Proceedings of the Estonian Academy of Sciences,
2014, **63**, 3, 341–345
doi: 10.3176/proc.2014.3.08
Available online at www.eap.ee/proceedings

BIOMEDICAL ENGINEERING

Fall detection in the older people: from laboratory to real-life

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Received 21 February 2014, revised 10 April 2014, accepted 10 April 2014, available online 28 August 2014

Abstract. Falls are an increasing problem of aging population, both in home-dwelling and institutionalized people. Automatic fall detection systems are a choice in supporting the independent and secure living of the older people. Typically, health technology applications such as fall detection systems are tested in experimental falls of young adults. However, sensitivity and specificity, and acceptability and usability of these systems in real-life conditions in end users should be the ultimate aim. This paper overviews our set of studies on the technology and algorithms for fall detection, from laboratory-based experiments to long-term real-life field tests. The data obtained during the incremental set of studies suggest that automatic accelerometric fall detection systems might offer a tool for improving safety among older people. Additional studies are needed for further improvement of fall detection sensitivity and decreasing the false alarm rate, and for the implementation of the technology to elderly care ICT platforms.

Key words: accelerometer, fall detector, field test, sensitivity, older people.

1. INTRODUCTION

Elderly population is growing rapidly. About one-third of home-dwelling people over 65 years of age fall each year [1]. Falls are one of the major health risks that affect the quality of life among older adults. Approximately half of fallers have been incapable of recovery to a standing position unaided [2].

Older people prefer to live at their homes, and thus, new technologies may offer a tool to support their independence and security. Commercially available personal emergency response systems (PERS) provide applications to call for help. However, around 80% of older people, wearing PERS, do not use their alarm system to call for help even if they fall [3,4]. Thus, automatic detection systems are needed.

Typically, health technology applications such as fall detection systems are tested in experimental tests with young adults. However, self-initiated, intentional falls may differ from sudden, unexpected falls [5]. Even the fall mechanics and compensatory movements may be different in older people compared to younger subjects. Thus, high sensitivity (detected proportion of actual falls) and low false alarm rate, and the acceptability and usability of these systems in real-life conditions in end users should be the ultimate aim.

In this paper, we will overview our set of studies [6–10] on the technology and algorithms for fall detection, from laboratory-based experiments to long-term real-life field tests (Table 1).

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Table 1. Five sub-studies overviewed in this paper

Sub-study	I	II	III	IV	V
Reference	[6]	[7]	[8]	[9]	[10]
Study aim	Sensor placement and thresholds	Complexity of algorithms	Sensitivity and specificity	Real-life falls vs. experimental falls	Long-term real-life test
Study set-up	Pilot study	Lab study	Lab study	Real-life test vs. lab study (III)	Real-life test
Number of subjects	2	3	20 + 21	3	16
Number of falls	31	59	240	5	15

2. SENSOR PLACEMENT AND ACCELERATION THRESHOLDS

The pilot study [6] determined acceleration thresholds for fall detection, using triaxial accelerometric measurements at the waist, wrist, and head. Intentional falls and activities of daily living (ADL) were performed by two voluntary subjects (aged 22 and 38 years). Forward, backward, and lateral falls were performed towards a mattress. ADL samples presented different kinds of activities and posture transitions, each separate activity used as one sample in calculating the specificity. Acceleration signal was recorded from the waist, wrist and head, using previously presented equipment [11]. Sensitivity (percentage of true alarms) was calculated from the fall data, and specificity (percentage of false alarms) was calculated from the ADL data.

All tested accelerometer-based parameters, measured from the head, were able to distinguish falls and ADL. Thus, a head-worn accelerometer might be a choice for fall detection, using, e.g., hearing-aid housing. On the waist, using simple thresholds for impact alone was not optimal for fall detection. When the simple threshold-based detection was combined with posture detection after the fall, the thresholds obtained resulted in a sensitivity and specificity of fall detection of 95%–100%. On the contrary, the wrist did not appear to be an optimal site for fall detection. In wrist, fall-related accelarations appeared to overlap with ADL. Additionally, hand and torso posture are not necessarily in phase, and posture detection was thus not used in the algorithms. However, high sensitivity was found in forward falls, indicating an impact to the hands.

3. COMPLEXITY OF FALL DETECTION ALGORITHMS

The second study [7] evaluated different low-complexity fall detection algorithms, using triaxial accelerometers attached at the waist, wrist, and head. Nine different standardized falls were performed with three middle-aged subjects (aged 38–48 years). Data from ADL were used as reference. The acceleration signals were recorded as previously [6,11]. Three different detection algorithms with increasing complexity were investigated using two or more of the following phases of a fall event: start of the fall, falling velocity, fall impact, and posture after the fall.

The results indicated that fall detection using a triaxial accelerometer worn at the waist or head is efficient. Even with quite simple threshold-based algorithms, a sensitivity of 97%–98% and specificity of 100% can be obtained. The most sensitive acceleration parameters appeared to be the resultant signal with no high-pass filtering, and the calculated vertical acceleration. The sensitivity of wrist-worn accelerometer remained only moderate (71% at the best for various types of falls). Since a head worn device includes limitations concerning usability and acceptance, a waist worn accelerometer, using an algorithm that recognizes the impact and the posture after the fall, might be an optimal choice for fall detection.

4. SENSITIVITY AND SPECIFICITY IN MIDDLE-AGED TEST SUBJECTS

The third study [8] validated the data collection of a new fall detector prototype and defined the sensitivity and specificity of different fall detection algorithms with simulated falls from 20 middle-aged (40–65 years old, 6 males and 14 females) test subjects. The sensor was attached at the waist with an elastic belt. ADL performed by the middle-aged subjects, and also by 21 older people (aged 58–98 years, 11 males and 10 females) from a residential care unit, were used as a reference. Middle-aged test subjects performed six different falls (syncope, tripping, sitting on empty air, slipping, lateral fall, rolling out of bed) in a laboratory environment onto a mattress.

The ADL protocol included (1) sitting down on a chair and getting up, (2) picking up an object from the floor, (3) lying down on a bed and getting up, and (4) walking, including both level walking and walking up and down the stairs. Each of these separate actions was considered as a separate ADL sample in calculating the specificity. New prototype hardware platform was used in the study. Fall detection algorithms, similar to those in the previous study [7], were used.

The results showed that the hardware platform and algorithms used can discriminate various types of falls from ADL with a sensitivity of 97.5% and a specificity of 100%, i.e. with no false alarms. The best fall detection sensitivity was achieved with the simplest criteria, based on monitoring the fall associated impact and end posture.

5. REAL-LIFE FALLS VS. EXPERIMENTAL FALLS

In most cases, fall detectors are designed and tested with data from experimental falls in younger people. The fourth study [9] was one of the first to provide fall-related acceleration data obtained from real-life falls. Wireless sensors were used to collect acceleration data from real-life falls among older people, and compared with the data from the experimental falls collected in the previous study [8]. A prototype sensor (CareTech Ab, Sweden) was attached on the waist using an elastic belt. The acceleration was continuously monitored, with an event-based trigger. When activated, the history of acceleration data was collected from a buffer. In this study, data from five fall events, representing forward falls, a sideways fall, a backwards fall, and a fall out of bed were obtained.

The signals from real-life falls showed similar features to those from intentional falls. Real-life forward, sideways, and backward falls all showed a pre-impact phase and an impact phase that were in keeping with the model that was based on experimental falls. In addition, the fall out of bed had a similar acceleration profile as the experimental falls of the same type. The beginning of the fall was detected in all of the real-life falls starting from a standing posture, whereas the high pre-impact velocity was not. In the two real-life falls on forward direction, multiple impacts suggested protective actions, whereas a fall that resulted in a hip fracture showed a very clear impact (Fig. 1). Some fall characteristics such as the high velocity towards the ground detected from experimental falls were not always detectable in acceleration signals from corresponding heterogeneous real-life falls.

6. LONG-TERM REAL-LIFE TEST IN THE ELDERLY

Even though good fall detection sensitivity and specificity in laboratory settings have been reported, knowledge about the sensitivity and specificity of these systems in real-life conditions is still mostly lacking. The fifth study [10] evaluated the long-term fall detection sensitivity and false alarm rate of a fall detection prototype in real-life use. A total of 15 500 hours of real-life data from 16 older people (aged 88.4±5.2 years, 3 males and 13 females), including both fallers and non-fallers, were monitored using the accelerometry-based sensor system [9], attached at the waist with an elastic belt, with an implemented fall detection algorithm (CareTech Ab, Sweden). Real-life falls were identified, based on the routine reporting by the care personnel.

The fall detection system detected 12 out of 15 real-life falls, having a sensitivity of 80.0%, with a false alarm rate of 0.049 alarms per usage hour with the implemented real time system. With minor modification of data analysis, the false alarm rate was reduced to 0.025 false alarms per hour.

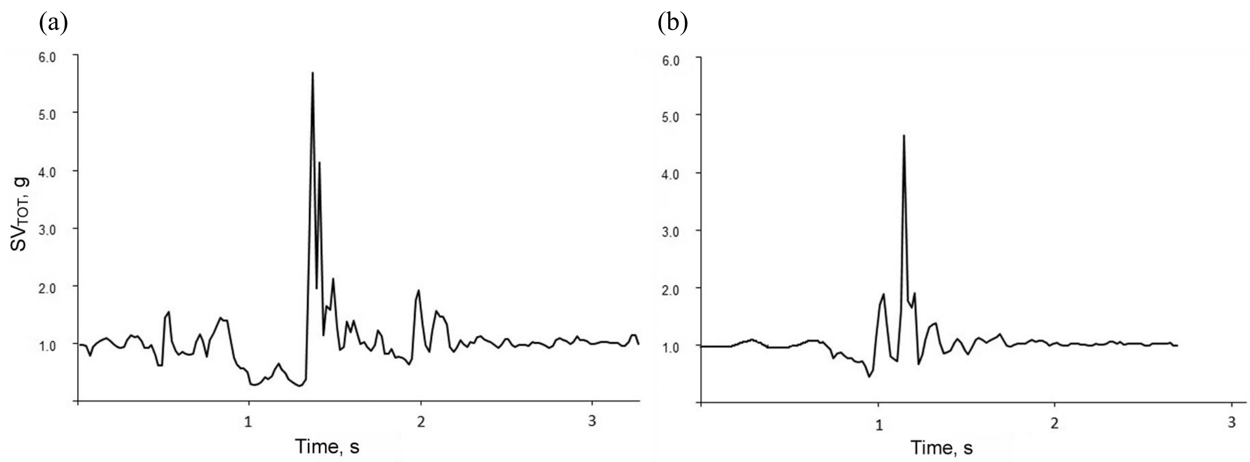

Fig. 1. Acceleration signal (resultant sum vector SV_{TOT}) recorded during two real-life fall cases: (a) A fall resulting in a hip fracture. The signal shows a major impact with no pre-impact actions; (b) A forward fall. The person got entangled in a blanket when moving from the bed. The signal shows pre-impact activity suggesting protective actions.

7. DISCUSSION

In this set of studies, we first evaluated different fall detection algorithms in intentional falls and ADL. The results indicated that fall detection, using a waist or head worn triaxial accelerometer, is efficient, even with quite simple threshold-based algorithms. The usability speaks in favour of waist-worn sensors, and waist was also used in our later real-life tests. On the contrary, the wrist did not appear to be an applicable site for fall detection due to overlapping of fall-related accelarations with ADL. Additionally, posture can not be reliably used as part of fall detection. Here, many of the fall events indicated active role of hands in the intentional falls. This is in contrast to typical falls of older people, in which the hands are not used to protect the body during falls.

Our field test with older people showed similarities between real-life falls and experimental falls. The start of the fall was detectable in all real-life falls starting from a standing posture (Fig. 1). However, the high velocity toward the ground was not detected in all falls from a standing height. The acceleration profile of the real-life fall that resulted in a hip fracture had a high pre-impact phase velocity followed by a major impact peak (Fig. 1a). The hazardous outcome of this real-life fall may be partially due to the lack of protective actions, which resulted in a major impact at the hip.

The usefulness of an alarm system is related to alarm accuracy. For a frequent faller, the high sensitivity rate would motivate the use of the detector, reducing fear and anxiety as well as the risk of long lies after a fall. For persons with a low risk of falls, on the other hand, even very low false alarm rates could heavily outnumber possible true alarms, causing nuisance and disruptions in daily activities and reducing detector's usefulness. The rate of one false alarm per 40 usage hours in this study may still be considered to be high and further development and further reduction of false alarm rates is therefore important. This could be achieved, e.g., by providing the user the possibility to inactivate the alarm when needed, and with more sophisticated data analyses for algorithm improvements.

8. CONCLUSIONS

Falls are an increasing problem of aging population, both in home-dwelling and institutionalized subjects. The data obtained during the incremental set of studies suggest that automatic accelerometric fall detection systems might offer a tool for improving safety among older people. Additional studies are needed for further improvement of fall detection sensitivity and decreasing the false alarm rate, and for the implementation of the technology to elderly care ICT platforms.

ACKNOWLEDGEMENTS

This study was supported by the ASTS study, Academy of Finland, and the GASEL study, Finnish Funding Agency for Technology and Innovation, Oulu University Hospital, Oulu Deaconess Institute, IsCom Ltd., Caritas Foundation, BelleGames Ltd., and BonWell Intelligence Ltd. The original studies were supported by the European Union under the Interreg III A North and Interreg IV A North programmes, the Finnish Funding Agency for Technology and Innovation, the Academy of Finland, the Regional Council of Lapland, the County Administrative Board of Norrbotten, the Norrbotten County Council, the Norrbottens Forskningsråd, National Semiconductor Finland, Elektrobit Ltd., CareTech Ab, and Kalix Electropolis Ab.

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Kukkumise avastamine eakatel: laborist tegelikku ellu

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Kukkumised on vananeva elanikkonna üha suurenev probleem nii kodudes kui ka hoolekandeasutustes. Automaatne kukkumise avastamise süsteem toetaks eakate iseseisvat ja turvalist elu. Tavaliselt testitakse tervishoiutehnoloogiate rakendusi, kaasa arvatud kukkumise avastamise süsteeme, katsetel noorte täiskasvanutega. Eesmärgiks peab siiski olema süsteemide tundlikkuse, spetsiifilisuse, vastuvõetavuse ja rakendatavuse testimine reaalsetes tingimustes. Artiklis on antud ülevaade autorite uuringutest, kus on käsitletud kukkumise avastamise tehnoloogiaid ja algoritme alates laborist kuni pikaajaliste testimisteni reaalsetes tingimustes. Erinevatest uuringutest saadud andmed osutavad, et automaatsed, kiirenduspõhimõttel toimivad kukkumise avastamise süsteemid võivad pakkuda abivahendi eakate turvalisuse suurendamiseks. Kukkumise avastamise tundlikkuse ja spetsiifilisuse täiustamiseks ning tehnoloogia rakendamiseks eakate hoolduseks mõeldud ICT-platvormides on vajalikud täiendavad uuringud.