A wireless platform for fall and mobility monitoring in health care

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ABSTRACT

In this paper a new platform for monitoring of mobility in health care is presented. The platform was designed with a primary aim at monitoring of mobility and fall incidents in elderly people and is part of a wider system that uses web interfaces to gather data on several vital signs, mobility and fall events, and to communicate with the elderly people and warn family, health carers or emergency services if necessary. The fall and mobility sensing platform is based on measurements of the subject's accelerations in three degrees of freedom. Gathered data can be relayed to a mobile phone using a Bluetooth radio after which the information can be relayed to a web server. In this paper the design of the platform and tests with healthy subjects and with elderly subjects are discussed.

Keywords: Mobility monitoring, fall sensing, wireless communications

1. INTRODUCTION

Current demographic trends in Europe suggest that for the foreseeable future the relative number of elderly people will continue to rise. This will of course put a higher strain on the elderly care systems across Europe. To reduce the cost of this care, but more importantly to increase the quality of living for those involved, it is of prime importance for elderly people to stay independent as long as possible. For this reason various research projects strive to develop sensor systems to aid the elderly in their daily lives and to relay warning and distress signals to family, care givers and emergency services. However, it is of great importance to recognise potential issues the elderly may have at an early stage. This will result in both improved quality of life for the elderly, but also reduced revalidation and hospitalisation costs as health issues can be dealt with before they develop into more serious problems. A common problem with elderly people is their reduction in mobility, which, almost always, will result in trip or fall events at some stage. The results of a fall can be dramatic, leading to long hospitalisation and, not seldomly, death as a direct or indirect consequence of the fall. The University of Limerick and the National University of Ireland, Galway, have been actively involved in a European project with the name CAALYX [Boulos et al., 2007], targeting the above mentioned health monitoring of elderly people. As depicted in figure 1 the project aims to develop a highly integrated health signs sensing and communication system for elderly people and their family, care takers and emergency services.

The elderly people are equipped with several health signs sensors: a fall sensor, blood pressure meter and ECG sensor, which wirelessly relay the gathered data to a 3G enabled phone or, in the home environment, a PC. The data is then relayed to a server, which can be consulted by health practitioners. The server relays events and alerts automatically to a care centre specialised in processing these events and alerts. Within the University of Limerick and the National University of Ireland, Galway, a wireless fall and mobility sensor has been developed for mobility monitoring and fall event identification. The system is based on the use of accelerometers to measure acceleration of the user in three degrees of freedom. The acceleration data is then analysed for activities of daily living (ADL) and trip or fall events. In this paper the design and implementation of the fall and mobility sensor system is described. Results from tests on healthy subjects within the University of Limerick and results from trials with elderly volunteers will be presented and discussed.

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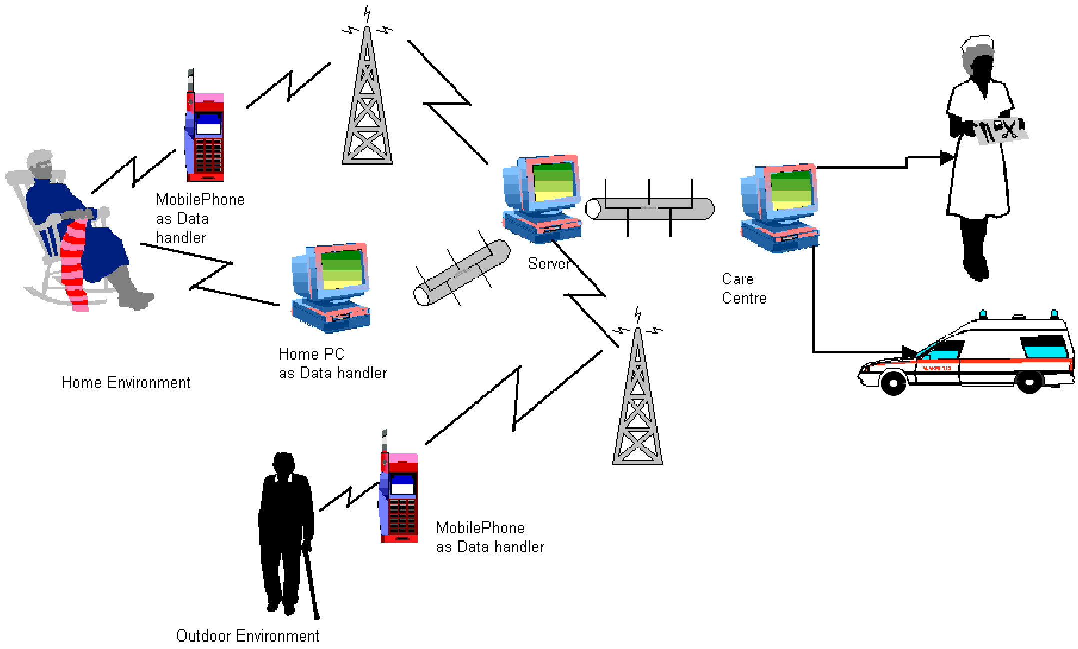

Figure 1: The CAALYX system

2. FALL AND MOBILITY SENSOR DESIGN

The fall and mobility sensor is based on a Freescale tri-axial accelerometer controlled by a Texas Instruments low power microprocessor. The microprocessor is used for AD conversion of the accelerometer data, extraction of mobility and fall data, storage of the data on a micro SD card and communication with a pc or mobile phone. A block schematic of the fall and mobility sensor system is shown in figure 2. The Bluetooth module used in this design is the Roving Networks RN-24.

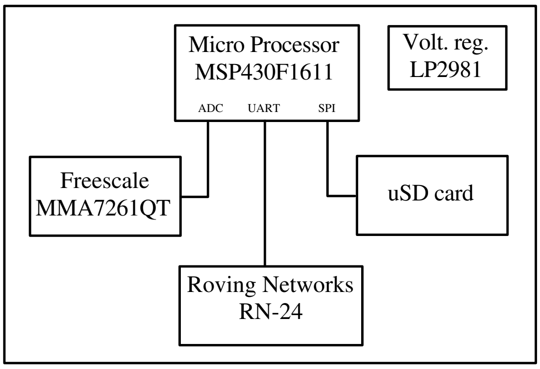

Figure 2: Block diagram of fall and mobility sensor

2.1 Microprocessor

The Texas Instruments MSP430F1611 was chosen for its low power consumption, sizeable memory (48kB flash with 256B user flash and 10kB RAM) and relatively high speed (8MHz). Using the IAR workbench or similar software, the MSP430 can be programmed using C/C++ or assembler. The MSP430F1611 is equipped with a 16 bit RISC processor, 3 DMA channels, a 12 bit ADC converter with 16 channels, a 12 bit DA converter, a hardware multiplier, 2 independent timers, 2 USARTs which can implement UART, SPI or I2C communication and a watch dog. Due to this impressive selection of hardware interfaces and the availability of three DMA channels, it is possible to implement significant functionality without the need to have the core of the microprocessor running continuously.

2.2 Freescale accelerometers

The Freescale MMA7261QT tri-axial accelerometer is a low cost accelerometer with selectable outputs between $\pm 2.5 - 10g$[1]. The principle of operation is based on sensing changes in capacity due to flexing of moveable beams under the influence of accelerations. With a power consumption of $500\mu A$, the sensor is ideally suited for low-power applications. The measured accelerations are filtered using on-board single pole switched capacitor filters and can be directly fed to an AD converter.

2.3 Bluetooth module

The Roving Networks RN-24 can be obtained as a class 1 or 2 module on a small pcb, which allows for through-hole, and thus easy, integration on prototype pcb's. The module offers sustainable data rates of up to 100 kb/s at transmit/receive powers of around 30-50 mA with which it is by far the biggest consumer on the board. Power consumption can be minimised by using appropriate sleep modes.

2.4 Power supply

For the prototype of this platform a rather large Lithium Ion battery with capacity of 1000mAh was chosen. With this battery it is possible to transmit mobility data constantly for periods exceeding 10 hours. For future applications, in which mobility data will normally only be stored locally and

[1] g Is the gravitational constant in $\frac{m}{s^2}$.

only urgent information is relayed using Bluetooth, the battery can be chosen far smaller. The battery voltage is reduced to 3.3 volts by a Texas Instruments LP2981-33 low drop-out voltage regulator.

3. FALL AND MOBILITY SENSOR ALGORITHM

A flow chart of the fall algorithm is shown in figure 3. The fall and mobility sensor continuously monitors the acceleration of the user. Using appropriate thresholds, both in acceleration and in time, the algorithm establishes whether the user has fallen and whether or not the user has recovered from this fall. While making its decisions, the algorithm takes into account the attitude and position of the user, the time (s)he needs to recover from a stumble and the relative time that the user spends lying, sitting or standing after a suspected fall. In addition to giving reliable information as to whether family, care givers or emergency services should be warned, the algorithm also assists health carers to assess the patients well-being and mobility trends over a much longer time-scale.

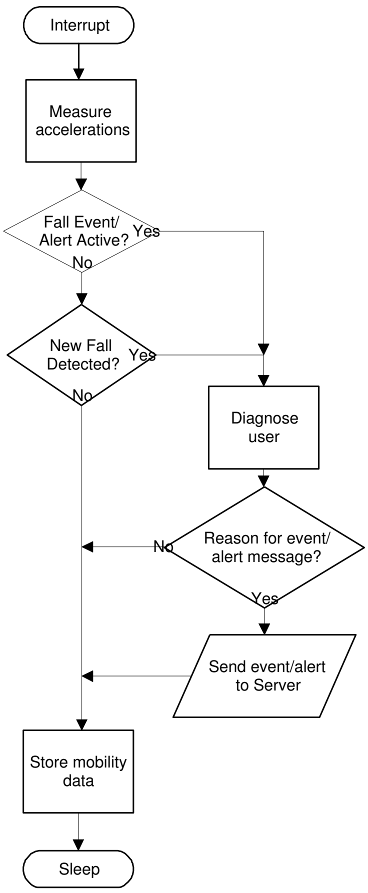

Figure 3: Flowchart of fall algorithm

4. JAVA INTERFACE

For ease of communication, debugging and data gathering, a Java interface for the fall and mobility sensor was developed. With this interface a personal computer can gather data from the fall and mobility sensor at run-time (currently 1200 bytes/second), fall event and alert messages can be relayed, the fall and mobility sensor can be calibrated and various settings, such as remote MAC address for communication, sampling rate, mobility data parameters and Bluetooth role (master or slave) can be configured.

4.1 Message Protocol

A message protocol was defined for bi-directional communication with the fall and mobility sensor. The payload of the message, with a maximum length of 226 bytes[2], is preceded by a delimiter (0xFC) and 8 byte header and followed by a second delimiter (0xFD). As the second byte of the header contains the message type, the protocol allows for early decisions on whether or not to read a message. The number of bytes to be read is stored in the first field of the header. In combination with the delimiters, the message length is used to decide on the integrity of the received message.

5. TRIALS WITH HEALTHY SUBJECTS

The algorithm developed for the University of Limerick fall and mobility sensor was based on research carried out by [Bourke et al., 2006]. In this work a total of 10 young subjects were recorded performing a number of simulated falls and 10 elderly subjects performed a series of normal ADL. This research provided the fall impact threshold used in the current algorithm. To achieve greater compliance with wearing the fall and mobility sensor located at the chest, a specially designed vest was developed as an alternative to the chest strap used in the previous study [Bourke et al., 2006]. The CAALYX Fall and Mobility Monitoring (FMM) Vest is a light weight garment (230g) with a zipper on the front for ease of donning and doffing of the garment. Support elastic is incorporated into the vest to ensure the sensor is held close to the body. A pocket is located at hip level for a mobile phone which can be used as the message handler instead of the pc based Java application. For the CAALYX project a Nokia N95 was chosen.Subjects performed a series of simulated falls and normal ADL while their movements were recorded using the fall and mobility sensor. The subjects were young (<35 years) healthy males. A total of 10 subjects were recruited for the study. The mean $\pm$ standard deviation age, height and mass of the subjects were 23.4 $\pm$4.6years, 1.8$\pm$0.076m and 80.9$\pm$13.3kg respectively. The exclusion criteria for this group was a history of any balance impairment, unexplainable spontaneous falls, neurological disease or uncorrected visual shortfall and all claimed to exercise regularly ($\geq$4 hours/week). All subjects, from this simulated fall-event study, gave written informed consent and the University of Limerick Research Ethics Committee approved the protocol. The fall types were selected in order to best simulate the type of fall that may occur and cause injury to an elderly person. Each fall was performed with the subject initially in a standing position. All the falls were performed onto large crash mats with a combined thickness of 0.76m. The simulated falls performed were: forward, backward and lateral falls left and right. All with both legs kept straight and with knees relaxed to allow knee flexion. Each fall was performed 3 times. Thus a total of 240 falls were recorded. The normal ADL that were performed include:

[2]The maximum payload size is determined by the wish to send DM5 packets in order to keep energy consumption to a minimum.

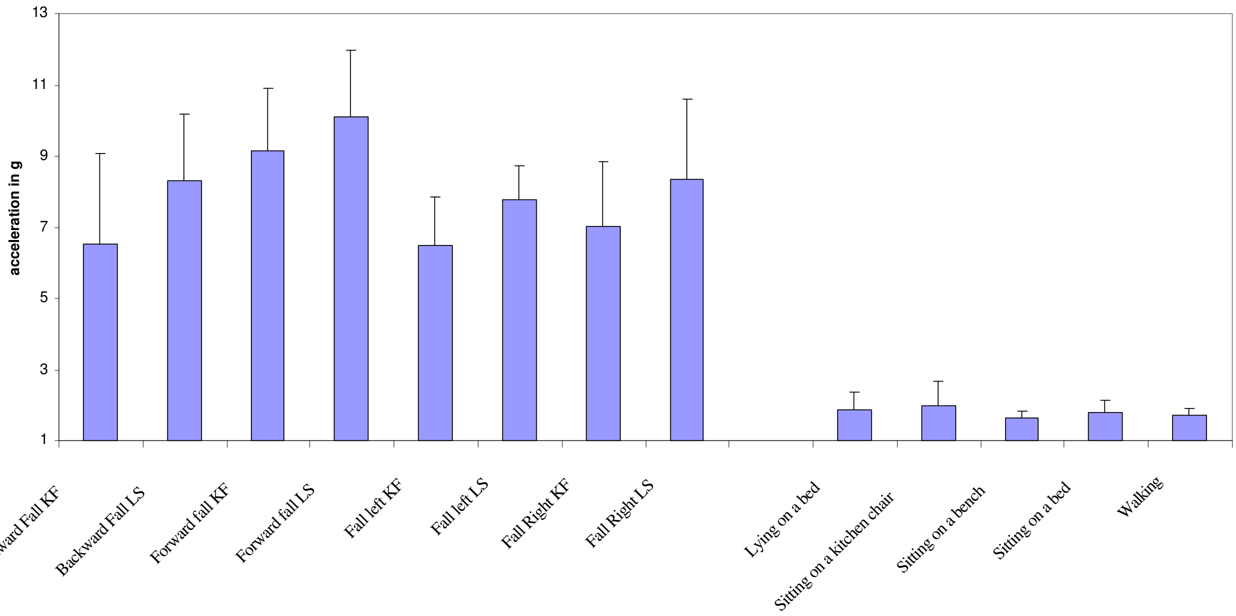

Figure 4: Mean (bar) and standard deviations (line ending in horizontal bar) for upper peak values in fall and normal ADL

sitting on a kitchen chair, sitting on a bench, sitting on a bed, lying on a bed and walking 10m. All were repeated 3 times. Thus a total of 150 ADL were recorded.

5.1 Data Analysis and Results

The accelerometer data from the fall and mobility sensor was calibrated and the resultant vector (R) magnitude for all the falls and ADL produced using the following formula:

$$R = \sqrt{x^2 + y^2 + z^2} \tag{1}$$

The Upper peak value for each fall and ADL was then recorded for later analysis. The recorded upper peak fall mean values were generally concentrated between 6g and 10g and the upper peak fall mean values were generally concentrated between 1.6g and 2g.

6. TRIALS WITH ELDERLY SUBJECTS

After the successful completion of the trials with healthy subjects, the fall sensor was used in an experiment involving the monitoring of elderly subjects as part of the aforementioned CAALYX project. In this experiment the fall sensor was part of a suit of sensors chosen to demonstrate the feasibility of unobtrusive monitoring of elderly subjects in daily living. During four weeks elderly people were equipped with the fall sensor for eight hours per day. In the first two weeks of the experiment over 400 hours of high resolution ADL data was gathered. Preliminary analysis of this data shows that 19 false positives, i.e. events mistakenly interpreted as falls, were triggered during these two weeks. However, many of these false positives can be attributed to sensor donning and doffing.

7. CONCLUSIONS

In this paper a wireless fall and mobility sensor platform which is part of a body area network constituting a health monitoring system for elderly people was described. The fall and mobility sensor, containing accelerometers, a microprocessor, μSD storage capability and Bluetooth communication capabilities was successfully used in trials with young, healthy subjects performing various falls and normal ADL. A major advantage of using the fall and mobility sensor in a body area network is the large decrease in intrusiveness of the experiments. Data was gathered using a versatile Java interface that can also be used for sensor calibration and configuration. The fall and mobility sensor platform is part of a wider system that targets health monitoring of elderly people, called CAALYX. As part of this European project the fall sensor system was tested in trials with elderly people performing normal ADL. Preliminary results of these experiments show that most false positives are due to donning and doffing the system.

8. REFERENCES

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