

Falls Management: Detection and Prevention, using a Waist-mounted Triaxial Accelerometer

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Abstract—We describe a distributed falls management system capable of real-time falls detection in an unsupervised living context and remote longitudinal tracking of falls risk parameters using a waist-mounted triaxial accelerometer. A self-administrable falls risk assessment is used to facilitate falls prevention. A web-interface allows clinicians to monitor the status of individuals and track their compliance with exercise interventions. Early identification of increased falls risk allows targeted interventions to be promptly administered. Real-time detection of falls allows immediate emergency response protocols to be deployed, reducing morbidity and increasing the independence of the community-dwelling elderly community.

I. INTRODUCTION

IT has long been established that falls and their related injuries are a significant problem for the elderly community. Research has shown that falls are the greatest cause for hospitalization for those 65 or over and are a major factor in the morbidity of this age group [1, 3]. For example, half of older people that experience a ‘long lie’, which is remaining on the ground for an hour or more subsequent to a fall, die within 6 months [1].

Traditional falls management involves the clinical assessment of falls risk [1, 3, 4], to identify the particular risk factors affecting an individual. Tailored interventions can then be prescribed, however one limitation to this is the inability to ascertain compliance with prescribed interventions, such as exercise, in an unsupervised living context. Studies have shown that the benefits gained from exercise interventions exist as long as the subject complies with their particular exercise regimes thus making

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compliance a valuable parameter to assess [3]. Additionally, group exercise sessions often have to be established, at the inconvenience of the individual, to ensure compliance and evaluate relative improvements in condition [1].

Miniaturization of motion sensors such as accelerometers and gyroscopes have allowed for the development of wearable devices that measure various constituents of human motion. Recent studies have demonstrated the ability of such systems to clinically measure various falls risk indicators such as standing balance, sit-to-stand transfers, and gait [5-8], quantify activities of the daily living [9-11] and long-term ambulatory monitoring [12, 13].

This paper describes a falls management system, in terms of real-time detection and long-term prevention, using a single wearable unit, a waist mounted triaxial accelerometer. A distributed approach based on unsupervised home monitoring and remote longitudinal tracking has been adopted [14]. A self-administrable assessment of falls risk is performed daily to facilitate the long-term prevention of falls. Free-living ambulatory recordings are processed locally for the real-time detection of falls and remotely evaluate compliance with exercise interventions and assess trends in extracted clinical parameters.

II. SYSTEM ARCHITECTURE

Fig. 1 illustrates the falls management system architecture. A distributed approach, based on unsupervised home monitoring and remote data processing has been adopted. In essence, events that require immediate action such as falls or severe stumbles are detected in real-time while longitudinal processing of data is deferred to a more powerful remote server for subsequent analysis and reporting. A simple web interface allows users and clinicians to view collected data.

A. Home monitor

A rechargeable, triaxial accelerometer based wearable unit and associated data portal were developed at the Biomedical Systems Laboratory, University of New South Wales, Sydney [12, 15, 16]. Subsequent commercialization by MedCare Systems Pty. Ltd, Sydney, Australia, has led to the development of the PreventaFall ambulatory monitor (PFAM) and MiiLink data portal (MiiLink) both of which form the platform for the developed falls management system architecture.

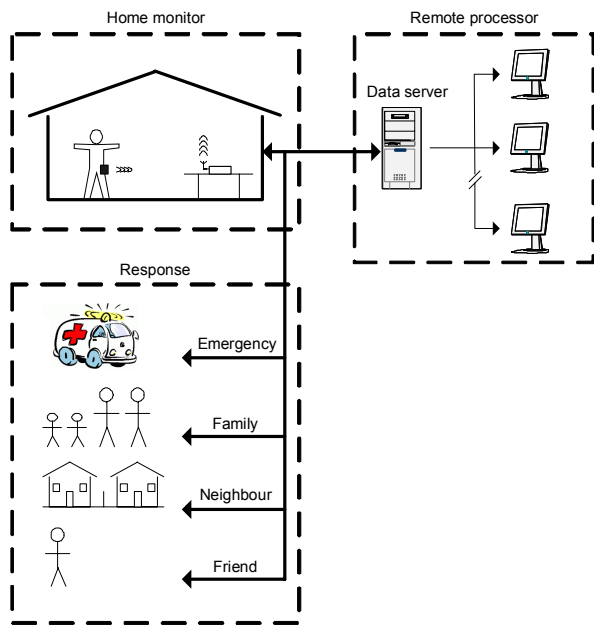


Fig. 1. The falls management system architecture based on unsupervised home monitoring, remote longitudinal tracking, and multi-level emergency response system.

The PFAM utilizes a $\pm 6g$ 3-axis accelerometer to monitor the movements of the wearer. It houses a class 1 Bluetooth radio which is used to transfer ambulatory recordings as well as establish a full duplex audio channel (when required) between the PFAM and MiiLink. Customized firmware has been incorporated into the PFAM to implement directed routine sequencing and event response mechanisms (see section III).

Similarly to the PFAM, the MiiLink contains a class 1 Bluetooth radio which constantly listens for incoming connection requests from the PFAM. Via data channels, the MiiLink stores collected ambulatory data to a Secure Data (SD) memory card. In the event of an emergency connection, as indicated by the PFAM, the MiiLink has the task of dialing the number of a chosen emergency respondent (see section III). Once a day, the MiiLink uploads collected ambulatory data to a remote server for long-term storage and post-processing by interfacing to an existing Local Area Network (LAN). If a LAN is unavailable a dial-up connection is established.

B. Event response

A multi-level response system has been adopted. Depending on the severity of the possible fall event an appropriate respondent is chosen. An audio channel is established between the respondent and user (see section III).

C. Remote processor

The remote server houses ambulatory data collected for each day. Collected data is processed to extract parameters relating to functional ability and falls risk of the user as well as verify if particular targeted events such as exercise

routines have been completed. Extracted parameters are appended to past measurements to form the longitudinal record for the subject. Patient data is presented via a web interface.

III. SYSTEM OPERATION

From the view point of the user, system operation is simple. Each morning after they wake, they remove the PFAM from the recharger and attach it to their waist belt. They then go about their daily lives as per usual. Once a day, at the user's discretion, they undergo a simple self-administered assessment of falls risk – the directed routine, which takes about 4 minutes to complete. At the end of the day, before they sleep, they simply return the device to the recharger.

Transparent to the user, is a complex web of distributed intelligence that actively monitors the user's movements; maintaining a constant vigil for falls, transmitting collected ambulatory data to a local MiiLink and uploading the collected data to a remote server for analysis where, falls risk is evaluated. The system also can monitor an analogue of metabolic energy expenditure and targeted events such as exercise.

A. Directed routine

A self-administrable assessment of falls risk – the directed routine – is administered daily. The routine comprises of a series of simple tasks of which the user's performance is associated to the risk of falling [2, 4, 17]. Table I describes the administered tasks, individual assessment duration and performance metric(s) for evaluation. Tasks that have demonstrated high test-retest reliability [2, 17] have been included in the routine.

The routine is designed to be as short as possible to avoid the onset of fatigue while as broad as possible to evaluate as many of the underlying risk factors.

The subject initiates the routine by depressing a push button on the PFAM for 3 seconds. A series of audio cues in conjunction with an instruction card direct the subject through the routine.

Fig. 2(a)-(e) shows a representative, contiguous sample of the ambulatory recordings obtained from a 68 year old male volunteer during the directed routine. It should be noted that the recordings for the samples in Fig. 2(b)-(d) have been smoothed using a Savitzky-Golay FIR filter ($k=0$, $f=19$). Fig. 2(a) shows the occurrence of a protective step as a result of a loss of balance during the near-tandem standing balance test.

Tiedemann et al. [2] identified cut-points of 10 seconds and 12 seconds for the alternative step test and sit-to-stand test with five repetitions respectively, to discriminate between multiple fallers and non-multiple fallers. Similarly, Whitney et al. [17] determined an optimal cut-point of 15 seconds for the timed up-and-go task for identifying those with a high risk of falling. The occurrence of a protective

TABLE I. DIRECTED ROUTINE ASSESSMENT TASKS, DURATION OF TASK, METHOD OF EVALUATION

Assessment Task	Task Description	Performance metric(s)
Near-tandem standing balance	Stand in the near-tandem position, that is, with feet laterally separated by 2.5cm and the heel of the front foot 2.5cm anterior to the large toe of the back foot, for 30 s with eyes closed [1].	Lateral sway, occurrence of protective step
Timed up-and-go (3m walk)	From a seated position, stand, walk 3m, turn 180°, walk back to the chair and sit down [2].	Time taken to complete
Alternative step test	Alternatively place the whole left and right foot as fast as possible onto a step (19cm high and 40cm wide) eight times as quickly as possible [2].	Time taken to complete
Sit-to-stand transfer (5 repetitions)	From a seated position, perform five sit-to-stand transfers as quickly as possible with arms folded [2].	Time taken to complete
Simple reaction time	Tap the PFAM as quickly as possible in response to an audio cue.	Average measured reaction time

* Duration includes time taken to complete the assessment task as well as prepare for the subsequent task.

step during a near-tandem standing balance test is taken as an indicator of poor lateral stability [1].

B. Free-living ambulatory monitoring

Ambulatory recordings are continuously buffered and transmitted to the local MiiLink by the PFAM. In this way the entire day's activities, from the moment the PFAM is removed from the charger until the time the recharger is reconnected, will be stored at the MiiLink. This 'daily record' is uploaded to the remote server for further analysis.

In parallel with this, the PFAM continuously monitors for fall events using the fall detection algorithm previously described in [10]. In the event of a fall, the PFAM signals the local MiiLink to dial an emergency number and an audio channel is established between the user and emergency respondent. In the case that a fall may have occurred (abnormally large acceleration detected followed by a change in orientation to a lying state) but the user has managed to get themselves up and appears to be active, the developed system allows for a secondary emergency number (nominated by the user) to be dialed. In this way a neighbor, friend or family member can be alerted and an appropriate response taken.

C. Remote processing

The daily records for all users are uploaded each night to the remote server for analysis. The directed routine is extracted from the record and the aforementioned performance parameters (see section III.A) evaluated for each directed routine task. The calculated performance scores are compared against their corresponding cut-points with abnormal scores flagged for review. The remainder of the daily routine is processed. Clinically relevant parameters such as the proportion of time spent at rest, and activity levels extracted. These are appended to previous measurements to form the longitudinal record for the user. These longitudinal records are also re-evaluated to look for long-term trends in the measured parameters.

The daily records are also screened using trained classifiers for targeted events such as prescribed exercise tasks.

The remote server includes a web interface that allows interested parties such as physicians to view the status of a user. Parameters of interest may be selected and viewed.

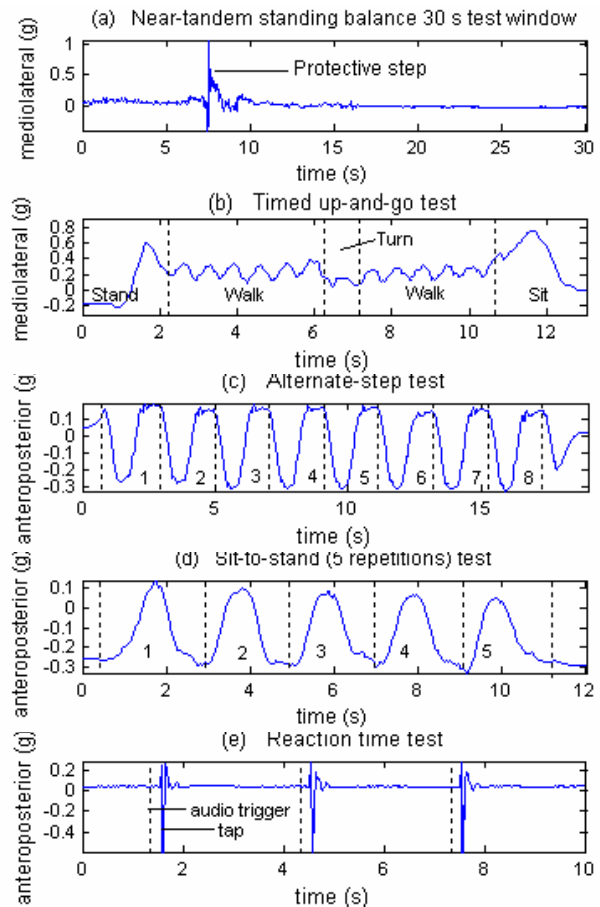


Fig. 2. Representative data for a directed routine.

IV. DISCUSSION AND CONCLUSION

Related studies have demonstrated the ability of kinematic sensors to measure various indicators of falls risk [5-8]. These studies, however, have focused on the clinical assessment of falls risk in contrast to the self-administrable assessment described in section III. Mathie et al. [12] demonstrated the utility of a directed routine in evaluating long-term changes in functional ability. The chosen routine consisted of basic functional mobility tasks. In contrast to this, the routines proposed herein comprise a series of tasks that have demonstrated significant association with falls risk and have been shown to have good test-retest reliability. Few studies have evaluated exercise compliance in an unsupervised environment. Steele et al. [18] used activity counts to verify compliance with exercise programs by noting increased levels of activity on days in which the subject complied with the exercise program. In comparison, our method utilizes more robust automatic classification techniques to objectively evaluate compliance with exercise interventions.

This paper describes our developed falls management schema in terms of real-time falls detection and response and long-term falls prevention by way of a simple, self-administrable falls risk assessment. An objective means to evaluate compliance with exercise interventions is described. Feedback is presented by way of a simple web interface that presents patient performance data.

The described architecture forms part of an ongoing clinical and long-term study of falls prevention using a PFAM.

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