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Embedded Fall and Activity Monitoring for a Wearable Ambient Assisted Living Solution for Older Adults

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Abstract— **With the rapidly increasing over 60 and over 80 age groups in society, greater emphasis will be put on technology to detect emergency situations, such as falls, in order to promote independent living. This paper describes the development and deployment of fall-detection, activity classification and energy expenditure algorithms, deployed in a tele-monitoring system. These algorithms were successfully tested in an end-user trial involving 9 elderly volunteers using the system for 28 days.**

I. Introduction

The world's population is "greying", with the proportion of the world's population aged 60 and older set to double to more than 22% of overall population by 2050 [1] Within this group those aged 80 and over, are the fastest growing, and are expected to represent 20% of this older population by 2050 [2]. Injuries as a result of falls are a primary health risk for this population, both in a home environment, hospitals and residential care homes [2]. With the recent progress in sensor miniaturization, wireless communication technology and increased affordability, this has enabled the development of more inexpensive wearable health monitoring systems. Thus, in order to reduce this projected burden on state and private health care services as well as individual health care cost, greater emphasis will be put on technology and care models to monitor the vital parameters of elderly people while at home and detect emergency situation, such as falls. Thus enabling and promoting independent living in their own homes for longer so that health-care costs can be kept manageable [3], thus also safely extend the period of residence of elderly people [4].

A number of fall detection systems do currently exist [5],[6],[7],[8]. However few fall detection system have been incorporated into a tele-monitoring system. One that has successfully been deployed in that developed by Tunstall[1], however limited results on accuracy in a real-world environment are available.

An example of the type of telemedicine system for monitoring of activity and the detection of falls in older adults to promote independent living is that developed during the eCAALYX project.

II. eCAALYX - A Telemedicine System

A. Overview

The eCAALYX project [9] (Enhanced Complete Ambient Assisted Living Experiment) (06/2009-06/2012 – http://ecaalyx.org/) is a three-year project funded by the European Commission under the Ambient Assisted Living (AAL) Joint Programme (http://www.aal-europe.eu/). The project builds on the strengths of the infrastructure and functionality already developed in the CAALYX project [10] (http://caalyx.eu/). One of the main objectives of the eCAALYX project are to provide a complete solution to improve the quality of life, reduce morbidity and mortality of elderly people suffering from chronic diseases via monitoring and assessing changes in activity of the patient. The system aims to fulfill these functions both inside and outside the home. The eCAALYX system is thus composed of three main subsystems, namely; the Home Subsystem, The Mobile Subsystem and the Caretaker Site, Fig. 1.

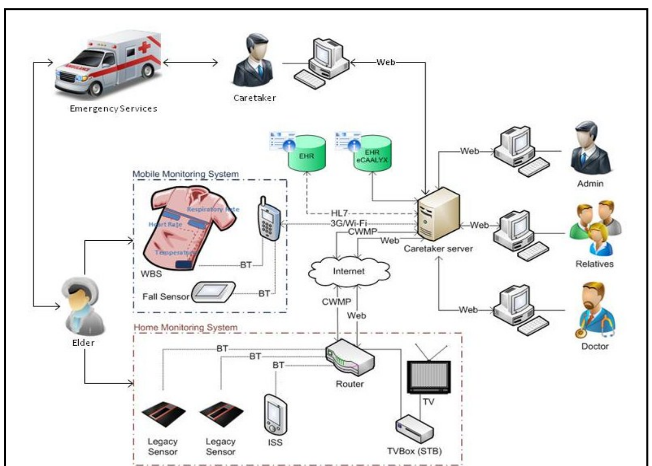

Figure 1. The eCAALYX System overview, including the three main parts: the mobile system, the home system and the caretaker site. Also shown are the end-users: Elder, Doctor, Caretaker, Relatives, Administrator and The Emergency Services.

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[1] Tunstall Ltd, Whitley lodge, Yorkshire, England.

B. The Mobile Monitoring System

The monitoring of human movement using strap-down kinematic sensors is now a major area of research and is quickly becoming a part of people's everyday lives [11]. The development of algorithms for the classification of; the intensity and type of activity [12] and the detection of falls , using body-worn tri-axial accelerometers (TA) has thus increased dramatically in the last 20 years.

The eCAALYX Mobile Subsystem for monitoring outside the home, consists of a Wearable Body Sensor System (WBS) includes a Smart Garment with embedded health and mobility sensors for respiratory rate, skin temperature, heart rate and includes a fall and activity monitoring sensor and Electronic Control Unit (ECU) for storing and forwarding the sensors measurements. The WBS communicates with an LG-P990 mobile phone to enable further propagation of information back to a Caretaker site, Fig. 2.

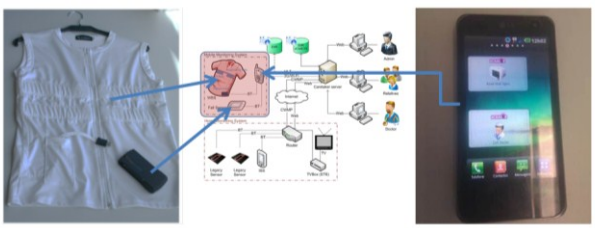

Figure 2. The Smart Garment, Electronic Control Unit (ECU), including the fall-sensor and Mobile Phone

As part of this system a sensor located at the left-under arm, embedded into a vital sign monitoring garment has been developed and produced by the University of Limerick. This sensor, whose hardware is the SHIMMER platform [13] is capable of: detecting falls, monitoring mobility and providing an estimate of energy expenditure, Fig. 3.

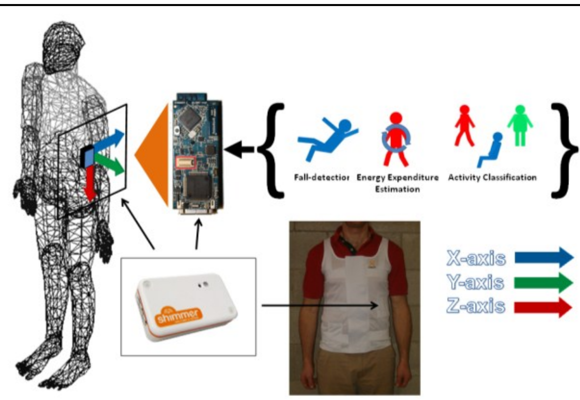

Figure 3. System overview. The different algorithms for activity classification, energy expenditure and fall detection were implemented in nesC onto the SHIMMER platform. The algorithms operate under the assumption of attachment to the left under-arm.

C. Communication protocol

In order to guarantee that messages from the fall-sensor reached the mobile-phone a robust messaging algorithm was implemented between the fall-sensor, ECU and Mobile phone. Upon the detection of an emergency situation such as fall-alert, the fall-sensor reports the event to the fall handler continuously until a propagation acknowledgement is received. This acknowledgement is by the fall handler to the fall-sensor subsequent to propagating the fall-alert message to the Caretaker site and server. The fall handler continues to propagate the fall alert until the server acknowledges the reception of this alert, Fig. 4.

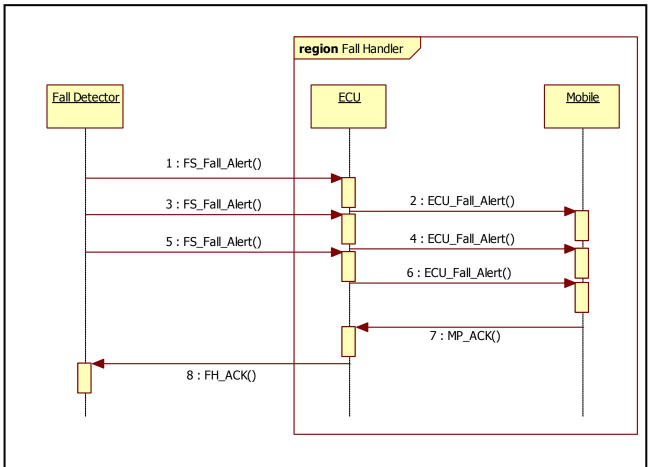

Figure 4. Interaction diagram for report a fall-alert event.

D. The Caretaker Site

The Caretaker Site, includes the Caretaker Server and a webserver electronic health records, Fig 5. The caretaker site is also responsible for patient management, data visualization, health agenda and observation pattern management. Fall-alert messages are propagated to the Caretaker via an intermediate gateway implemented at the server which also filters duplicate messages.

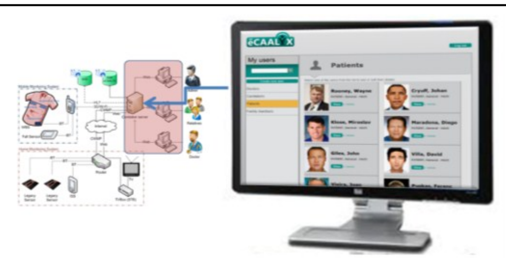

Figure 5. The Caretaker Site.

III. Methods

A. Algorithm Development

In order to develop the algorithms for the embedded system a number of minor trials were performed where a SHIMMER tri-axial accelerometer was attached to the left-under arm of the body.

B. Activity classification algorithm

To develop the activity classification algorithm a total of 8 older adults (77.2±5.38years) were recorded performing a set of 8 scripted, lying, sitting and walking activities. As well as 6 older adults (77.2±5.38years) who were recorded over a period of 5 days each. In total, 192 scripted activities and

171 hours or unscripted normal activities of daily living were recorded.

The developed activity classification algorithms monitors, trunk posture, trunk angular velocity, static/dynamic activity and related temporal parameters in order to indicate the current activity.

C. Fall detection algorithm

To develop the fall detection algorithm a total of 10 young health volunteers ranging from 24 to 35 years (27.2±3.6years) performed a series of 8 different fall types in all direction, performed with both legs straight and knee flexion. An additional 4 normal activities were also recorded. All scripted activities were performed 3 times each. The activities recorded for the development of the Activity classification algorithm in Section B above were also included in this data-set to develop the fall detection algorithm.

The developed fall-detection algorithm employs the following algorithm. Examine posture change on 0.5s windows, 1.5 seconds before and 1s after the fall-impact. The fall-impact was detected using the profile detection algorithm by Bourke et al. [8]. The thresholds for the UFT, LFT and t_{RE} were chosen to optimize for fall-detection sensitivity.

D. Energy expenditure algorithm

To develop the energy expenditure algorithm a total of 14 volunteers (>65 years) were recorded using the Oxycon Mobile portable metabolic system[2]. Volunteers were recorded for a total of 2.5 hours each performing a series of 10 free living physical activities or varying degrees of intensity. The activities included: resting (lying), dressing, walking, watching TV while sitting, standing washing delf, reading while sitting, climbing and descending stairs, writing while sitting, dusting while upright, quiet standing, folding laundry. All except stair climbing (5 minutes) were performed for 10 minutes each. The developed algorithm for energy expenditure estimation was based on the following popular equation for EE estimation (1).

$$EE_{METs} = \sum_n |x| + \sum_n |y| + \sum_n |z| \qquad (1)$$

E. Algorithm implementation

A floating point implementation of the algorithms was initially performed however due to the constrained processing resources of the platform a fixed point implementation was later adopted in order to increase the sampling rate to an acceptable 25Hz. A reduction in algorithm processing time from 82.3ms to 32.4ms was achieved through a fixed point low-pass and band pass filter implementation using specific scaling factors.

IV. End-user trial Protocol

A total of 9 volunteers, aged >60years with at least one chronic disease were included in the trial. All patients performed measurements for 28 days, additional details are provided in Table I. During the trial all patients wore the [3]activPAL™ activity monitor. The activPAL is a single thigh mounted unit measuring 53 x 35 x 7 mm and weighing 20 grams, it incorporates a uni-axial accelerometer. The device measures bodily accelerations and, using the orientation of the thigh, identifies the subject activity into epochs of sitting/lying, standing and stepping. It is worn on the midpoint of the anterior aspect of the right thigh and is attached to the skin directly using a PAL*stickie*; a hydro-gel adhesive pad. The activPAL has previously been validated for the determination of static, dynamic and postural activity in adults [14].

Ethical approval for this trial was granted through Charité - Universitätsmedizin Berlin, Ethics Commission. Data protection was approved by Data Protection Officer of the Charité - Universitätsmedizin Berlin.

Table I

Variable	Value
Age	69years±14
Gender	5 Male, 4 Female
Chronic diseases/volunteer	2.4 (average)
Trial length	28 days

V. Results

During the trial no falls occurred, however 2 false positives were registered. A total of 2 false positives were registered but 11 messages arrived, 1 set within 36 seconds the 2nd set within 63 second windows. This was due to the message receipt confirmation protocol adopted by each communication link in the Mobile system. However since no fall actually occurred during the trial (false-positive rate) an average false positive rate of (2/28*9) 0.0079FP/day was achieved.

Results from the activity classification measured by the fall and activity sensor were forwarded to the gateway portal at the caretaker site and are currently under analysis.

Results for the energy expenditure measured from each volunteer were used to indicate the amount of different activity intensity in the categories of resting, light, moderate and intense activity and quantified in Metabolic Equivalent Task (MET). MET is a physiological concept expressing the energy cost of physical activities as multiples of resting metabolic rate. Results of the Energy Expenditure compared to that measured using the activPAL are under analysis.

VI. Discussion

This study aimed to assess the long-term accuracy and reliability of a wearable fall-detection and activity monitoring system deployed with real end users. A high compliance of wearing the system was experienced during the trial, ensuring that a reliable data-set exists. During the

[2] Carefusion Germany 234 GmbH, Hoechberg, Germany.

[3] PAL Technologies Ltd, Glasgow, UK.

trial no falls did occur, however a total of 2 false positives were registered however 11 messages arrived, 1 set within 36 seconds the 2nd set within 63 second windows. A false-positive rate of 0.0079FPs/day was achieved, however this does appear quiet unrealistic and further analysis is required.

Thus further development is required to improve the communication reliability between the nodes in this communication arm of the eCAALYX system.

VII. Conclusion

In conclusion a fall detection algorithm was developed and successfully implemented and deployed to 9 independent living elderly end-users, monitored using a tele-monitoring system for 28 days.

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