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Event detection in an assisted living environment

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***Abstract*—This paper presents the design of a wireless event detection and in building location awareness system. The systems architecture is based on using a body worn sensor to detect events such as falls where they occur in an assisted living environment. This process involves developing event detection algorithms and transmitting such events wirelessly to an in house network based on the 802.15.4 protocol. The network would then generate alerts both in the assisted living facility and remotely to an offsite monitoring facility. The focus of this paper is on the design of the system architecture and the compliance challenges in applying this technology.**

I. Introduction

At present assisted living facilities rely on a variety of methods to alert to a fall within a facility – the majority of these are based on physical checks and periodic inspections of specified areas. In certain purpose built facilities there are more sophisticated technology solutions in place to monitor and track such events however there is a significant cohort of facilities that were not built for this purpose. These invariably do not have adequate network infrastructure in place to support a technology based solution.

The aim of this paper is to set out the approach to implement a wireless solution in a building that is more than 80 years old and has been operating as an assisted living facility for over 30 years.

For the purpose of this paper we are concerned with the system architecture and end user compliance over and above any wish to validate the event detection or location awareness algorithms.

The project monitored the following aspects:

- Device deployment
- Battery management
- Residents' device allocation
- Residents' position monitoring
- Fall detection
- Communications and alerting

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II. Method

Shimmer[1] is a small wireless sensor platform designed for wearable health-sensing applications. The key features of the device are as follows:

- 8MHz Texas Instruments™ MSP430 CPU (10Kbyte RAM, 48Kbyte Flash, 8 Channels of 12 bit A/D)
- Class 2 Bluetooth® radio
- 2.4GHz IEEE 802.15.4 Chipcon™ wireless transceiver
- 3-Axis Freescale™ accelerometer
- MicroSD™ slot for up to 2Gbyte
- Integrated Li-Ion battery management
- Wearable form factor
- Extension connectors (Internal and external) for application customisation and increased functionality

In this project, Shimmer as seen in figure 1 was used as the wearable sensor with a cohort of 5 residents. The device was worn in a pocket with some residents, while the others used an elastic strap with a plastic clip in order to wear the device.

Fig. 1. Shimmer device with the elastic strap.

An 802.15.4 network was installed in order to transmit position, status and alarms, as in figure 2:

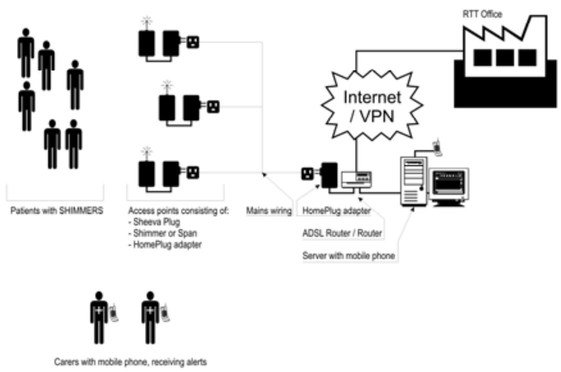

Fig. 2. Event detection project architecture.

As Access Points (AP) for this structure, a small Linux based wall-wart form factor computer (Sheeva Plug [2]) was used, together with the Shimmer Span [3], an 802.15.4 Access Point, member of the Shimmer platform.

Given the relatively small coverage of the AP's, a network had to be installed, consisting of 6 AP's. As no network cabling was present and in order to minimize the disturbance of the environment, an Ethernet-over-Powerline structure was implemented.

All AP's were connected as clients to a laptop computer that had server software receiving UDP messages from the Shimmer devices over AP's / network.

The server computer/software was able to perform the following functions:

- Residents' management
- Nurses management (including the SMS communication)
- Device allocation
- Mapping of the location
- Alert management (battery, falls)
- Communication (SMS messages sent when alarms occurred), including local visual and audio indications

III. Device Configuration

In order to perform the fall detection, Shimmer devices were programmed with a fall detection algorithm that monitored the status of the accelerometers on the device. Independently of the fall detection status, Shimmer's area location was monitored by the communication to the closest AP where Shimmer was last visible. While this is not a very precise location detection mechanism, it was deemed sufficient in the case of the scope of this project.

IV. Fall Detection

In general, the fall detection algorithms are based on monitoring the output of an accelerometer and checking for patterns of activity.

In order to detect falls, one or more of the following methods are employed:

- Energy expenditure, described in [4], being the sum of the integration of the square of the dynamic acceleration of the person for the specified time;
- Modulus acceleration monitoring, based on dynamic acceleration compared to thresholds and sequence of events;
- Data analysis based on Kernel Fished Discriminant or other AI methods[5];
- Modulus acceleration and angular speed monitoring, based on dynamic acceleration compared to thresholds and sequence of events[6];
- Monitoring of acceleration on each axis, employing thresholds and sequencing of events [7].

A comprehensive analysis of the different algorithms and placement of the sensor is in [8].

We chose to use a Modulus acceleration monitoring, as it was the most obvious to implement in an assessment project such as ours.

As per study [8], the Shimmer device was installed in the median area of the body (belt or pocket worn), in order to minimize the impact on the subject.

In order to achieve this, the data was processed as follows:

- data was sampled at 50 Hz;
- an averaging moving window over 32 samples (0.64 seconds) was maintained, in order to compute the dynamic acceleration (see fig. 3)

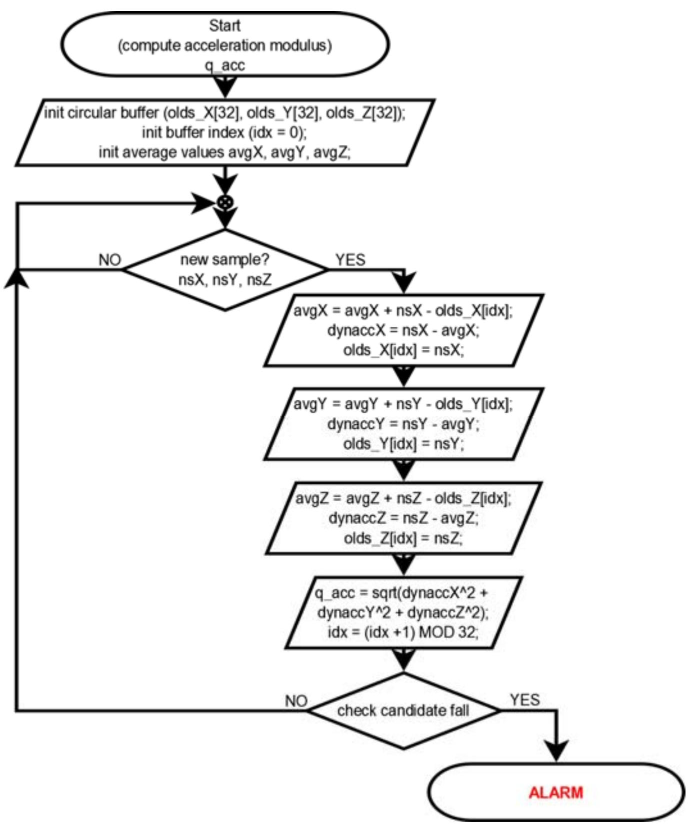

Fig. 3 Calculating acceleration modulus

(in Fig 3, *q_acc* is the calculated acceleration's modulus, *avgX, avgY and avgZ* are the averaged acceleration on the three axes, wich is incremented with *new_sample(nsX, nsY and nsZ)* and decremented with *old_sample (olds_X, olds_Y and olds_Z)*, then the *old_sample* on each axis is updated with *new_sample*, maintainded in a circular buffer)

- the dynamic acceleration's modulus was compared against a threshold, in order to detect the start of the candidate fall;
- the candidate fall was then checked against of a double-bump pattern which would indicate a fall or a false alarm.

Applying the above algorithm to the backward fall will result in a acceleration modulus exemplified in below graph (fig. 9). Similar graphs are obtained in the case of forward and sideways falls.

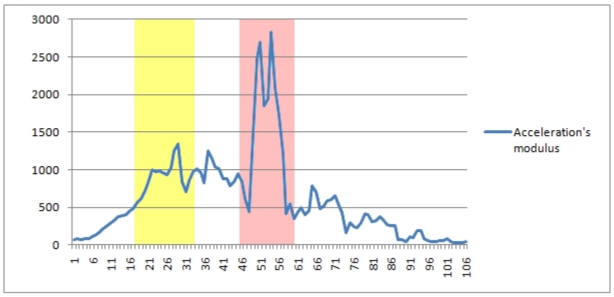

Fig. 4. Acceleration's modulus calculated for backward fall.

There are two regions to be monitored, the start of the fall (the yellow area) and the end of the fall (the red area), when the body hits the floor. The moment when the body hits the floor produces a sharp rise in the modulus of acceleration.
By comparing the two regions amplitude with prescribed thresholds, a fall detection algorithm can be implemented in Shimmer's.

V. COMMUNICATION

Whenever a fall is detected, an alarm has to be raised. The communication infrastructure ensures that the alarm is properly dispatched and the location where the fall happened is indicated.
The Span's configured as AP's can maintain a map of the area where each subject worn Shimmer was visible last. This is done via the 802.15.4 network that automatically manages the connection of each Shimmer to the closest AP. Each Span used as an AP was configured to send an UDP message whenever a Shimmer connected to it. That message identified the Shimmer and the Span that was connected to. The server computer received that message and updated the location's map to be used in case of alarm.
In case of alarm, a different communication mechanism was triggered; in this case Shimmer directly connected via AP's to the server, sending a TCP message that was repeated until the message was received by the server. The message was then dispatched as an SMS message to the list of phones of the carers allocated to the respective subject and a local alarm was raised.
The communication from Shimmer devices to the server was using the 802.15.4 radio module in Shimmer and Span. The custom firmware on Shimmer was based on the Telnet server exemplified in the Shimmer's TinyOS firmware branch [9][10].

VI. SERVER SOFTWARE

The server software is based on a MySQL database, installed locally – but support for a remote database exists as well. The database stores each member's of the cohort data, the carers details and access phone numbers, Shimmer devices, AP's, and allocation of Shimmers and carers to the subjects. The event logs and reports are maintained in this database as well.
The software provides a user friendly interface to the database and manages the messages received through the system.

VII. PROJECT DEPLOYMENT

The assisted living facility was mapped and AP's were installed in order to maximize the coverage area. While there was some overlapping between AP's, the location detection was properly managed by the Shimmer/AP 802.15.4 mechanism. The location of the devices was reported back to the server, and a mapping of the residents' location was maintained reliably based on a zoned layout of the facility.
In order to maintain the battery charge, each resident was supplied with a Shimmer charger dock, which was to be used during the night.
The staff nurses were trained to use the system and respond to alarms. The standard "Fall Report Form" (paper based approach that was in use) was included in the software on the server, in order to make the system more useable, and help in keeping electronic records.
The training was carried out in two stages, in order to ensure that the devices are properly managed (it was envisaged that some of the residents needed assistance in order to dock Shimmer for charging).
A test run was performed, with simulated falls / trips.
The database was loaded with the resident, nurses and devices data.
The cohort that was part of the project was fully briefed on the project goals and the usage of the devices.
The deployment outcome was a functional system, passing all the technical tests required.

VIII. PROJECT RUN

The project was intended to run over a period of six weeks, with a review period of two weeks.
However, from the very first stage it became evident that the cohort were not able to manage the devices themselves. The role of the staff nurses was increased to help in managing the devices and a new procedure was designed for this approach.
During the project run, there were several cases when the devices were not charged, not worn or damaged by mishandling (in several instanced the devices were washed together with the garments).

No fall occurred or was detected during the project, which is positive in respect to the cohort's wellbeing, but did not prove the functionality of the device in this context. The project was terminated after 3 weeks.

IX. RESULTS

The raw data collected by Shimmer is exemplified in the following pictures.

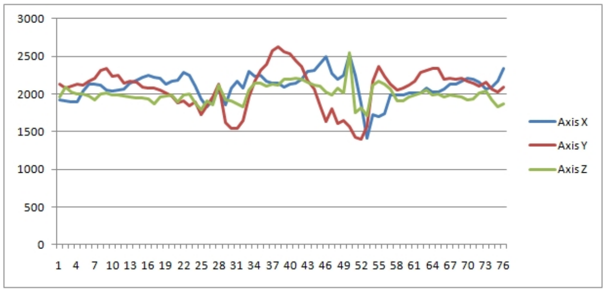

Fig. 5. Typical walk Shimmer collected raw data.

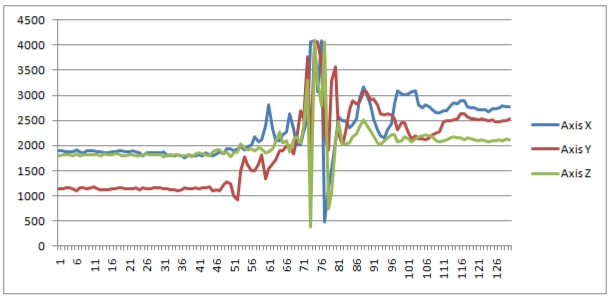

Fig. 6. Backward fall Shimmer collected raw data.

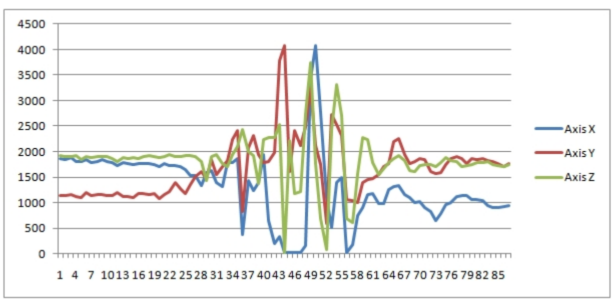

Fig. 7. Forward fall Shimmer collected raw data.

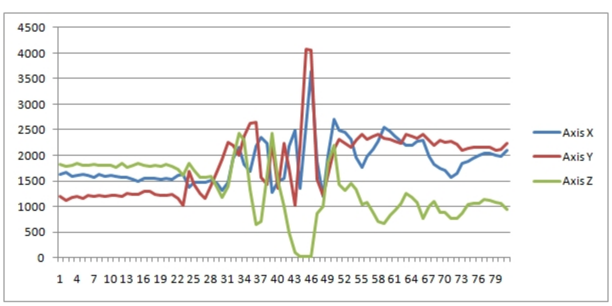

Fig. 8. Sideways fall Shimmer collected raw data.

As visible in the above graphs, the data collected by Shimmer provides enough granularity to enable fall detection. However, there are cases when false alarms are triggered or just at the borderline and further decision has to be based on advanced algorithms.

X. DISCUSSION

From a technical standpoint the project did not provide enough data to validate or otherwise the system architecture and associated algorithms. Some of the key findings include:

- The battery charging process is too frequent, people forget to charge it – it should be greater than one week between charges.
- Integration into a garment or more ergonomic form factor should improve one element of the compliance.
- The sensor device should be wearable in the shower and therefore needs to be waterproof.
- There should be regular updates – either automated or manual – indicating the system is still working and monitoring.

Most of the issues were related to compliance with the user interaction procedures that were designed. These procedures need to be more user-friendly and any solution deployed should include greater end user input.

XI. FUTURE WORK

Future work will integrate and test the key learning's associated with the end user compliance aspect of any implementation. To this end we will develop this project in conjunction with partner company Insight Diagnostics who work with a more controlled in-clinic cohort to increase compliance and ease of user interaction.

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