Available online at www.sciencedirect.com

ScienceDirect

Medical Engineering & Physics 30 (2008) 84–90

Medical Engineering & Physics

www.elsevier.com/locate/medengphy

A threshold-based fall-detection algorithm using a bi-axial gyroscope sensor

A.K. Bourke, G.M. Lyons *

Biomedical Electronics Laboratory, Department of Electronic and Computer Engineering, University of Limerick, Limerick, Ireland

Received 5 September 2006; received in revised form 28 November 2006; accepted 3 December 2006

Abstract

A threshold-based algorithm, to distinguish between Activities of Daily Living (ADL) and falls is described. A gyroscope based fall-detection sensor array is used. Using simulated-falls performed by young volunteers under supervised conditions onto crash mats and ADL performed by elderly subjects, the ability to discriminate between falls and ADL was achieved using a bi-axial gyroscope sensor mounted on the trunk, measuring pitch and roll angular velocities, and a threshold-based algorithm. Data analysis was performed using MATLAB® to determine the angular accelerations, angular velocities and changes in trunk angle recorded, during eight different fall and ADL types. Three thresholds were identified so that a fall could be distinguished from an ADL: if the resultant angular velocity is greater than 3.1 rads/s (Fall Threshold 1), the resultant angular acceleration is greater than 0.05 rads/s^2 (Fall Threshold 2), and the resultant change in trunk-angle is greater than 0.59 rad (Fall Threshold 3), a fall is detected. Results show that falls can be distinguished from ADL with 100% accuracy, for a total data set of 480 movements.

Keywords: Falls in the elderly; Fall detection; Gyroscope; Activities of Daily Living; Threshold

1. Introduction

Falls in the elderly are a major problem for today's society. Approximately one in every three adults 65 years old or older, falls each year [1,2]. Falls are the leading cause of injury deaths and accounted for 83% of all fatal falls in 2005 in Ireland [3] and are the leading cause injury-related hospitalisation among people 65 years and older in society [4]. Injuries sustained from falls include broken bones, superficial cuts and abrasions to the skin as well as connective and soft tissue damage [1,2,5]. Fall related admissions of older adults are a significant financial burden to the health services world wide and is estimated to have an annual cost of €10.8 m alone for just one Irish hospital [6].

A serious consequence of sustaining a fall is also the 'long-lie', which is identified as involuntarily remaining on the ground for an hour or more following a fall [7]. The 'long-lie' is a common occurrence and it has been shown that many elderly people lack that ability to stand up, even from non-injurious falls, and as a result remain on the ground for even longer than an hour [8]. It has also been found that half of those elderly who experience a 'long-lie' die within 6 months, even if no direct injury from the fall has occurred [7], indicating a deterioration in general health. Thus, if an elderly person experiences a fall followed by a 'long-lie' while living alone, the consequences can be quite serious and potentially fatal.

Detection of a fall, either through automatic fall detection or through a Personal Emergency Response System (PERS), would help to minimize the occurrence and ramifications of the 'long-lie', by reducing the time between the fall and the arrival of medical attention [9]. However, the most common existing PERS, the push-button pendant, is not always a satisfactory fall-detection method, as during a loss of consciousness or a faint the pendant will not be activated [10]. Also, even when elderly people have fallen and injured themselves, they still did not activate their PERS, even though they had the opportunity to do so [11].

A number of different approaches for the automatic detection of falls, using subject worn sensors have appeared in

* Corresponding author. Tel.: +353 86 202621; fax: +353 61 338176.
E-mail address: Gerard.Lyons@ul.ie (G.M. Lyons).

1350-4533/$ – see front matter © 2006 IPEM. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.medengphy.2006.12.001

recent years [12–16]. These fall-detection devices use either the near horizontal orientation of the faller, following the fall, and/or the impact of the body with the ground to identify a fall, the typical sensors used for this are accelerometers.

Currently work is underway by several groups to attempt to detect falls prior to impact. Patents detailing inflatable hip protectors to cushion the fall prior to impact exist, although these systems do not describe how they pre-empt falls, and are essentially anticipating technological advances in this area [17–19]. Pre-impact detection of falls has been shown, by Wu [20], using motion analysis techniques. Wu showed that falls can be distinguished from ADL 300 to 400 ms before impact, by thresholding of the horizontal and vertical velocity profiles of the trunk. For this to be accomplished using a wearable sensor, both 3-D accelerometer and 3-D gyroscope sensors must be employed to obtain the velocity profiles used by Wu with 3-D video motion analysis.

Thus, it is expected that the future overall sensor arrangement for pre-impact fall detection will consist of both a 3-D accelerometer and a 3-D gyroscope. A question then arises about the fault tolerance of such a system. If one of these components fails, pre-impact detection of a fall cannot be obtained. However, if under these circumstances a fall on impact could be detected, this would be desirable as non-detection of a fall either prior to, or at impact could have very serious consequences. Previously, it has been shown that detection of falls, upon impact is possible, using just a 3-D accelerometer on the trunk [12]. However, in the event that the 3-D accelerometer sensor fails in the pre-impact fall sensor, fall detection on impact using the 3-D gyroscope is required if sensor fault tolerance is to be accomplished. This paper describes the development and testing of an algorithm for the detection of falls at impact using a 2-D gyroscope.

Najafi et al. [21] used gyroscope sensors to evaluate fall-risk in elderly people through the measurement of stand-sit and sit-stand transitions, however this work used gyroscope instrumentation as a screening device to determine if an elderly person was at an elevated risk of falling and did not attempt to detect falls in real time. Pre-impact fall detection using gyroscope sensors has been attempted by Nyan et al. [22] who attached gyroscope sensors at three different locations: the sternum, front of the waist and under the arm. With this system, Nyan achieved 100% sensitivity; however, 16% of ADL events tested were misdetected as falls.

Several Fall-detection systems have used young subjects to test the extent of misdetection of ADL as falls by their systems [13–15]. Elderly persons often move differently than younger people as they typically have less control over the speed of their body movements due to reduced muscle strength with old age. As a result, elderly persons may "fall" into a chair when sitting down instead of sitting in a controlled manner and thus would be expected to produce higher peak accelerations and angular velocities when performing certain ADL. Thus, it was considered appropriate by the authors of this paper that the ADL based measurements be performed using elderly subjects to increase the robustness of the test methodology. As it was not appropriate to request elderly subjects to perform simulated-falls, elderly subjects were asked to perform ADL and young subjects performed the simulated falls.

This paper thus describes the development of a threshold-based algorithm, capable of automatically discriminating between falls and ADL, using a bi-axial gyroscope sensor. The gyroscope signals were acquired from simulated-falls performed by healthy young subjects and from ADL performed by elderly persons in their own homes.

When a person falls and hits the ground it is expected that the changes in angular acceleration, angular velocity and body angle would be different from those experienced during normal daily activities. We hypothesised that: trunk bi-axial angular acceleration, angular velocity and body angle signals will have peak values, during a fall, which will be distinct from those produced during normal ADL.

2. Materials and methods

To establish our hypothesis, trunk pitch and roll gyroscope readings Fig. 1, were recorded, during separate simulated-fall and ADL studies, and their results compared. As it was not appropriate to request elderly subjects to perform simulated-falls, different groups of subjects were used for the two studies. The first study involved young subjects performing simulated-falls, in a safe controlled environment, under the supervision of a physical education professional. The second study involved elderly subjects performing Activities of Daily Living (ADL) tasks in their own homes. Both studies were completed with subjects wearing the same sensor arrangement, namely a bi-axial gyroscope sensor, on the trunk.

2.1. The simulated-fall study

The simulated-fall study involved 10 young healthy male subjects performing simulated-falls onto large crash mats,

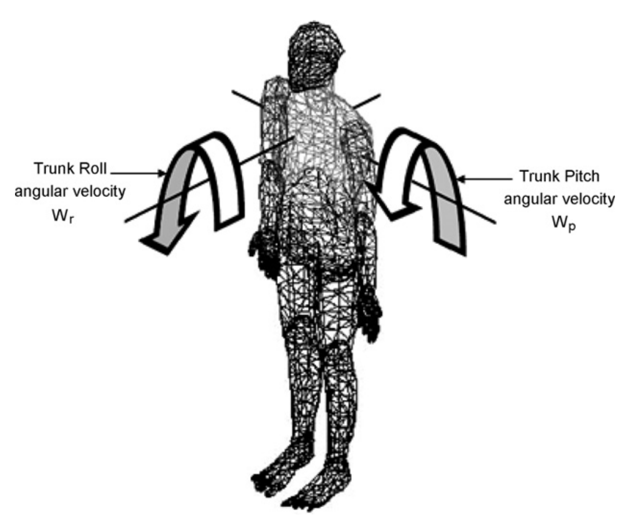

Fig. 1. Trunk pitch and roll angular velocity measurement system.