5% Specificity:96.92 %	Activities like picking an object quickly, standing suddenly are detected as fall.
[8]	Accelerometer	Shoes	Sensitivity: 81.5%	Jogging, walking on stairs, jumping activities are classified as fall
[9]	Accelerometer	Anywhere on the torso	Sensitivity: 99% Specificity:100%	Failed to detect falling to right and left side with bent knees
[11]	Accelerometer and barometric pressure sensor	Waist	Accuracy : 94.12% Sensitivity: 87.77% Specificity: 85.24%	The height of subject affects the performance of barometric pressure sensor.
[12]	Thermistor: palm of non-dominant hand Skin resistance sensor: the second phalanx of the index finger and the third finger of the non-dominant hand. ECG electrodes		Sensibility: 70.37%, specificity: 80% positive predictor: 73.8%.	Physiological parameters are measured instead of body posture and acceleration. The study of autonomic nervous system during fall conditions
[13] [14]	Accelerometer of smart phone	Waist worn [14]	The application enables the user to set sensitivity according to the requirement	The challenge is to classify acceleration values when the device is worn different parts of body. Facilitated with GPS and SMS alert

IV. AMBIENT SENSORS FALL DETECTORS

The correlation between sound and height information is used to detect fall [19]. An array of microphones mounted vertically (along with Z axis) was used to collect sound information. After removing the noise by Wiener adaptive filter, energy of the signal was calculated over windows of 1s with 50% overlap between consecutive windows. Computed energy was compared to threshold, to detect fall. Height information was used to reduce false alarms. The relative height was computed by normalized spectrum cross correlation, and time delay between different microphone signals. The signal below 2 feet was further evaluated by the recognition procedure. This procedure gave 100% sensitivity but poor specificity; 5 false alarms per hour. The fall detector architecture developed by [19] is given fig.4.

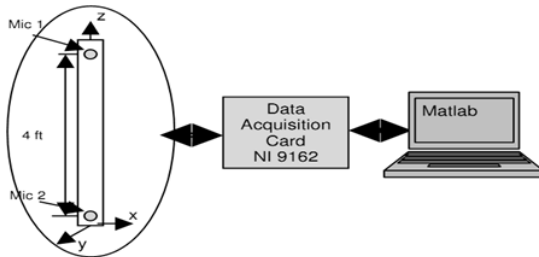


Fig.4 The fall detector architecture [19]

In order to improve the performance during noisy and reverberant environments, linear microphone array in [19]'s system was replaced by a circular array of 8 microphones by Yun Li et al. [20]. The sound localization and signal modeling is done by the steered response power estimation using phase transform (SRP-PHAT). Key design features of the array such as the number of microphones, the preamplifier setting and radius, were determined using a MATLAB array simulation toolbox. The system gave a better 3-D estimation of the sound location. The obtained classification results: specificity of about 90% and 87% sensitivity for a pilot dataset with 55 falls and 120 non-fall sounds. The detection performance could be improved by greater radius. The algorithm can be improved by beam forming technique. [21]. Mihail Popescu et al. [22] used vertical array of passive infrared sensors to replace microphone array which was used for data acquisition in their previous research. The PIR sensors get activated by infrared rays when a human being walks through the field of view. In order to avoid non targeted radiations infrared filters are employed (to allow only 10 micrometer wavelength). To differentiate between falls and other human activities such as walking, sitting on a chair, bending over etc., a pattern recognition algorithm based on hidden Markov models (HMM) is used. The classification algorithm needed a training session to classify daily activities and occurrence of fall. They got best result when it was trained for 10 minutes and 7minutes of training gave 85% accuracy.

Floor vibration and acoustic sensing system and a pattern recognition algorithm to discriminate between human or inanimate object fall events was developed by Dima Litvak et al. [23]. Vibration and sound signals from an accelerometer and a microphone respectively constitute input data. Vibration and sound features of fall events were extracted and classified based on a pattern recognition algorithm. Initially the system was trained by storing the signal features of various kinds of human and object falls. The input signals were de-noised by adaptive filtering, and then extracted time and frequency features were compared with trained data for classification. The system architecture is depicted in fig.5. A similar approach with sensitivity of 97.5% and specificity of 98.6% was done by Yaniv Zigel et al. [24]. Adaptive event segmentation algorithm detects suspicious event by comparing energy with threshold. The event segmentation algorithm was run over both sound and floor vibration signals separately to do classification of fall/non-fall events.

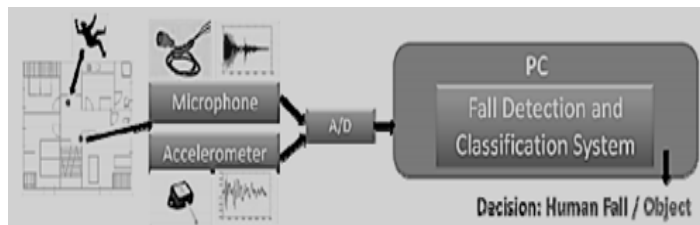


Fig.5 The fall classification scheme [23]

Doppler radar fall detection system was proposed by Liang Liu et al. [25]. Range control radar (RCR) and synchronized web camera were used for data acquisition. A window of short time Fourier transform detects

events when run over entire length of the signal. Support vector machine classifier distinguishes non-fall events from fall events. By several experiments they conclude that ceiling mounted RCR yield more stable fall detection results than wall mounted RCR but it is less sensitive to the fall direction and the wall mounted RCR gives fall direction.

Dual-technology wireless ambient sensors (microwave/infrared motion detectors and pressure mats) are used to track the movement of multiple persons and to unobtrusively detect falls when they occur [26]. A path-finding algorithm was used to simulate the movement of one or more persons through the residential area. For analysis, the sensor network is represented as an undirected graph, where nodes in the graph represent sensors, and edges between nodes in the graph represent an overlapping physical region in their area of sensitivity. Another undirected graph was used to represent the physical adjacency of the sensors (even where they do not overlap in their monitored regions). The two graphical representations enable the tracking of multiple subjects/groups within the environment, by analyzing the sensor activation and adjacency profiles. This technique allows isolating individuals/groups when multiple persons are present, and monitors for falls events. This method of fall detection proposed by Arni Ariani *et al.* yielded sensitivity, specificity and accuracy of 100.00%, 77.14% and 89.33%, respectively.

A stereo vision fall detection system developed by A.N. Belbachir *et al.* [27] consists of two optical detector chips, an FPGA, a digital signal processor and a wireless communication module. The information acquired by stereo vision is fed to FPGA for data preprocessing and stereo matching. Interpretation of real time data and fall detection are done by digital signal processor. The wireless communication module alerts caring institutions instantly. This system was designed for incident detection in private homes of elderly to foster safety and security.

V. FALL DETECTION BY IMAGE PROCESSING

Multi-view fall detection system was proposed by Nicolas Thome *et al.* [28]. The system consists of multiple cameras working independently in fuzzy logic context. The algorithm considers the images of each camera separately and then the features are merged. The human body is first detected by background subtraction technique. The motion and fall like events are modeled by layered hidden Markov model (LHMM). They prove that two cameras suffice the multi-view requirement. The multi-view system is depicted in fig.6.

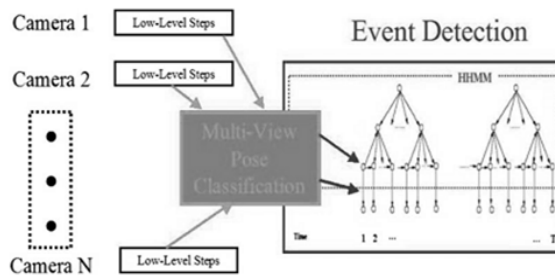


Fig.6 The multi-view system, designed by [28]

Fall detection by posture recognition is done by Miao Yu *et al.* [29] with a detection rate of 97.08%. The first step is background subtraction, similar to [28]. The recognized body posture is fitted in an elliptical window. Different postures of the human are distinguished by the information from ellipse fitting and a projection histogram along the axes of the ellipse (extracted features). Directed acyclic graph support vector machine (DAGSVM) does posture classification by analyzing the image features. The result of DAGSVM is then combined with derived floor information to detect a fall. The algorithm recognizes fall if the ellipse is lying horizontally for certain time.

Miao Yu *et al.* [30] developed a video processing algorithm which employs head tracking for fall detection. The three types modeling methods namely Single Gaussian model, Mixture of Gaussians, and Parzen window were compared.

Behzad Mirmahboub *et al.* [7] used the variations in silhouette area to detect fall. The video sequences that are obtained from only one camera. Stationary background is separated from moving object to find the contour of human posture. Extracted feature is fed into a support vector machine for classification.

Pre-fall detection system exclusively for hospital wards is developed by Bingbing Ni *et al.* [31]. Using video processing technique the system alerts hospital nursing staff when the patient tries to get up from bed.

VI. COMBINED WEARABLE SENSOR AND AMBIENT SENSOR FALL DETECTOR

Alan K et al. [33] combined tri-axial accelerometer and camera for data acquisition. The chest worn accelerometer gives vertical velocity profile, and the special markers placed on the area of human body of anatomical interest help the camera to track human activity. A simple algorithm which thresholds the vertical velocity and body posture tracking from camera is employed to detect fall. The algorithm separated daily activity from six types of falls with an accuracy of 100%. The fig.7 shows the overview of the system. The same research team Alan K et al. [32] developed ambient assisted wearable sensor fall detection system. The smart garment includes tri-axial accelerometer and vital parameter sensing units. The tri-axial accelerometer sensor is placed under arms of the garment. The sensor signal is communicated to stationery fall handler via wireless networks. The fall handler sends messages to care takers and to the care taker website. The fall can be detected only if the patient is in the 'sight' of fall handler.

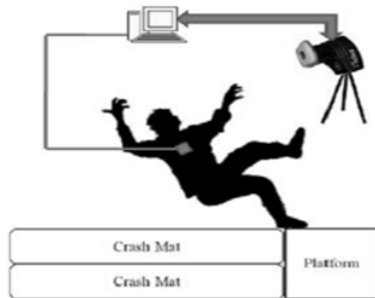


Fig.7. Overview of the system, designed by Alan K et al. [33]

Luca Della Toffola et al. [34] present preliminary work towards the development of a robotic platform, SENSOBOT. The robotic platform does monitoring of elderly people in the home environment and responds to fall. According to the author the data acquisition system constitutes wearable sensors, ambient sensors and camera. The continuous monitoring is done at the caregiver computer screen.

The research works done by M. Grassi et al. [35] and Antonio Fernández-Caballero et al. [36] are similar to that of Alan K et al. [33], the system uses wearable sensor and a camera for data acquisition. The acceleration values and recognized body postures are merged by the algorithm to detect the falls. Fernández-Caballero et al. [36] also discussed about ambient sensors such as passive infrared sensors for computer vision.

VII. CONCLUSION

The each type of approach above discussed has its own advantages and disadvantages. The main advantage of wearable sensors is portability and cost efficiency. But the disadvantage is discomfort of wearing the gadget and the elderly people may forget to wear all the time. The rest three approaches have the disadvantages of non-portability, limited field of view, vulnerability to noises from environmental objects and maintenance charges if servers are installed in smart homes. By considering all these we can conclude that the improved low cost wearable sensor fall detector and air bag system may give better solution for fall related injuries.

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