# Elder Care's Fall Detection System

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**Abstract.** With the increase of the elderly population, new challenges to enable a healthy and dignified life for the elderly arise. One of these challenges, comes from a very serious problem to which the elderly population is subject: falls when they are alone. This article intends to present the initial study performed, and the resulting architecture of a complete system, that in conjunction with the rest of the Elder Care project, will enable the rapid detection of falls and sending of requests for help, that may well save lives.

**Keywords:** fall detection, body area network, health monitoring, aging.

## 1 Introduction

The populations' aging tendency, which is more significant in first world countries, is also an alert to the necessity of adapting existing technologies to the physical challenges that aging entails. A recent Eurostat study predicted

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that the percentage of people older than 65 years old will raise from 17,1% to 30%. This corresponds to an increase of 84.6 million people in 2008 to 151.1 million people in 2060[7].

With the aging problems in mind, the Elder Care project was envisioned [10]. Elder Care distinguishes itself from other health care projects, by providing a complete package for elder health care support. It gives complete monitoring support of the elderly not only in his home, but also when he is away from it. This project does not limit its concerns to the physical health of the elderly, it also has modules responsible for making sure that the mental health of the elderly does not deteriorate due to loneliness and social neglecting.

To be able to provide this type of support, Elder Care is divided in various sub-projects, being one of them the Body Monitor module, that has the intention of developing a system to allow the constant monitorization of the elderly's vital signs. This module is only possible due to the big advancements in the domain of miniaturization technology, the emergence of wireless sensor technologies and more recently the studies made in the area of Body Area Networks[8]. One of the items in study by the Body Monitor module is fall detection, and it is where our atention is mainly focused in this article.

In a recent report from the Health Evidence Network for the World Health Organization [12], it is established that 30% of the population over the age 65 falls at least once each year, this percentage is even higher in the group of 80 and over, where it reaches 50%. Still not only falls are the main reason for injuries that need hospitalization, but it is also the primary cause of injury-related deaths.

Not only there is a problem with the actual impact, but also if the fall is unattended for a long period of time, will by itself, bring additional problems to the elderly. The contact with the ground may lower the body's temperature to values that can lead to delicate health conditions, like for example pneumonia [6]. The longer the elderly stays in the ground unattended, more will he be prone to become fearful of having a normal day-to-day life [12].

In this article, the Body Monitor architecture is being approached and the fall detection tests exposed. Our main concern is to show the evolution of our tests that aim to reduce, and ultimately eliminate,false positives. Taking into account the constraints underlying sensor's energy costs.

## 2 Fall Detection

Many studies have been done on the area of computer assisted fall detection; in the early 90' with the advent of more accurate sensors, and after their early project using video monitoring failed due to legal and moral concerns, the researchers Lord and Colvin using a small tri-axial analog accelerometer started studying the acceleration sustained by the human body during the impact [9]. This approach was the one followed by the majority of the following studies. Some years later, in 1998, was developed the first prototype of a fall detection device to be used on a telecare system. Like the Lord and Colvin study, this device detected the fall by measuring the force of the impact when the body hit the ground, and complemented it by using a mercury sensor to verify if the person was on a laying position [13].

This first systems all had a sub 90% success rate, and suffered from many false positives, this was due in part to the inefficient hardware being used and to the way the problem was being approached, as the system relied on the energy of the impact to be transmitted through the human body, in case the energy was absorbed by the body the fall could not be detected or would be confused with an activity of daily living (ADL).

In order to mitigate this problem, a study was conducted by Ge Wu [14]. In this study, instead of focusing on the actual impact, Wu decided to study the velocity of the human body during both ADL and falls, using image processing equipment he measured the velocity of the body during multiple types of activities that would normally cause false positives. After studying the results, he discovered clear differences between ADL and falls, for example, both the vertical and horizontal velocities are between two and three times higher during a fall than during a normal activity. Not only did this study prove, that it was more precise to use velocity instead of only the impact, it also proven that by using velocity it was possible to identify a fall even before the impact occurs.

More recent works [3, 5, 4], by Alan K. Bourke, have taken the study of ADL differentiation from falls a step further, in [3] it is proven that it is not necessary to use both vertical and horizontal velocities to undoubtedly detect a fall. This works have also proven that it is not necessary to measure the velocity of multiple parts of the human body, because the velocity of the trunk by itself, is enough to correctly identify a fall.

## 3 Body Monitor Architecture

The research team behind Body Monitor has decided to implement a scalable architecture for Body Area Networks, this enables that in the future other types of sensors, not only those chosen for the fall detection, can be easily added to the system. The proposed architecture consists in a set of sensor nodes positioned on a human body, collecting data and detecting abnormalities. The information is afterwards sent to a central sensor node (nominated by coordinator). This coordinator will then send information to a base station (Root) or a mobile phone (PDA). The base station or mobile phone will manage alerts sent according to the occurred events, see fig. 1.

One of the biggest problems in a Wireless Network, like this one, is the energy spent on the communication. To optimize the power consumption this architecture uses a routing protocol that tries to forward data with the minimum hops possible.

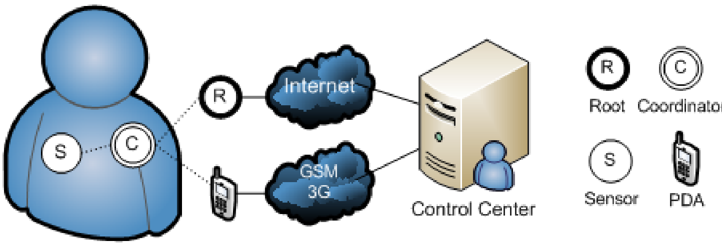


**Fig. 1** The Body Monitor Architecture

In terms of the actual fall detection system, it is not just a simple process of making decisions based on individual data, obtained from the accelerometer sensor. This type of solution would create a lot of false positives, which by itself is nefarious for the acceptance of the project, because it would create a "peter and the wolf" problem where the warnings would stop to be taken in account and when a real fall occurred it would be ignored. Another problem would be the battery drain caused by all the connections made to the central system.

So to implement a viable solution, it is necessary to be able to distinguish a real fall from an ADL, with such a system in place it has been proven that a fall can be detected and confirmed even before the actual impact occurs [14]. It is also important to take in account that this is a BAN so the system should have the least energy consumption possible, to do this it is necessary to study what is the lowest sampling rate necessary to guarantee a near 100% success rate on fall detection without causing false positives.

For this system a tri-axial accelerometer has been selected, each one of its axis is positioned perpendicular to the other, simulating the orthogonal axis. The data collected from this sensors is then stored, so that it can be continuously analyzed. Also, the values of each axis are analyzed independently and in conjunction, with this it is hoped not only to be able to detect and distinguish unhampered falls, but also to reinforce the data gathered from other sensors. For example, a decrease of the elderly's activity followed by an immobilization, if accompanied by an abnormal variation of the heart rate, would undoubtedly be a cause for an alert.

## 4 Tests

The first testing stage consisted on implementing the detection model on a prototype board. This research group has opted to use the iMote2 platform [11] instead of an Atmel-based platform. The iMote2, with its PXA271 XScale Processor, is able to achieve processing speeds of up to 520MHz [1], a lot higher than the commonly used Atmel ATmega128L microcontroller can with its 8MHz processor[2]. At these clock rates, it was expected that the power consumption would also be many times superior, but this is avoided due to the scalability of the PXA271 processors, that allows them to work at speeds as low as 13MHz; at these speeds its possible to obtain power consumptions near the ones of the Atmel processor, while still being able to manage more sensor sources. In particular, the iMote2 is able to acquire, process and send data from three acceleration axis without stopping the sampling cycle. For testing purposes, the accelerometer used was the one present on the Crossbow iMote2 sensor board, the ST Micro LIS3L02DQ.

To be able to correctly test the prototype, it was first necessary to correctly calibrate the sensors and prepare the system for the acceleration data being returned. This is very important because the accelerometer sensors do not only return acceleration when there actually occurs movement, they are always returning the acceleration applied to them by the gravity field. It was also important, to gather data of a fall when there was only the force of gravity in action.

To accomplish this, was necessary to design a second testing phase with as few as possible external interferences, so it was decided not to use any human subjects in this phase. In order to study a vertical fall it was used a 5kg box with the sensor coupled to it, this box was then dropped from a height of one meter. To test a fall where there were more axis involved that just the vertical axis, was design a system that would create falls with a consistent arc trajectory. This system consists on two wood boards, one of them with the size of 1,7m to simulate the height of a human being, the size of the other board is irrelevant as it only serves to fixate the system to the ground; the one representing the human is placed upright and are both connected on the extremities by a hinge. During the actual test the sensor was placed in one of two positions, at a high of 0,85m to simulate the height of the hip and at 1,45m to simulate the height of the shoulder.

Following the calibration of sensors and the creation of a reference table with the values from the previous tests, comes the third testing phase that consists on the study of the ADL of a voluntary. As it is not practical to record the complete day of a person and then evaluate the results, due to the immense data that would be obtained, some simple and direct tasks are performed instead. The tasks performed by the voluntary are:

- Walk in both directions on an L-shaped route
- Sit and raise from a chair
- Pick an object from the ground, in the correct way (by bending the knees) and the wrong way (by bending the back)
- Go up and down a flight of stairs, both in a slow pace and in a quick one

The forth and last phase, consist on testing actual falls using young voluntaries in a controlled environment. This final test, was used to validate the gathered information and to confirm that if with even more noise it was still possible to correctly detect a fall.

## 5 Analysis of Results

During the ADL tests what was analyzed, was that none but the "sit and raise from a chair" test, presented any data that could be confused with the one collected from the previous fall tests. In fourth phase, with tests of normal falls, the acceleration was enough to detect the fall and there was not any problem in distinguishing it from an ADL, a representation of the data collected can be seen in fig. 2.

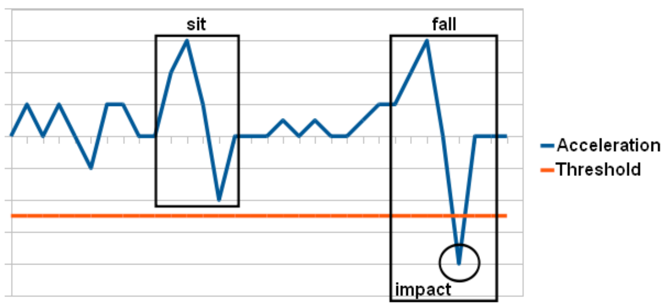


**Fig. 2** Representation of a test using only acceleration

In the case of the sit down tests, when the volunteer would abruptly let is body fall on the chair, the data collected had samples of the same magnitude of those of an actual fall. This occurs because, during a more brusque sit down, the upper part of the body is not sported so its, almost, in free fall.

The problems also appears when the fall is not completely unhampered, and the person is able to hold to something before actually hitting the ground, this causes an intermediary deceleration causing the final impact to be of a smaller magnitude. This in conjunction with the human body's natural absorption of the impact, can lead to problems in differentiating the fall acceleration values from those of a sit down action done with more violence, see figure 3.

When using the velocity instead of the acceleration, the small intermediary deceleration would not have that much impact on the final results, as the speed of the person is the result of the combination of past and present data. The data gathered in velocity is a stream of continuous values, and not a group of isolated values like in the case of acceleration. The fall test in figure 4 is a representation of the same data as in figure 3, but this time using velocity.

Unfortunately, using velocity instead of acceleration has its own perils, while the use of acceleration is a direct analyze of the data gathered from the sensors, the velocity must be calculated, so it needs extra processing power and it is more sensitive to loss or errors in the gathered data.

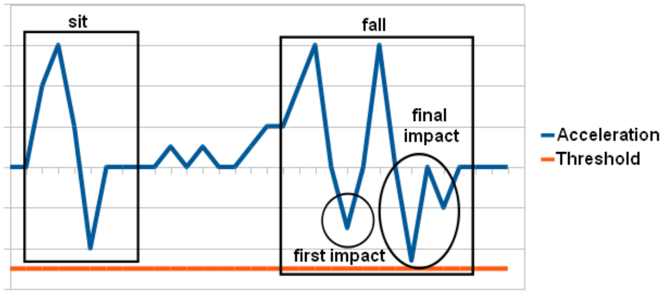


**Fig. 3** Problem of only using acceleration

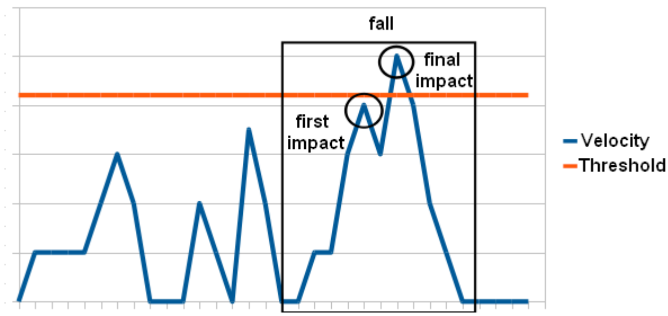


**Fig. 4** Detection using velocity

## 6 Conclusions and Future Work

Detecting a fall using wireless sensor networks has two major problems: distinguishing false positives and sparing sensor battery.

It is very important to identify unequivocally situations where a fall happens and situations where other human movements are made and can be wrongly interpreted as falls. Otherwise, alerts will never be reliable. It is also very important, when working with wireless sensors, to have in mind their limitations, especially battery limitations. A continuous communication may lead to the crash of the system in a few hours.

For the main function of the system, the detection of unhampered falls, instead of relying on the older technique of using the body's impact, it has been decided to use the calculated velocity. This decision came after studying, the already referenced works of Wu and Bourke, and after confirming it with the available equipment. But using velocity over acceleration may overload the sensors and crash the system. So it is important to gather not only more information about acceleration and / or velocity, but also parameters such as abnormal variation of the heart rate or even interpret frames from a camera monitoring the elderly.

Regarding the fall detection using only physical data sensors, there are already plans to test new types of sensors and verify to what extent, it is beneficial the addition of new data sources, like oscilloscopes, to the energy consumption. It should also be evaluated, that if by combining the data from the horizontal velocity with the data from the vertical velocity it is possible to reduce the necessary amount of acceleration readings, thus allowing the reduction of the global sampling rate. Even if it has been proven by Bourke in [5] that it is possible to detect a fall by only using the vertical velocity.

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