USING SMART SENSORS AND A CAMERA PHONE TO DETECT AND VERIFY THE FALL OF ELDERLY PERSONS

Thomas Riisgaard Hansen*, J. Mikael Eklund**, Jonathan Sprinkle**, Ruzena Bajcsy** and Shankar Sastry**

* Department of Computer Science,
University of Aarhus, Aarhus, Denmark
** Department of Electrical Engineering and Computer Sciences,
University of California, Berkeley, CA, 94720

thomasr@daimi.au.dk, {eklund,sprinkle,bajcsy,sastry}@eecs.berkeley.edu

Abstract:
In this paper we present a fall detection system for elderly people. The core of the system is an intelligent sensor consisting of three accelerometers and a processor capable of analysing incoming data in real time and classifying motions events such as falls or other normal and abnormal events. The sensor is able to communicate these findings to nearby camera phones or PCs through Bluetooth for further processing. We have used the system to collect data of falls and non-falls which we have used to evaluate different algorithms.

Introduction

A major issue for elderly people living on their own is concern about their health and whether there will be someone there to help them in case of an emergency [1]. The estimated incidence of falls for independent people aged over 75 is at least 30 percent per year [2]. Sensor devices and communication technology provide the opportunity to improve the safety and security of such people by enabling them to receive assistance quickly even in the event that they are immobilized by a fall and not able to request the assistance themselves.

In this paper, a setup of smart sensors and mobile camera phones is presented. The setup uses smart sensors worn by elderly persons to detect potential situations where a fall might have occurred. This information is transmitted wirelessly to a mobile phone which queries the user about their condition, and if no response is received an alert is raised. Sensor data, pictures from the camera phone and location data is transmitted to a nearby emergency responder. However, to protect the users privacy, data is only transmitted if an alarm is raised.

Several systems exist in which emergency help can be called by pushing a button on a worn device, but in some cases a fall may result in the person being unconscious or otherwise unable to push the button either as a result of the incident or a preexisting condition, such as dementia. On the other hand many systems based on sensors automatically requesting emergency services can result in a large number of false positives.

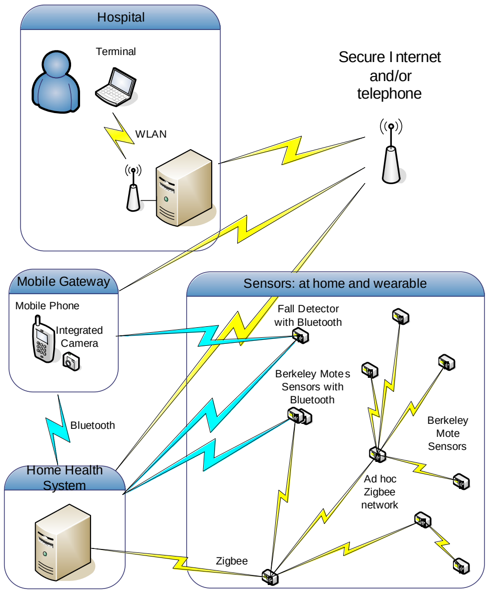

Figure 1: The Information Technology for Assisted Living at Home (ITALH) system overview

The setup we present is part of a larger project to design information technology for assisted living and home project (ITALH) [3] which incorporates many sensors both in the home and worn by the user as shown in Figure 1. In the presented setup a camera phone is used in conjunction with a smart fall detector to verify and transmit live data in case of a fall.

Technical Setup

To detect a fall we use a fall detection device equipped with 3-axis accelerometers, a GPS receiver (which is not used in this paper) and an embedded processor for analyzing the data [4]. The data from the accelerometers are processed locally and if a suspected fall is detected a connection is made to a camera phone through Bluetooth and the data from the sensor box is then streamed to the phone.

The phone first attempts to make contact with the user by using the external speakers on the phone and requests

 ISSN: 1727-1983

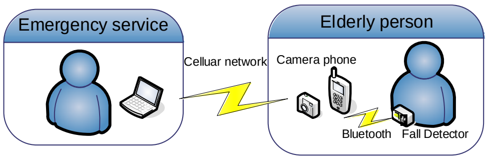

Figure 2: Fall detector system setup

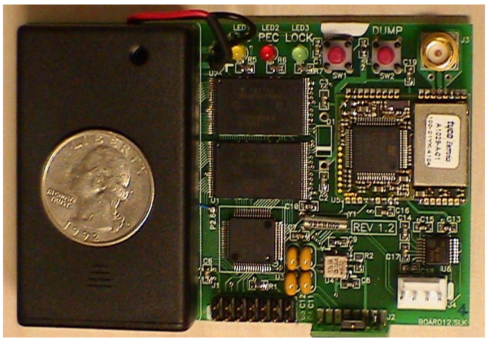

Figure 3: The Berkeley GPSADXL fall sensor

a vocal or keypad response from the user. In case of a serious situation, triggered by the user not responding or actively requesting help, the phone will automatically call an emergency service and the data from the phone is streamed to the emergency service worker who will be able to access the data from the microphone, camera and fall detector to further analyze the situation. Figure 2 shows an overview of the system.

Fall detector

The fall detection sensor used in the system is based on the second generation of a device developed at Berkeley. The device has been used to collect data and test different fall detection algorithms and communication protocols. It is based on the "GPSADXL", a microcontroller-based data logging system that integrates two $\pm$ 10g MEMS ADXL210 accelerometers with a compact GPS module and four megabytes of static RAM. The device is powered by three AAA 1.2 volt rechargeable NiMH batteries and measures 63.5 mm x 95.2 mm x 17.8 mm (2.50" x 3.75" x 0.70") and is shown in Figure 3. The battery life of the sensor board is approximately 10 hours and it can store approximately 4 hours of data recordings. Each MEMS accelerometers has two measurement axes and they are arranged at a ninety degree angle to each other to allow the measurement of acceleration in three dimensions and provide acceleration data at a rate of 80 sample groups per second. The GPS module supplies time of day and latitude and longitude information, as well as "lock" status and the number of satellites in view. The accelerometer and GPS data are transmitted in ASCII form via serial RS-232 communications to an external device. The serial port settings are: 115,200 baud, 8 data bits, no parity, no flow control. A detailed description can be found in [5].

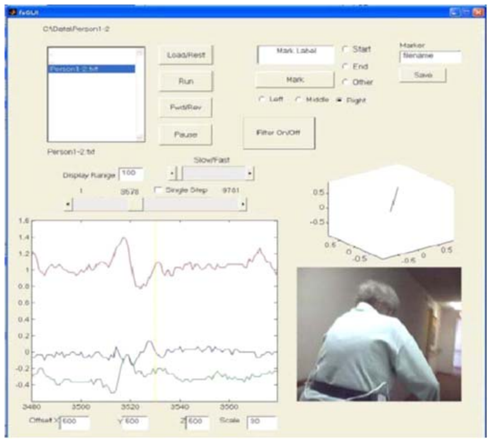

Figure 4: Graphical User Interface for segmenting and filtering the camera and fall sensor data

Wireless connection

In the initial version of the fall detector's embedded software, the data was stored on board then dumped via RS-232 to a laptop computer for analysis of the data. Later, the fall sensor device was connected to the SensorNet web by using BlueGiga Bluetooth RS-232 cable replacement device to enable wireless connection to a laptops and mobile phones.

The software on the fall sensor was then upgraded to support the use of a BlueGiga Bluetooth RS-232 cable replacer, which enabled streaming of data in real time to nearby laptops and mobile phones.

We used this wireless connection in two different ways:

- For development purposes we streamed all captured from the fall sensor to a PC that timestamp and stored the data in a file together with time stamped images captured with a USB web cam.
- For testing the fall detection algorithm we only initiated a connection from the fall sensor if a fall was detected by the algorithm. A nearby PC or phone would run a C++ program called BlueServer that was able to respond to incoming Bluetooth Request.

The BlueServer program running on the PC used the Microsoft Socket API to access the Bluetooth Stack. The phone version ran on Nokia 6680 Symbian phone and used the API provided by Symbian to access the Bluetooth stack.

Data recording and analysis tools

To analyze the data offline a set of programs were developed. On the laptop PC, a C# program, FallGraph, was written which displays the streaming data from the accelerometer and the BlueServer program in real time. Additionally, Matlab programs were developed which allowed for direct integration with Matlab in which the fall detection algorithms are being developed.

ISSN: 1727-1983 © 2005 IFMBE

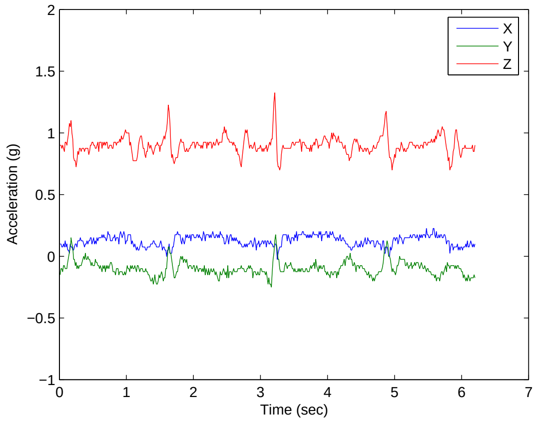

Figure 5: Subject 1 walking

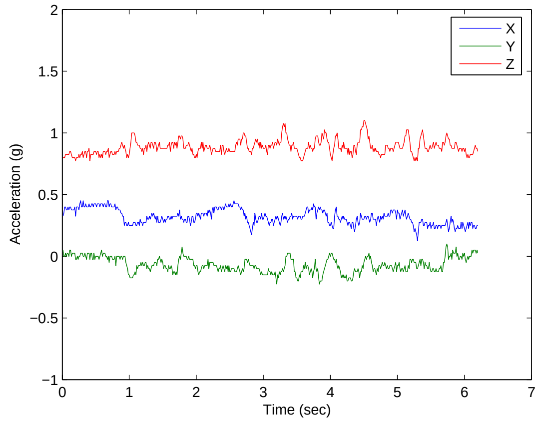

Figure 6: Subject 2 walking

To enable algorithm development, tools for segmenting and classifying the data in to the various activities was developed which included the integration of USB web cameras into the system. With the camera images synchronized to the acceleration data, we were able to extract the epochs of interest from the data and classify them in to the appropriate categories, e.g. walking, sitting, standing, falling. The Matlab GUI shown in Figure 4 was developed to assist in this by enabling the display of the data and images individually or as movies. The data and images can be paused, reversed, steped, etc. through the images; the user can annotate the images with start, end and other marks, and extract and save the epochs of interest for later analysis such that they could be grouped by category.

Results

We have built a prototype version of the described system where we are streaming live data from the fall sensor and live video from the camera on the mobile device to a nearby PC over Bluetooth (to simulate high bandwidth wireless Internet access not yet available in the US). We envision using high speed 3G networks to stream video and sensor data to emergency services, but in this preliminary version we use Bluetooth.

This prototype is being used in on-going data collection for the fall detection algorithms at a local elder care facility, where further information about what characterizes fall situations is being evaluated, and the prototype will be used to study the usability of the system and its acceptance by the study participants.

The purpose of the data collection sessions so far has been to acquire data from a set of different elderly persons doing normal activities. Data collection sessions have been done at a facility near Berkeley, where a group of elder people live in their own or shared homes, and also on the Berkeley Campus.

For the data collection the recording tools described above were used and we were able to capture over an hour of picture and fall sensor data with three elderly persons doing daily activities e.g. walking with walker, sitting in soft chair, showing pictures, running to get a phone, stretching, making coffee, walking outside, and telling stories.

In this paper a comparison between two of the subjects is presented in two specific tasks: walking and sitting. Both subjects were females over the ages of 65. One walked with the assistance of a walker, the other walked unassisted. In Figure 5 and Figure 6 the distinct walking pattern of Subject 1 with the walker is clearly visible through the higher spikes in the Z axis acceleration with a period of about 1.75 sec, and the flatter periods between the spikes.

A clear distinction is also seen in the sitting data in Figure 7 and Figure 8, in which the less mobile Subject 1 accelerates (down from 1g in the Z axis) very slowly compared to Subject 2. Subject 2 also demonstrated more control during the sitting movement by slowing the downward acceleration before impact at about 2.0 sec.

In addition to the collection of data from these subjects, they have provided valuable feedback on the form factor requirements of such devices, the likely acceptance of them by elderly users and the value that they would place on such technology. All have been very positive and encouraging.

Conclusions and Future Work

Falling is one of the main health concern for elder people. In this paper we have proposed a system that uses a smart sensor to detect potential situations in which a fall might occur. We use a mobile phone to further verify that the fall has occured and to notify emergency services.

An embedded processor with a three-axis accelerometers has been developed and used with Bluetooth wireless connection to create a system for development and evaluation of fall detection algorithms. Data has been collected and an initial set of fall detection algorithms have been developed. The fall sensor can connect to a

 ISSN: 1727-1983

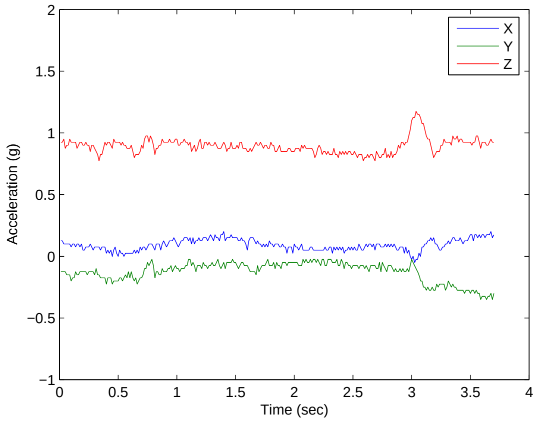

Figure 7: Subject 1 sitting down.

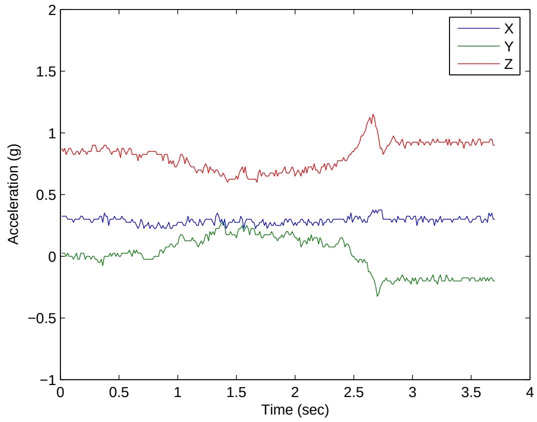

Figure 8: Subject 2 sitting down

laptop PC for data collection and system evaluation, and to a mobile telephone for data and alert monitoring.

Using the data segmentation and classification GUI, these data are grouped into appropriate categories for use in identifying algorithms to correctly identify the activities of the subjects. Once the normal activities are identified, studies will be conducted with the same equipment with subjects trained to fall safely (e.g. Judo and/or drama students). With these subjects, the normal activities performed by the elderly will be repeated in order to mimic their activities and then they will perform safe falls in a controlled environment. Using this data, an initial set of algorithms will be applied and used by the elder in order to determine and reduce the false positive rate. Validation of the fall detection with the elderly will only be performed following this, and in a safe and controlled environment.

This is one of the primary functional components of the ITALH project and will provide for emergency notification and rapid evaluation and response. The sensor system can be worn continuously and will be capable of interfacing to a home based system as well and the mobile system, thus relieving the user of carrying the mobile device at all times. Other wearable sensors will also be added in a modular manner to the mobile system and a primary focus of future work will be the improvement of the fall detection algorithms and the integration of wider ITALH project.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance and participation of the Center for Information Technology Research in the Interest of Society (CITRIS), Nokia, Steven Glaser, Garrett Brown, Rustom Dessai and Albert Chang in their continuing work of this project, and the volunteer subjects involved in this on-going study.

References

[1] Philip E Ross. Managing care through the air. *IEEE Spectrum*, pages 26–31, December 2004.

[2] A Sixsmith and N Johnson. Smart sensor to detect the falls of the elderly. *IEEE Pervasive Computing*, 3(2):42–47, April-June 2004.

[3] J Mikael Eklund, Thomas Riisgaard Hansen, and Shankar Sastry. Information technology for assisted living at home: building a wireless infrastructure for assisted living. In *27th Annual International Conference of the EMBS*, 1-4 September 2005.

[4] Ruzena Bajcsy, Jay Chen, Karric Kwong, Dennis Chang, and Jerry Luk. Fall detection using wireless sensor networks. In *27th Annual International Conference of the EMBS*, 1-4 September 2005.

[5] Garrett Brown. An accelerometer based fall detector: Development, experimentation, and analysis. Technical report, Summer Undergraduate Program in Engineering at Berkeley (SUPERB) 2005, University of California, Berkeley CA, 94720, August 2005.

ISSN: 1727-1983