Acknowledgment: this work has been sponsored by the European Community through the CRAFT project Hebe contract nº 5935

Automatic Fall Detection and Activity Monitoring for Elderly

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Abstract- Our modern societies are suffering the increase of elderly population while at the same time social security and health costs must be cut down. In order to avoid the need of special care centers, the actual trend is to encourage elderly to stay living autonomously in their own homes as long as possible. The product presented in this paper contributes to this objective, since it provides user localization, automatic fall detection and activity monitoring both for indoors and outdoors activities, associated to a complete call centre for medical monitoring of the patient as well as to provide support and manage emergency situations.

I. INTRODUCTION

In most of our countries, elderly people represent the fastest growing segment of the population, and this trend will increase over 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 restrictions and increasing pressure to limit costs. Together with the lack of rooms in the care centers, these evolutions lead to encourage elderly to stay living longer at home instead of being admitted in care centers. 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. Tackling these expected needs, 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 centers, as efficient tool to assist carers in their tasks.

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, representing 75% of the victims of falls. The fall event is responsible for 70% of accidental deaths in persons aged 75+, and for increasing the 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 occurs [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.

After an overview of the actual systems available, this paper describes an innovative product developed to offer new services to elderly. A mobile and totally autonomous module, associated to a highly advanced call centre, offers full activity monitoring, automatic fall detection and user localization to the elderly both for indoors and outdoors activities with one unique system. The functionality of the system (both regarding to services and technologies implemented) as well as its use are explained in the following paragraphs. Fig. 1 shows an overview of the services implemented on the automatic fall detection and activity monitoring system presented in this paper.
II. 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, 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. Furthermore, its use is limited to indoor use.

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. Fig. 2 shows examples of fall detectors.

Worn device, unusual behavior:

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 behavior comparing to a typical behavior pattern of the person. Such systems may last some time before raising an alert (an unusual behavior can only be detected on a time increment of 1 hour or more), and do not differentiate a fall from another abnormal behavior.

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 behavior:

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 analyzed thanks to intelligent analysis systems (artificial intelligence) to detect an unusual behavior, 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 seem 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 new product presented, Fatronik pretends to introduce an innovative system with improved performances and functionalities, including activity monitoring and fall detection functionalities, both for indoor and outdoor use. Product’s main functionalities are presented hereafter.
The first step in the design of the product has been to clearly identify the user’s requirements and the lack in the existing products to meet these requirements. Focus groups with final users have been organized to discuss the functionalities that the fall detector should include as well as other aspects final users consider important to be taken into account (i.e. user interface, services, ease of use, esthetics, etc...). Special efforts have been made to have a product user-oriented. Indeed, elderly are quite exigent users, and the system has to be specifically designed to meet their needs to be used. The most important user’s requirements to be taken into account, in order of importance, where given for:

Reliability of the system:
Wearing such a system is an additional complication to elderly people, and is worth only if the system is reliable in detecting falls and abnormal situations. One of the main aims of the product is to give more confidence to users in their daily life, and such objective will be achieved only with a highly reliable system. Final users do not want false detections neither they want falls not detected.

Functionalities and services to be implemented:
A wide offer of services can be implemented in such a platform. However, according to final users, three services are like the most important for them to be implemented. Activity monitoring is useful in order to have a medical monitoring of the person. Automatic fall detection, without the need to push a button to raise the alarm, is considered as an important added value comparing to existing systems. Finally, user localization has two main interests: localization of the user when a fall is detected to send emergency services to the right spot, and help a lost user to find his way back home from the call centre. The possibility to use the detector both inside and outside is considered as a real advantage.

Design for non intrusive and discrete system to be worn:
To wear a fall detector is perceived as an intrusive and quite disturbing step to take from elderly: they lose their autonomy and admit the need of such a service is hard. To make it easier, special effort has to be made to make the fall detector discrete to wear and non intrusive in the daily life of the elderly. The ideal would be other people not being able to detect that someone is wearing the fall detector.

User interface and ease of use:
Elderly people are not used to new technologies and electronic devices, and their acquisition process is always more difficult that in young people. The interface of the detector must be simple, intuitive and easy to use. The information displayed must be clear. Taking into account possible little disabilities of elderly, both visual and auditory signals should be used. Finally, a “Reset button” will be implemented on the interface: it will allow disabling an alarm automatically set, and well as voluntarily setting an alarm by the user if necessary.

Respect of privacy and personal data:
Some of the data managed by the detector and the call centre is considered as critical and should be protected to ensure privacy aspects. Indeed, information such as user localization or activity of daily living is considered as personal enough as to be treated with the necessary considerations to respect user privacy. Some mechanisms will be implemented to respect user’s privacy.

Most of the requirements detected from the final users where expectable. These discussion groups permitted validating the need to develop a new system with new features, as well as the main functions to be implemented. Requirements are really demanding regarding to final size or weight of the system, however technological limitations will have to be taken into account. The functions implemented are user localization, activity monitoring and automatic fall detection. GPS, GSM and GPRS technologies will be implemented to allow indoor as well as outdoor use. Finally, special effort will be made to take into account user requirements regarding to interface, use and privacy. The project will be developed in close collaboration with elderly and gerontology centre.

IV. DESCRIPTION OF THE SYSTEM

This section describes the system developed, as well as its main functions. The system includes the following main elements:

- A mobile module worn by the user, performing the user localization, automatic fall detection and activity monitoring;
- A call centre for data reception from the mobile module, data analysis and saving, and for managing emergency situations.

MOBILE MODULE

- Functionalities:
The mobile module is worn by the user at any time. It is the analysis centre of the user’s motion used to perform activity monitoring and automatic fall detection.

   Ergonomic aspects and interface:
The mobile module will be worn at the belt, since this place has been defined like the most discrete and convenient taking into account the size and weight of the module. Its interface will include a “reset button” easily accessible to cancel an alarm if necessary (case of false alarms, or of falls without consequences for the person) or to set voluntarily an alarm (need of assistance even if a fall didn’t occur). The user’s interface is completed by luminous and auditory signals regarding to the state of the mobile module: battery charge, fall detected, validation of alarm sent, etc… This interface is simple and reduced to the strict minimum.

   Activity Monitoring:
Kinematical activity of the user is continuously real time analyzed while the user performs any activity in its daily life. The activity monitoring classifies the user activity according
to three levels: low, medium and high level activity. This monitoring is performed once a minute and data is recorded on the module. Once a day, the activity of the last 24 hours is sent to the call centre for analysis. This function allows carers to monitor user activity and detect abnormal activity.

**Automatic Fall detection:**

The automatic fall detection is also continuously real time carried out while the user performs any activity in its daily life. Implemented algorithm detects when a fall occurs. Based on fall patterns, the system is able to differentiate day to day activity from falls of any kind, and so to avoid false alarms (activities that have been detected as a fall and that are not a fall). On the one hand, day to day activities are numerous and varied, and on the other hand any kind of fall has to be detected (reliability), which leads to possible hypersensitivity of the system (numerous false alarms). The fall detection algorithm implemented takes into account these difficulties to perform reliable automatic fall detection. Furthermore, in an extreme case that a false alarm occurs, or that a fall has not been detected, the “reset button” can be used.

**User localization:**

User localization service is integrated on the system. The use of GPS technology allows total outdoor localization at any place, giving more flexibility in the use of the system. This function is necessary to complete two main aspects: precise localization of the user in case an alarm is sent (due to an automatic detection of a fall or to an alarm set by the user on the “reset button”) to send emergency services to the right spot and increase rapidness in the response, and to help user to find its way back home in case it get lost (some elderly people do have problems of memory and orientation, and get easily lost). From the call centre, instructions will be given to the user to route him safely back home.

**Bidirectional voice communication:**

The system also includes a bidirectional voice communication between the patient and the call centre, as a kind of cell phone. The system is not a cell phone, and this functionality is activated from the call centre only. However, it is useful in case an alarm is received, to be able to talk to the user and assess the gravity of the event as well as the type of emergency or help needed at this moment.

**Technology:**

High level technologies have been implemented within the system to perform the required functions as well as to allow indoor and outdoor use. Miniaturization and low power consumption have been specifically taken into account from the beginning considering that the system is wearable and is chargeable batteries powered.

**Kinematical activity:**

Both activity monitoring and fall detection algorithms require the kinematical activity of the user to be continuously monitored on real time. A biaxial accelerometer is used to detect the different movements of the user during its activities of daily living. Fig. 3 shows the typical outputs from an accelerometer during different type of activities. To reduce to the maximum the system’s final size, specific MEMS (Micro-Electro-Mechanical Systems) technology has been chosen to be implemented.

Activity monitoring is performed through a neural network which, by analyzing the inputs from the biaxial accelerometer, is able to classify the user’s activity in three main categories: low, medium and high level activity. Each minute, the level of activity is assessed and saved. The activity monitoring report is sent to the call centre once a day (24 hours recordings).

The fall detection algorithm is mainly based on the comparison of the instantaneous inputs from the accelerometers to defined activity patterns and parameters to differentiate between a fall and a normal activity. This algorithm is designed to reliably detect most of the falls (frontward, backward, lateral, lost of consciousness) and to differentiate it from other normal activities (sit down, go upstairs or downstairs, run, etc…).

**User localization:**

GPS technology is used to localize the user. The main advantage of GPS is that user can be localized wherever he is around the world, except within the buildings. In order to optimize power consumption, GPS coordinates acquisition is configured to be dependent on the movement speed of the user: if the user is moving rapidly (within a bus or a car for instance), GPS coordinates will be acquired more frequently than when the user moves slowly. Furthermore, the last acquired GPS coordinates is saved within the system to be used in case GPS reception is lost, or in case the user is within a building (the last saved GPS coordinate will indicate the entrance door of this building, making possible user’s localization). GPS receiver and its antenna are integrated within the mobile module.

**Communications:**

The mobile module will be used both indoors and outdoors, and will require permanent communication with the call centre. The use of wireless technologies widely available worldwide is required. GSM/GPRS emission / reception module and its antenna have been implemented within the mobile module. This network is used both to send and /or receive data from the call centre (alarm, activity monitoring report, localization) and for the bidirectional voice communication. Reception and emission is managed through UDP socket protocol. GSM/GPRS technology is widely available at a low cost, including inside the buildings.
makes possible to use the system both for indoor and outdoor activities without any problem.

When an alarm is detected, ensure good communication is critical. A specific communication protocol, including the necessary acknowledgments, has been implemented to ensure that the alarm has been successfully received by the call centre. The user has confirmation that the call centre received the alarm. If no alarm can be sent (due to loss of GPRS network), the user is also noticed to give him the chance to find another way to get help.

Use of the system

The mobile module has to be worn by the user at any time to be effective. Fig. 4 shows the first prototype that has been implemented. The final system, waterproof, will be of much reduced size and will be fixed to the user’s belt. The user has nothing more to do than to turn its system on and to clamp it to its belt.

If no abnormal situation is detected, the system will periodically save the user’s localization and activity level. Once a day, an activity report is sent to the call centre, without requiring any action from the user.

If abnormal situation is detected (fall detected, user pushing the “reset button” or any other abnormal situation), the system sends an alarm to the call centre with the necessary information (type of alarm, user localization, date and time of the alarm,…). A confirmation to the user is given when the alarm is going to be sent (the users has 20 seconds to cancel the alarm before it is sent), and when the alarm has effectively been sent and received by the call centre. Call centre operator can, if necessary, get into contact with the user to get further details on the situation. Finally, adequate help is sent from the call centre.

The mobile module is battery powered. A battery charge indicator will tell the user when to change the system’s battery and put the empty one to be charged.

CALL CENTRE

Functionalities

A call centre is an organizational unit which is responsible for collecting and handling incoming calls. The call centre centralizes all information from the different patients equipped with a mobile module. Its main functions are to receive the data from these modules, analyze and save it in databases, as well as to detect and manage emergency situations.

Receive and classify information:

One call centre can manage several mobile modules (several users can use the same service). The information received from the mobile module is of different kind: activity monitoring report, once a day, and alarm message, when an abnormal activity is detected.

Activity monitoring report is received once a day from each mobile module. It includes as a minimum the mobile module ID, time and date of the report, as well as the activity level for each minute of the last 24 hours (activity level is monitored each minute). This information is automatically received, analyzed, classified and saved in the corresponding databases. If abnormal activity is detected comparing to predetermined patterns, an alarm message pops up on the call centre.

Alarm messages are received whenever a fall is detected or the user voluntarily set an alarm on the mobile module. The reception protocol of this kind of message follows specific characteristics with the required acknowledgments to ensure that the critical information is received. Such a message includes as a minimum mobile module ID, type of alarm (fall, set by user, etc…), date and time, user localization. When such a message is received, it is automatically analyzed and emergency message pops up on the call centre interface depending on the kind of alarm. Furthermore, instructions on how the carer should actuate to respond to this emergency is displayed.

Retrieve information:

Apart from the information automatically received by the call centre from the mobile module, specific information can be retrieved by the call centre, such as activity report and localization data. At a given time, the carer has the possibility to retrieve given information from a specific mobile module. Indeed, if abnormal activity is suspected, an anticipated activity monitoring report can be retrieved from the call centre, without waiting for the mobile module to automatically send it. Regarding to user localization, real time localization information can be retrieved from the call centre from a given mobile module, functionality very useful in case the user get lost and asks for help. The localization data retrieved is the last valid data acquired by the system.

Localization:

User localization data is given from the mobile module through GPS coordinates. The call centre integrates maps to automatically transform these coordinates into useful information such as the city and the street that corresponds to this GPS data.

Reports:

The information received from the mobile modules is saved within a data base. In order to facilitate medical monitoring of the users and to exploit better the available information, reporting generation functions have been implemented on the call centre. Oriented to the carers and medical staff, they aim to automatically retrieve the pertinent information from the database according to search parameters and to present it on a report. This function allows studying historical data from given users to monitor their evolution over the time.

Fig. 4: First system’s prototype
Technology

On a technological basis, the call centre is mainly made by two elements: the reception software and the call centre itself.

Reception software:
Specific software has been developed to manage the communication with the mobile modules and receive and/or retrieve the data. The application is developed under Visual Basic and is integrated to the call centre, installed on a PC. Through the serial port, a modem is activated to manage the communication protocol on UDP socket. Reception software has different routines implemented, depending on the kind of information retrieved (for critical information, additional security and acknowledgment are implemented). For the user, this reception software is totally transparent in its use.

Call centre:
The call centre has been developed as a web-delivered application to reduce cost of ownership and increase ease of deployment and maintenance regarding to desktop delivered application. Furthermore, Microsoft.net platform has been preferred towards Java application for the development for a better scalability and lower cost of development. Regarding to the databases implemented, SQL Server technology offers all the required functionalities for this application. The call centre is built according to the following architecture: Operating system is Windows, Database developed under SQL Server, development tool is Microsoft.NET platform, and user interface is web browser based.

Furthermore, security issues have been covered on the application, by defining different access privileges levels depending on the information accessible in each area of the system.

Use of the System

The use of the reception software is totally transparent to the user and carer. The call centre is based on forms, accessible to users according to their privileges by login on the system. Each category of users will have access to a determinate security level, and so to determinate functions on the system.

Once logged on (the call centre is web based and so accessible form any browser worldwide), the user accesses to different forms in which information can be filled, retrieved or parameterized. The main forms available on the system are:
- Patients: information related to the different patients equipped with a mobile module (Fig. 5),
- Devices: information related to the mobile modules available,
- Events: information related to the events received by the call centre from the mobile modules,
- Reports: reporting functions according to filters to retrieve information from the database,
- Parameters: to parameterize the call centre.

The call centre has been designed for non initiated users since carers and medical staff is not necessarily used to this type of application. Its use is intuitive, simple, and the different forms limited to the necessary features. Advanced functions have been implemented in order to automate the use of the system.

V. CONCLUSION

Growing demand on services oriented to elderly makes justified the development of improved system to help elderly live longer in their home increasing their quality of life. The product presented here represents an important step beyond the actual state of the art in services to elderly. Indeed, the service offers complete activity monitoring, automatic fall detection and user localization on a small autonomous mobile module both for indoor and outdoor use. The system, composed by a mobile module worn by the user and a call centre to analyze and save the information, has been developed as easy to use and reliable, and final user requirements have been taken into account on every stage of the development.

The first tests and validations, both realized in laboratory conditions as well as with final users (elderly in gerontology centre) show that the system meets well the requirements, is reliable (above 90 % of fall detection) and well accepted by final users.

This work has been sponsored by the European Community under the CRAFT project HEBE contract number 5935 in collaboration with partners from Spain, France and Greece.

Fig. 5: Example of the patient’s form in the call centre

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