Fall Detection: Project of an Improved Solution
A Fall Detector More Reliable and with New Features

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Abstract. In the case of old people living alone at home or in care centres, falls represent the most important cause of accidents. To reduce the impact of a fall event, fall detectors have been developed, which are supposed to automatically detect a fall event when it occurs and to send an alarm to a care central in a short period of time. Within the existing projects are especially interesting the autonomous worn fall detectors. In this paper, Fatronik presents its project to develop an improved fall detector. The objective is to enhance the fall detector's reliability and easiness of use comparing to the existing solutions, and to add new features such as improved location and communication capacities. This paper describes the working outlines of the project, open to suggestions and modifications according to the results obtained at the different stages.

1 Introduction

In most of our countries, the elderly people represent the fastest growing segment of the population, and this trend will increase the next years. Indeed, by the year 2035, one third of the European population will be more than 65 years old. At the same time, the Public Health Services institutions have to face budget reductions and increasing pressure to limit costs. Together with the lack of rooms in the care centres, these evolutions lead to encourage people to stay living at home instead of being admitted in care centres. For the elderly population, which represents a large part of Social Health Services expenditures, it means most of the time living alone and independently in their homes, with all the risks it involves. To offset these new problems, investigation has led to the development of a wide range of telemedicine systems over the last 20 years[1]. Such systems are designed to offer major security to persons living alone in their homes, including to persons admitted in care centres, as efficient tool to assist carers in their tasks.

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One of the major risks incurred by the fragile population (elderly, illness, people in adaptation time after a chirurgical intervention, etc…) is to fall. Indeed, 30% of elderly people fall once a year at least, which represents 75% of the victims of falls. The fall event is responsible for 70% of accidental deaths in persons aged 75+, and for increasing the person level of fear, anxiety or depression leading to the reduction of the day to day activity. These observations have encouraged the development of fall detection devices to detect or even prevent a fall event and to ensure a rapid and efficient help when such an event has occurred [2]. But very few fall detection systems are yet commercially available today, due to lack of reliability, lack of easiness to install and use, or because people did not accept a system found too intrusive or expensive for instance. This paper presents the outlines of Fatronik's project to develop a new and innovative worn fall detector. Even if the development is at its first stage, the outlines of the project are presented.
After giving an overview of the actual situation in the sector, the main expected development tasks are presented. Starting by analysing the possible ways to improve the reliability of the fall detector comparing to the actual solutions (by a more appropriated sensor's choice, or by a better signal and pattern analysis), the document will go on showing how such a system could be implemented (through two main techniques: thanks to a PDA device, or in a more industrial way, by using a micro controller). Finally, a notable innovation of the fall detector Fatronik wants to develop is presented: its communications features. Indeed, the detector will also include GPS and GSM/GPRS modules for embedded communication.

2 Background

Telemedicine systems include all the systems designed to help high risk population (due to old age, illness such as epilepsy or Alzheimer, recent chirurgical intervention) to improve their quality of life, by reducing the risk factor and the stress it involves, by giving them more freedom in their movements and activities they can perform, and by reducing the stress level of their carers (relatives or professional carers). Such systems are designed either for people living alone in their home as for people living in a care centre.
Different telemedicine systems have been developed, with different complexity levels, from a simple device to remember the person when to take her/his medicine, to a completely instrumented house with complex multi-users interface and artificial intelligence to adequate decision-making tasks [1] [3]. The most common systems in Europe are certainly the so-called social alarms, which consist on an alarm button worn by the user. The user raises an alarm by pushing the button, and a care centre is alerted through an automated phone call made by a central connected to the user's telephone. Such system is of course limited: if the person has no possibility to push the alarm button (unconsciousness, broken arm, etc…), no alarm is sent.
Since falls is the major concern for elderly and their carers, logically most of these telemedicine devices are dedicated to the fall detection. The fall detection requires a device with special features due to the large number of parameters involved and to avoid the system to be uncomfortable or perceived as too intrusive [4]. Different

technologies have been investigated to detect a fall, which can be divided in four main groups [5]:

- *Worn device, immediate detection:*

This category includes small devices worn by the user able to detect the fall event when it occurs and to raise an immediate alarm. The technologies used are impact, position and tilt sensors, and accelerometers together with adequate control algorithms performed in a micro controller.

- *Worn device, unusual behaviour:*

These fall detectors are also small devices worn by the user, but they are not able to detect a fall event. They rather monitor the activity of the person, and detect an unusual behaviour comparing to a typical behaviour pattern of the person. Such systems may last some time before raising an alert (an unusual behaviour can only be detected on a time increment of 1 hour or more), and do not differentiate a fall from another abnormal behaviour.

- *Environment sensing, immediate detection:*

Such technology consists in the installation of sensors in the environment of the person to detect a fall event. Technologies used are for example video recording and image analysis, sound analysis, installation of shock sensors on the ground or in the carpets, etc… The main disadvantages of these systems are that they require installation of sensors in each room of the house (including wiring), that they are too intrusive and that they might be expensive (video analysis).

- *Environment sensing, unusual behaviour:*

Like in the previous category, the environment is equipped with sensors to be able to monitor the activity of the person. For instance, contact sensors or Infra Red (IR) barriers are placed on the doors and windows, passive IR detectors are installed in the rooms. The information collected by the sensors is then analysed thanks to intelligent analysis systems (artificial intelligence) to detect an unusual behaviour, and so the eventuality of a fall. Such systems require heavy infrastructure (lot of sensors and complicated wiring) and good analysis system. They often result to be quite expensive.

This rapid state-of-the-art makes evident that no system actually completely meets the user's requirements. Worn devices with immediate detection seems to be the most adequate solution to fall detection in the elderly. Nevertheless, very few commercial systems are actually available on the market. The main difficulties are to design a reliable detector, no cumbersome and easy to use. Through the project presented, Fatronik pretends to take advantage of the research work already done in this domain thanks to partnerships and collaborations and to design a really innovative system with improved performances and functionalities, including activity monitoring and fall detection functionalities, both indoor and outdoor (with GSM/GPRS and GPS features).

Under this scope, the project development will be scheduled in the following phases:

- *Fall Pattern Definition*, dealing with sensors selection, falls simulation by healthy people, data acquiring and analysis, and reliable fall pattern definition.

- *Fall Recognition*, based on the previous defined patterns, and handling hardware and software processing devices selection, signal treatment and prototype implementation.
- *Location & Communication*, tackling the choice of potential applicable scenarios and the location and communication needs as for providing control over the elderly to the care centres in charge of them.

3 Fall Pattern Definition

To achieve a good reliability is essential to the success of the system. On the one hand, a detector failing in detecting a fall will not be accepted by users because they will not be able to trust the fall detector. Such system would be more annoying than advantageous. On the other hand, a too sensitive fall detector will mistake day to day movements (sitting, bending…) and detect them as a fall. A too frequent false alarm, even if the system offers an alarm reset option, is not acceptable, and would be rejected by final users.

Most of the systems developed until now are based on the association of various sensor's types (accelerometer, tilt sensor, shock sensor, gyroscope) to intent to monitor the person's movements. Thanks to an adapted signal analysis methods, the system is able to differentiate a fall event from other day to day events. Fatronik's approach will be similar to most of the developments already carried out by universities and manufacturers as for the method used for the fall's detection (based on the analysis of a signal recorded from a set of adequate sensors). Indeed, Fatronik wants to take advantage of the research already carried out in this domain, and enhance the process to improve the detector's reliability with regard to the existing solutions by using new sensor's technologies, by optimizing sensor's layout, by improving signal reliability, and by reducing power consumption as well as detector's size. In 1995 *Bussman and Veltink* showed that two uni-axial accelerometers, one mounted on the trunk and another mounted on the thigh are sufficient to discriminate between sitting, standing, lying and moving. According to the experiments realised in different centres or universities, accelerometers are the most adapted sensors for this kind of implementation. The idea would be to use MEMS (Micro-Electronic Mechanical System) technology accelerometers: one biaxial accelerometer if sufficient, or a set of two biaxial accelerometers to be able to monitor the accelerations on the four axes and to create at the same time a tilt sensor. Another solution would be to use a biaxial accelerometer together with a last generation MEMS inclinometer, offering a low power consumption for a very small size. Indeed, the MEMS technology has two great advantages for this kind of applications which are a low price and a very reduced size.

One signal per axis is recorded (analogical or digital), proportional to the acceleration detected on each axis, from the accelerometers. The data obtained from the sensors will be analysed and compared to a pre-defined "reference signal pattern" (electronic signature) in order to determine the users activity -distinguishing between different activity situations- and evaluating if a fall has occurred. The definition of the reference signal pattern for data comparison (fall detection and activity monitoring) is the

most complex and delicate work of the project since the effectiveness of the system will be proportional to the characterization of this biomechanical model. An important part of the project's success rely on this stage. Considering this, an ergonomic design of the system is expected using the minimum number of sensors as possible. The experimental analysis to define the reference signal pattern will consist in simulating the fall event using healthy people with different physiognomy. According to the specifications defined in the first stage of the project, all the different types of falls will be simulated. All the experimental analysis will be carried out under ethical, safety and psychological parameters, performing the necessary simulated fall events.
Next the different Ethical, Safety and Psychological issues, regarding not only the fall pattern definition phase, but also the entire prototype development, are detailed:

- *Ethical issues:*

- Regarding people locations, big efforts aimed to preserve the intimacy and private life of the involved elderly will be accomplished, fulfilling the needed policy and legal issues rounding these aspects.
- The same approach tackling the privacy of the elderly in their usual movements, and maintaining the location of the people in a private way.
- The final fall detector will be designed and developed according to criterions of maximum comfort and no cumbersome and annoyance.

- *Safety issues:*

- Due to ethical and safety considerations, instead of elderly people, healthy people will be used to simulate falls, resulting in some inherent differences in user's biomechanical behaviour comparing to real situations.
In order to avoid healthy risks, the fall event will be simulated onto foam crash mats. The use of crash mats will distort the results due to the shock absorption characteristic of the foam.
- The final fall detector will be designed and developed so that no injury will be caused to elderly in sudden and hard movements like a fall.

- *Psychological issues:*

- Different ways and means will be considered and surveyed in order to achieve the elderly to assume that they should use the fall detector, convincing them that it doesn't imply discriminatory issues.
- The final prototype of the fall detector will be designed and developed according to privacy rules as for being impossible to be detected by other people when it is being used.
A large period of tests and simulations is expected, since the definition of a good pattern is one of the keys leading to a reliable sensor. This development will be carried out together with the INGEMA (Instituto Gerontológico Matia), a R&D Institute in the Health Care area, belonging to the foundation MATIA Fundazioa. This partnership will ensure all users needs, ethical, safety and psychological issues are respected. Indeed, as a care center for elderly, MATIA Fundazioa counts with a special fall study cell, with specialized staff and great experience in this domain. Its participation in the project will make sure to develop a system close to final users needs on the one hand, and will provide a perfect tests and validation environment on the other hand. A special emphasis will be put on this aspect, on which previous projects have failed and thus been rejected from users. But together with the definition of a good

fall pattern, the signal analysis method and its implementation are critical steps is the project development.

4 Fall Recognition

Once all the different actions aimed to achieve the optimum fall pattern have been accomplished, the stage of signal processing, pattern-comparison, and system implementation should start. This stage includes analysis of the optimum implementation model for the fall detection pattern, processing algorithms definition, final devices choice and elements integration and implementation. Thus, the result of this stage will be the final prototype able to produce reliable fall detections, so the need of conscientious analysis is evident.

4.1 Signal Treatment and Implementation

During the fall pattern definition stage, the signals from the sensors will be recorded with the software LabVIEW from National Instruments and analysed to define the best way to differentiate a fall from other movements. Various signal analysis methods are available to analyse the sensor's outputs in the time, frequency or both time and frequency domains:

- *Time Domain:*

- Analysis of the signal's amplitude and definition of limit thresholds,
- Extraction from the acquired signal of any other judicious characteristic to check the pattern matching;

- *Frequency Domain:*

- Filter of the signal, to eliminate noise,
- Frequency analysis. The Fourier analysis calculates the amplitude of the signal for each frequency,
- Complex demodulation: it consists in the calculation of the phase and the amplitude of the mode (the frequency peak) we are interested in;

- *Time & Frequency Domain:*

- Short-time Fourier Transform consists in the calculation of the Fourier transform every given time window. This method gives us certain information about the evolution of the frequencies in time,
- Wavelet is a method of complete decomposition of the signal in an orthogonal basis of wavelet functions, which are special functions, localized in time and frequency. The result is a three dimensional information in amplitude, time and frequency of the signal.

Most of the existing fall detectors are running with quite complex detection algorithms, but without reaching an outstanding reliability level. Fatronik's approach will slightly differ on this matter, focusing more on the sensor's layout. Indeed, well chosen and implemented new generation's detection sensors (most likely accelerometer

and/or inclinometer) should make the fall detection easier. Thus, an effort will be made to simplify the detection algorithm to enhance robustness and reliability.
A major difficulty in the fall recognition is certainly the huge variety of situations one can find in a day to day life basis. Each case is almost unique, hence the automatic detection of an unique event is hard to implement. This situation can lead to mistaken signal acquisition and analysis, which result would be the generation of false alarms. Our objective is of course to reduce to the maximum the false alarms' situations. This stage is considered as critical in the project, and a large battery of simulated as well as real tests will be performed to adjust the algorithm and ensure the success of a reliable fall detection.

4.2 Prototype Implementation

Various software packages are foreseen to be used for signal analysis, as Cooledit, Matlab and LabVIEW to realize the prototyping of the sensor. When a movement is detected, the signals from the different sensors will be analysed according to the techniques described above, and compared to the fall pattern defined in the first stage. If the signal recorded and analysed matches with the fall pattern, a fall will be detected and the alarm process will be launched. All these tasks have to be carried out automatically by the detector, and due to the kind of application, the system must be small and of low power consumption.
For the prototype implementation, Fatronik has thought in a two steps development: the implementation thanks to a PDA-based solution (for user friendly environment for programming and debugging of the signal analysis and comparison to the pattern) and a second development stage, more industrial, with a micro-controller and the implementation of all the components.

4.2.1 Implementation through a PDA

This PDA-based technique makes up the foundation of the first phase of the development. Although it can't be considered as a final solution due to the high requirements of the approach as for dimensions, weight, easy of use for elderly, time requirements, maximum reliability and precision…, it's a very suitable option for the development as for the reasons next described.
At a first stage, the current actual software development possibilities for PDA environments are fully integrated within the typical and marketable Interface Development Environments (IDEs). For example, Microsoft allows the development of PDA-based applications in the same way as a typical Windows application, by means of its Visual Studio .NET IDE. This guarantees accomplishing algorithm codification and tests at a very early stage of the implementation phase.
Also, a lot of expansion possibilities exist for PDA devices, even for industrial applications. For this project, Fatronik has thought in incorporating a PCMCIA Data Acquisition Card into the PDA-based prototype, through a standard PC Expansion Pack connected to the PDA. In this way, soon data acquisition and processing can be accomplished.
Other important issue, aimed to achieve an optimum system, is disposing of means to accomplish the analysis and comparison tasks in optimum conditions. In this line, the

PDA devices capabilities regarding graphical visualization and advanced displaying means (high precision and high colour screen allowing 2-d and 3-d data analysis…) will allow a reliable debugging process for the prototype before generating the final version (micro-controlled based), guaranteeing the correct operation of the algorithm.
Summarizing, the PDA-based prototype is chosen as the most suitable mean for verifying the correct performance and reliability of the algorithm as for signal treatment and pattern-based evaluation, making up the first and most important phase of the implementation. This verification success will guarantee an optimum operation of the algorithms just before their migration to the final micro-controller based adoption.

4.2.2 Implementation through a Micro-Controller

Once the algorithms for signal analysis and pattern comparison have been developed and debugged thanks to the friendliness of the PDA, a more industrial implementation will be carried out. The signal analysis will be run through optimised algorithms in the micro controller, and once a fall event has been detected, the micro controller will raise the alarm and generate an alarm report including the person localisation with the GSM/GPRS and GPS functionalities, as next described.
The type of micro controller used depends on the type of signal analysis to be performed. That means, an analysis in the frequency domain for example, requires high calculation capacities. This, added to the fact that the sensor's signal must be checked continuously to detect falls at any time, makes it necessary to use a DSP. On the other hand, if it is determined that the analysis in the time domain is the most suitable one, a general purpose micro controller will be used. In any case, the micro controller will be programmed with a high-level language (C, C++, Basic) and the programs will then be translated into machine language by a compiler.

5 Location & Communication

Once all the foundation elements of the prototype are clearly defined, and aiming to incorporate the final means to support the communication needs, there has to be decided the potential application approaches of the present fall detection device.
According to the initial global objectives about communicating the fall location (once detected it) from the place in which the elderly person has fallen (both indoor and outdoor), this stage will be focused on incorporating the hardware and software means supporting this location and communication issues, into the final micro-controlled based solution.
Initially, two different approaches will be tackled by the solution, and consequently 2 different fall detection systems developed:

- *A solution tackling the elderly people home.*

At home, the elderly person will only accept a device that allows him enough mobility and comfort in routine home tasks, but at the same time, the device must be able to give service along all the different zones of the house. In this line, Fatronik thinks in typical standards used in home communications, and will incorporate a DECT-based module to the micro-controller based solution, that every time a fall is detected, it sends the necessary information to a base central device in order to be transmitted to the care centre via phone call. Most of the actual fall detectors work in this way.

- *A solution tackling outdoor.*

Fulfilling the same objectives of comfort, reliability and mobility than in the previous application, in this case the fall detection system has to transmit the outdoor position in which the fall has taken place. For this kind of application, in addition to the sensors and the micro controller, the fall detection system includes both a GPS receiver and a GSM/GPRS module. The GPS module receives and computes the positioning and other useful information (date, time…) and transmits this data in some standard format (usually NMEA-0183) to the micro controller via an asynchronous serial (UART) interface. The information will be transmitted at user-defined intervals and the last data will be continuously stored and updated. In case that the user enters an indoor localization and it is not possible to receive the GPS signal, the received last localization will be available.

Referring to the GSM/GPRS module, this also communicates with the micro controller via serial interface. The GSM technology will be used to send an SMS whenever a fall event is detected. However, not only an alarm can be sent. In a future improved version of the detector, the micro-controller will be able to calculate and store the average data of user's activity (time walking, sitting…) and reports with this information will also be transmitted. Due to the volume of this data, the GPRS technology is found to be the most convenient one for this transmission. Other possible components on the board will be a flash memory (depending on the available storage memory in the micro controller) and a multiplexer for the serial interface in the micro controller.

Such possibilities are real innovations comparing to the existing systems. They offer matchless liberty of use until now, and pave the way to numerous new applications in a close future (full activity monitoring…).

6 Conclusion

A fall detector is a nice example of how technology can improve human quality of life (in this case for elderly people) and serve the general interest (by reducing public health expenditures). Nevertheless, to design a reliable system meeting all the patient needs is difficult, due to the high requirements from the potential users and to the technological difficulty it represents.

Even if this paper has been written at the very beginning of the project, and even if the project stages presented are not more than open outlines subject to modifications, Fatronik pretends to develop a fall detector which will fulfil some of the requirements that are not fulfilled today. Even if the detection method will not differ very much from existing solutions, by taking advantage of the work already performed in this area, and of the last technological evolutions, this new fall detector should be more reliable and secure. Improving sensor arrangement and pattern recognition algorithm are key elements to succeed in this task, which is maybe the most difficult and critical one. A special focus is given with respect to the users requirements, by developing the system together with the Institution INGEMA, keeping close to the final user. Easy of use and global design are highly concerned by this objective. Finally,

Fatronik wants to incorporate to the detector the last communication technologies (GSM/GPRS and GPS) to make it more polyvalent and easy to use. These features represent a real novelty comparing to the existing systems.
A reliable fall detector will be useful for elderly living alone at home or admitted in care centres (to help their carers). Moreover, the improved communication features pave the way to enhanced services such as a complete activity monitoring, with vital constants analysis, for a complete real time and automatic health checking…

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