# Survey of Fall Detection and Daily Activity Monitoring Techniques

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***Abstract*—The risk of sustaining heavy injuries through accidental falls creates a major medical problem for elderly people. This paper conducts a survey of the various automatic techniques and methods proposed to detect falls and anomalies in movements of the elderly, through monitoring of their daily life activities. These methods can be broadly divided into three main categories: 1) Video Analysis Based; 2) Acoustic and Ambience Sensor Based; and 3) Kinematic Sensor Based. This paper critically analyzes the various proposed methodologies, comparing their strengths and weaknesses. We further propose our own technique for fall detection and monitoring of common daily life activities (walking, running, sitting, standing, and lying down), through a novel approach that provides a low cost solution and ensures the safety and security of the elderly without restricting them to confined surroundings.**

***Keywords:* Fall Detection, Activities of Daily Life Monitoring, Bioinformatics, E-health, Accelerometer, Computer Vision, Acoustic Sensors and Kinematic Sensors Based Analysis**

## I. INTRODUCTION

According to a press release on global population by United Nations in 2005 [1], the world population is expected to increase by 2.6 billion over the next 45 years. The global life expectancy, which was estimated at 65 years in 2000-2005, is expected to steadily rise to reach 75 years in 2045-2050.

Population ageing (where the share of elder people in a population increases relative to that of the youth) is most advanced in the highly developed countries. 20 per cent of today's population in the developed countries is aged 60 years or above, and by 2050 that proportion is projected to be 32 per cent, so that there will be two elderly persons for every child. Among the current developed countries, the overall median age (the age at which 50 per cent of the population is older and 50 percent is younger than that age) rose from 29.0 in 1950 to 37.3 in 2000, and is forecast to rise to 45.5 by 2050.

This constant rise in population ageing urgently requires changing the current agenda and focus of the developed countries. Their major concerns are rapidly shifting towards improvement of health care services to provide the increasing number of older people with a better standard of living. Modern technology can fulfill this aim along with greatly reducing the prices of the latest health care facilities.

Falls are detrimental events for the elderly and according to Noury et al [2], more than 33% of people aged 65 years and above experience one fall per year. Falls cause physiological and psychological damage such as injury, restricted activity, worry about living independently and fear of falling [3,4]. This is why reducing risk of patient harm resulting from fall is ninth in the fifteen National Patient Safety goals in China [5]. Mobility is a vital issue for maintaining independence for the aged; falls can reduce this mobility and pose a major health risk. Even the fear of falling can lead to reduced activity [6].

The conventional method for ensuring the safety of the elderly is through constant and vigilant observation of their daily activities under the eyes of hired nurses and caregivers. The elderly must be supervised and accompanied at all times, which places a large burden on the caregiver. Thus, one caregiver usually takes care of one or very few patients, which ultimately increases the personnel required in a nursing home. The cost of hiring such a staff privately at home or collectively in an elderly shelter is very high. Moreover, it is near impossible to completely supervise anyone and at times when the caregivers are not present; the elderly may fall and get seriously injured. Immediate medical attention would be required for them, but it may be delayed until the caregiver returns or receives knowledge of the accident. This raises a major issue of complete reliability. Thus, more cost effective and reliable options must be considered to provide safety and security to the elderly.

For this reason many new automated methods have been devised to monitor and manage falls using the latest available technology in order to reduce the dependency on the caregivers. These methods can be broadly classified into three types. (1) In computer vision (image processing) based method, real time movement of the subject is monitored through video and an algorithm is employed to determine the posture of the subject; (2) Acoustic based method detects a fall by the frequency component of vibration produced by the fall; (3) In worn sensor based method, kinematic sensors (accelerometers and/or gyroscopes) are used to distinguish a fall from activity of daily life (ADL). All of these approaches reduce the number of personnel required to monitor the daily activities of the elderly and also minimize the caregiver's efforts. Moreover, they ensure that proper medical care is urgently provided to the elderly, in case of any fall. Despite these benefits, the state-of-the-art in fall detection is quite premature and there are many problems. A great deal of research is still required in these approaches to come up with a system that overcomes all the drawbacks of the traditional approach and also can monitor multiple people simultaneously. In addition, a method of accurately predicting a fall (before it actually occurs) needs to be developed so that some fast preventive measures can be taken to avert any serious injury from occurring.

In this paper, we provide an extensive survey of fall detection techniques proposed under the umbrella of the above mentioned categories. Our intent is to highlight the advantages

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and drawbacks of each one of these existing methods in order to identify the potential areas of research in the domain of automatic fall detection. Besides highlighting the distinguishing features of the existing techniques, we also outline our perspectives regarding them. Based on our analysis, we propose a novel fall detection approach that tends to overcome the limitations of the existing methods. The proposed approach is a kinematic sensor based method that provides greater accuracy than the existing approaches. It also utilizes the GSM technology to send a distress message, in case of a fall, without the need for setting up a communication network as is the case with the existing approaches.

The paper is organized as follows: Section II to IV present the three existing major techniques of fall detection. Section V presents the proposed approach, Section VI concludes the paper, and Section VII gives the acknowledgements.

## II. Computer Vision Based Techniques

Computer vision based techniques provide an unobtrusive way of monitoring person of interest. These types of approaches provide a single setup that can be used to monitor multiple persons. Computer vision and video analysis based systems mainly consist of a set of cameras and a dedicated PC server. The cameras record video and send it to the PC. The PC then performs all other processing work like segmenting the individual from the background, feature extraction and then fall detection.

### *1. Relevant Work*

Cucchiara et al [7] proposed a system consisting of a normal online workstation and a fixed calibrated camera in an indoor environment. In this approach, first of all the background is identified. Foreground segmentation is then achieved by subtracting the background from the current frame. Shadows and ghost pixels are also processed to achieve better foreground segmentation. Projection histograms are used to estimate the posture of the person. If the person is detected to be in lying position and is static for too long, an alarm is generated indicating detection of a fall or system failure. Experimental results showed up to 90% success rate. This system cannot differentiate between standing and crouching.

Miaou et al [8] used a detection system consisting of an omni-direction camera and a computer server. An omni-direction camera has the advantage of capturing the whole 360$^{o}$ simultaneously in a single shot. This way the problem of conventional cameras of blind spots has been removed. In this approach, a clean background is first obtained. After that, the foreground of interest is obtained by subtracting the clean background from the current image. After removing noises from the picture, a rectangle enclosing the object is created. The height to width ratio of this triangle is used to detect falls. The threshold value in this system is customizable depending on personal physique. The experimental results show a sensitivity of 78% without personal information that increased to 90% with personal information. The drawbacks of this system are that the monitored individual needs to give his personal information, such as height, BMI index, etc. This increases the infrastructure required to implement this system.

Anderson et al [9] used a system consisting of a single camera and a computer. In this approach, video is recorded at 3 fps and then the individual’s silhouette is segmented from the background. This is done by first statistically modeling the background and then segmenting the human, based on color information. The brightness feature is also used for the detection and removal of shadows. After the silhouette is obtained from the frames of the video, a feature is extracted to determine a falling activity. The feature extracted is the width to height ratio of the bounding box of the silhouette. Experiments show encouraging results, although no exact figure is stated. This approach has certain shortcomings, such as using only a single feature to make decision and a single camera which limits the viewing angle of the individual, and it has a limited range of experimentation.

Nasution et al [10] proposed a system consisting of a fixed camera and a PC. The first step in this approach is segmenting the foreground. It is done by subtracting the background from the current frame. The next step is the feature extraction process. The features extracted in this approach are the horizontal and vertical projection histograms of segmented foreground and the angle between last standing posture with current foreground bounding box. As a final step the falling speed is used to infer real falling events. A recognition rate of about 90% is achieved in the experiments. The occlusion problem, which is obstruction of the individual by some other object, (caused due to a dynamic background) exists in this approach. The possible blind spots are also a major concern due to the use of a single camera.

Huang et al [11] used a detection system composed of a computer server and distributed cameras. The distributed cameras are used to capture images from different places in a house and then the computer server is used for fall detection. In this approach an adaptive background model is established and then it is subtracted from the current picture to obtain a segmented foreground. After that two features are extracted from the segmented picture. The first feature is known as ‘α’ and it is the aspect ratio of foreground object’s bounding box. When a person falls or lies down, its value gradually increases. The second feature is known as ‘β’ and it is the root mean square value of difference of widths and heights of the bounding box of two consecutive frames. This value changes rapidly if a fall occurs and slowly if a person lies down. Initially only feature ‘α’ is used to recognize a fall which was able to give a 52% fall recognition rate. By adding the feature ‘β’ and then considering surroundings and personal information in the system, a success rate of 78% and 85% are achieved respectively. The drawback to this approach is the requirement of the setup to not be occluded in a certain scope and the subject wearing tight clothes or having marks on their body. Both of these conditions are not possible in a normal dynamic living environment.

Foroughi et all [12] proposed a new method for fall detection based on human shape variations. Several new features extracted from segmented foreground are used to detect fall and other actions. A combination of best-fit approximated ellipse around the human body, projection histograms of the segmented silhouette and temporal changes of head pose are used to obtain useful clues for detection of different behaviors. Extracted feature vectors are fed to a multi-class Support Vector Machine for precise classification of motions and determination of a fall event. A reliable rate of 88.08% is achieved in the experimentation. Although this approach does not need tight clothes to be worn, the system has restricted functionality due to the occlusion problem.

### *2. Discussion and Perspectives*

All the approaches discussed above have their advantages and there are some shortcomings as well. One big advantage of this kind of approach is that the person does not wear any device on his body. These approaches are totally unobtrusive. Also multiple persons can be monitored using a single setup, although this area needs further research. Another plus point of these approaches is that communicating the alarm to the concerned person is also very convenient as only an internet link is required.

First and foremost disadvantage of the above approaches is its very limited range of operation. Due to the fixed nature of the camera, it can only be used in indoor environments. Elderly people going for a walk cannot be monitored. This is a real area of concern as walks are generally advised for elderly people and if they suffer a fall during that time, it can lead to fatal consequences. The infrastructure required for such approaches is expensive for reliable detection as a camera needs to be installed in every room and other places in the living environment. Connecting the cameras to a single dedicated server also requires some kind of communication link to be established. All these factors contribute to increasing the cost involved for deploying such a system. Other limitations include camera blind spots and occlusions due to the presence of a dynamic environment.

## III. Acoustic & Ambience Sensors Based Techniques

Another domain researchers have looked into is acoustic and ambience sensors based technique to detect falls. Systems based on this class of techniques may include infrared sensors, microphones or vibration sensors. The results obtained from related studies show the proof of concept. Acoustic techniques also provide an unobtrusive way of monitoring persons of interest, just like the computer vision based techniques. The hardware and infrastructure required for such techniques is relatively simple and inexpensive, in most cases, when compared to computer vision based methods. Acoustic and ambience based systems consist of a set of acoustic or ambience sensors and a dedicated PC. The sensors gather data and send it to the PC for analysis. The PC, based on certain conditions and thresholds, decides on the detection of a fall event.

### *1. Relevant Work*

Sixsmith et al [13] have developed a system known as Smart Inactivity Monitor using Array-Based Detectors (SIMBAD). This system is based on low-cost, array-based infrared sensors. The system's infrared sensors can locate and track a thermal target within sensor's field of view. This system considers two distinct characteristics of observed behavior. Firstly, it analyzes target motion to detect fall's characteristic dynamics. Secondly, it monitors target inactivity. Falls are detected based on these characteristics. Field trials have been carried out with a prototype and they indicate that SIMBAD could significantly enhance the functionality and effectiveness of existing monitoring systems and community alarm systems. This system has limited application due to limited range of infrared sensors. Outdoor monitoring is also not possible at all. Alwan et al [14] proposed a design for a floor vibration-based fall detection system that is completely passive and unobtrusive to the resident. The system uses a special piezoelectric sensor coupled to the floor surface by means of mass and spring arrangement. Successful differentiation between the vibration patterns of a human fall from other ADLs and from the falls of other objects is achieved. Laboratory tests were conducted using anthropomorphic dummies. The results showed 100% fall detection rate with minimum potential for false alarms. The drawback of this approach is the very limited range of the vibration sensor; i.e. 20 feet only. Moreover, the vibrations cannot be detected on all kinds of floor materials.

Popescu et al [15] developed a method of fall detection based on an array of acoustic sensors. The loudness and height of the sound are used to recognize a fall. Two microphones are mounted on the vertical z-axis and are placed 4 meters apart. The first step in this technique is noise removal. Then, fall detection decision is made based on the energy of the signal received by both the sensors. A 70% recognition rate is achieved with no false alarm. By adjusting the system, a 100% success rate is achieved but with a penalty of 5 false alarms every hour. This system can only be used in indoor environments. Moreover, the false alarms encountered are too many for the system to be a reliable one.

### *2. Discussion and Perspectives*

One advantage of these types of techniques is the relatively simple and inexpensive hardware when compared to the computer vision based techniques. Moreover, systems based on these sensors are passive and unobtrusive. This type of approach also eliminates the privacy issues that some people may have with the computer vision based techniques. Multiple persons may be monitored with these techniques but a huge amount of research is needed for that.

The acoustic based approaches discussed above show that although these techniques can be used, they are not well suited for a normal living environment. The reason being that excessive noise is present in a normal living environment which degrades the signal obtained from the sensors. These systems also have limited range as they can only be installed in indoor environments.

## IV. Kinematic Sensors Based Techniques

Kinematic Sensors based techniques are classified as the most preferred and practically applicable class of fall detection techniques. Many variants exist in this domain. Some use accelerometers while others use gyroscopes and some few use both to distinguish falls from ADL. The data gathered by kinematic sensors is either processed by a remote PC or on-board by a microcontroller. This class of techniques overcomes the problem of range of operation. As it is a standalone wearable device, the person of interest can go wherever he wants and still be constantly monitored.

### *1. Relevant Work*

Bourke et all [16] used a tri-axial accelerometer to detect fall and certain ADL. In this approach, the accelerometer is placed on thigh and trunk to determine the optimal place for the accelerometer. Simulated falls were performed by 10 young volunteers and ADL were performed by 10 elderly persons. A single threshold is calculated for fall detection. 100% sensitivity is achieved but a few ADL are falsely identified as falls. The study also showed that trunk is a better place than thigh to place sensors.

Tong et al [17] used an accelerometer and a gyroscope to detect acceleration and orientation of the subject for detecting falls. The data from sensors is processed locally and then distress call is sent wirelessly. A button is used to eliminate false positives (system recognizes daily activity as a fall). The system is attached to chest or back of the person which has been determined as the best option after considerable research on positioning of kinematic sensors. According to the algorithm devised, in case of a fall, the accelerometer senses acceleration greater than threshold value and the gyroscope is used to determine the orientation of subject, then if there is a fall, distress call is sent ( if button indicating false positive has not been pressed within 20 seconds). This system has a very fast response time and false alarms are almost negligible.

Li et al [18] designed an embedded system for fall detection which uses kinematic sensors placed on the chest and thigh. Accelerometer and gyroscope are used in the kinematic sensor module and the data is processed locally via microcontroller for fast response. Using two tri-axial accelerometers at different body locations, the system can recognize four kinds of postures: standing, sitting, bending, and lying. This is more accurate than only using body orientation information. To determine whether a transition is intentional, the system measures not only linear acceleration, but also angular velocity with gyroscopes.

Nguyen et al [19] have developed a mobile waist mounted device which can alert caregivers if the subject encounters an emergency. An accelerometer is used to detect falls and a 3 channel ECG circuit to determine heart rate. A tri-axial accelerometer and a CDMA standalone modem are used to detect and manage fall events. In this approach not only a simple threshold algorithm is used but also some supporting methods to increase the accuracy of the system. If an emergency event happens, ECG and acceleration data will be sent to remote server via CDMA module. The data is not being processed locally so response time is greater as compared to systems where data is processed locally.

Zheng et al [20] describe a fall detection mechanism using a 3 axis accelerometer and a wireless alert system. The device is worn on the waist and performs real time fall detection and if a fall is detected, the device gets the location of the wearer and sends an alarm SMS via CDMA/gpsONE module. Another added functionality is that the system detects non-movement for extended times and sends alert SMS as this can also be dangerous in case of the elderly. This system has a push button (with a timeout of 10 seconds) to eliminate false positives. 325 tests were conducted with different subjects simulating activities of daily life and falls. The device succeeded 255 times and failed 81 times.

Dinh et al [21] have used an accelerometer and a gyroscope for fall detection and an acoustic sensor for heart beat detection (vital signs monitoring). The system is worn on the chest and communicates wirelessly via Zigbee protocol with a computer which stores the data and sends it to monitoring network. The system comprises of a 3 axis accelerometer, a dual axis gyroscope, a heartbeat sensing circuit and an RF-ready microcontroller. The device has a feature that when battery is low, the sensors are turned off and alert is sent via Zigbee link to recharge battery. Five different algorithms were used to test the device and the accuracy varied from 92% to 97%.It was observed that using only the accelerometer gave an accuracy of 90% and when both accelerometer and gyroscope were used, an accuracy of 97% was achieved.

Huang et al [22] designed an embedded system for fall detection which extends the scope to informing the concerned authority of the location of the subject in case of fall. The system uses a tri-axial accelerometer connecting to a ZigBee evaluation board with plugging sockets of ZigBee tag. The tag is an electronic chipset containing a CC2431 Micro-Controller Unit (MCU) and an antenna. The CC2431 MCU hybrids 8051 kernel and 802.15.4 ZigBee wireless location engine. They have used the algorithm proposed by Wang et al [23] (2008) which can accurately distinguish 8 kinds of falling postures and 7 kinds of daily activities. In case a fall is detected by the accelerometer, the position engine is triggered which locates the wearer and sends distress call to caregivers.

### *2. Discussion and Perspectives*

The above literature review shows that these kinds of systems can easily be used in normal living environments. They have many advantages over the Computer Vision and Acoustic & Ambience sensors based systems. The foremost advantage is that a person can go outside his home and still be monitored. There are also no such problems of noise or living environment restrictions. These systems tend to be low cost as there is no infrastructure requirement.

These approaches, however, also have some shortcomings. One is that these approaches provide an obtrusive way of monitoring. Moreover, in designing such stand-alone systems, the battery life also becomes a major issue to deal with. The weight of the device is also an important aspect to consider.

## V. Proposed Approach

We believe that the kinematic sensor based approach is the best because of its cost effectiveness, portability, robustness, and reliability. Therefore, we propose a standalone kinematic sensor based system, which has three main modules: accelerometer, microcontroller, and GSM connectivity. In case of a fall, the accelerometer will detect the acceleration and the algorithm coded into the microcontroller will distinguish the fall from an ADL. Once a fall is detected, an SMS will be sent to concerned authorities via GSM module. The system will also monitor activity of the subject and log it into the memory of the microcontroller. This data can be downloaded into a computer via data cable for analysis, so that the caregiver can monitor the daily activities conducted by the subject and perform routine checks without physically being present with the subject at all times.

To the best of our knowledge, the proposed system provides the most accurate information due to its digital accelerometer and is the first fall detection standalone device with the GSM communication capability. We have opted for GSM network for our communication because it has a large coverage area. It also provides a cheap solution, which ensures that the elderly people can go outside their homes as well. We can generate an emergency alert SMS on detection of a “fall” event.

The major hardware components required for our system are an ADXL345 accelerometer, an AVR Atmega32 microcontroller and a Sim300DZ GSM IC.

The ADXL345 is a small, low power, tri-axis accelerometer with a high resolution (13-bit). It has an accuracy of up to ±16 *g*. Its digital output data is accessible through either an $I^2C$ or SPI (3- or 4-wire) digital interface. It can detect and measure static acceleration of gravity, as well as dynamic acceleration of mobile devices. ADXL345 has a built-in free fall detection feature, which is very suitable for our project.

Atmega32 is an AVR enhanced RISC architecture based 8-bit microcontroller, which has a low power consumption due to a CMOS fabrication technology. It provides many features including a sufficient built-in memory, Timer/Counters, SPI port, and an interrupt system. It provides an ideal feature set and internal memory module for our current project.

The Sim300DZ IC is used for GSM communication. SIM300DZ is tri-band GSM/GPRS engine that works on frequencies, GSM 900 MHz, DCS 1800 MHz and PCS1900 MHz. Sim300DZ provides a serial interface for communication with the microcontroller. It has a power saving mode, in which it consumes as little as 2.5mA of current.

The device would be placed on the upper trunk of the subject. An algorithm would be programmed into it, which would first calculate the root mean square (RMS) of the inputs from the accelerometer. Under static conditions the RMS is usually near or equal to 1. This would mean that the subject has a stable static posture. The orientation of the subject is then checked by calculating the angle (θ) between the vertical and the subject`s upper trunk and compared with some threshold values ($th_x$) to determine whether the subject is sitting or standing. If the value of RMS is greater than 1, the subject is undergoing irregular movement. Under such dynamic conditions, it is vital to take an average RMS value over a short interval of time in order to accurately categorize the movement. The microcontroller’s internal timers would suffice for this task. A set of consecutive RMS values during this time interval would be saved in an array. The average RMS value will then be compared with some threshold values ($th_y$) to determine whether the subject is walking or running. The ADXL345 accelerometer has a built in free fall detection feature which sends an interrupt to the microcontroller in case a fall occurs. To prevent false positives (where the system recognizes an ADL as a fall), if the microcontroller detects the interrupt, the orientation of the subject is also checked to confirm that an actual fall has occurred. A signal would then be generated by the microcontroller to activate the GSM module to send the alert SMS.

This proposed system provides a very high level of accuracy due to the use of a digital accelerometer, which reduces the data losses that occur in A/D conversion required for the conventional analog accelerometers. Moreover, the three major components used in this system consume very low power (due to their power saving modes) and are very small and lightweight (as mentioned above), prolonging the battery life and producing a very small device that can easily be attached to the subject without placing any burden on him. It also utilizes GSM communication (which is very common everywhere due to the extensive use of mobile phones) for sending alerts, eliminating the problem of setting up any new network. It utilizes a novel algorithm that accurately and effectively determines the various daily activities commonly conducted by the elderly and identifies any falls that have occurred. These features give our proposed system an edge over the present kinematic sensor based techniques mentioned in this paper.

## VI. Conclusion

We have surveyed and discussed three main methodologies for fall detection and daily activity monitoring. The first focuses on computer vision and video analysis based techniques. These techniques can only be used indoors as the cameras are fixed and the costs involved are high because they need a network of cameras and a dedicated computer for processing data, whereas they are best suited for monitoring large groups of people in an unobtrusive manner. The acoustic and ambience sensor based techniques, which use vibrations or sounds to detect falls are also limited to indoor use and are very ineffective in normal living environments as the excessive noise degrades the signal received from the sensors.

They are, however, very suitable for a group of people and are also unobtrusive, like the previous approach. The third is kinematic sensor based approach and it has the most potential for future advancements. It involves using accelerometers and/or gyroscopes to distinguish falls from ADL. The sensors worn on the body of the subject allow them to roam about freely both indoors and outdoors. Traditionally the data was processed on a PC but latest trend is to process the data locally for fast response. Kinematic sensor based approaches have high accuracy (95% to 100% in a laboratory environment).

We have also proposed a fall detection and daily activity monitoring embedded system which uses a tri-axial digital accelerometer. The data from the sensor is processed by an onboard microcontroller which contains the algorithm devised to distinguish falls from ADL`s. The system logs the activities of the subject and in case of a fall, sends an alert message via GSM. The distinguishing characteristics of the system are its portability, cost effectiveness, accuracy, and GSM connectivity.

The future work of this proposed methodology is the hardware implementation of the system, which is underway. The algorithm and the required hardware have been finalized. The GSM module which is used for alerting (in case of a fall) has been implemented. Interfacing and testing of the microcontroller with the accelerometer is in the pipelines. Testing of the finished prototype will be done by simulating different types of falls and ADL`s. We are expecting to achieve accuracy above 95%. The system will be further improved and tested once its implementation is complete.

## VII. ACKNOWLEDGEMENT

We have applied the Equal Contribution [24] approach for the sequence of authors. The sequence does not specify decreasing credit. All the authors have contributed equally in the writing of this paper. We are grateful for the excellent guidance and stimulating discussions and comments by our adviser, Dr. Osman Hasan.

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