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Technical note

Unobtrusive monitoring and identification of fall accidents

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ABSTRACT

Falls are a societal and economic problem of great concern with large parts of the population, in particular older citizens, at significant risk and the result of a fall often being grave. It has long been established that it is of importance to provide help to a faller soon after the event to prevent complications and this can be achieved with a fall monitor. Yet, the practical use of currently available fall monitoring solutions is limited due to accuracy, usability, cost, and, not in the least, the stigmatising effect of many solutions. This paper proposes a fall sensor concept that can be embedded in the user's footwear and discusses algorithms, software and hardware developed. Sensor performance is illustrated using results of a series of functional tests. These show that the developed sensor can be used for the accurate measurement of various mobility and gait parameters and that falls are detected accurately.

1. Introduction

In this paper a sensor proof of concept is presented that offers a solution to a range of issues encountered in traditional fall sensors. A third of older people over the age of 65 years fall in the community each year with prevalence rates increasing to over a half of individuals over 80 years [1]. Falls related injuries come at a high cost to society and individuals. Society as a whole is faced with high annual bills in the order of €400 million for a country such as Ireland and this is predicted to increase to €1 billion by 2020 [2]. Following a fall, individuals may be impeded in their daily lives by the fear of falling, reduced self-efficacy and the physical consequences of the fall [3]. A high proportion of uninjured fallers (47%) are unable to get up from the floor after a fall [4] due to lack of strength and physical fitness [5]. An inability to get up from the floor after a fall can result in a long lie, which is defined as remaining on the floor for more than an hour after a fall. The long lie is associated with co-morbidities including dehydration, pneumonia, hypothermia and pressure sores and has been found to significantly increase the probability of death (50%) within 6 months [3,6]. Hence, detection of a fall is of great importance and numerous fall detection systems have been developed. Most wearable fall detection systems rely on detecting impact. This, however, is not always a feature of significance in a fall. Moreover, device discreteness and obtrusiveness negatively impact on the acceptability and usability of many current devices [7].

This paper presents a sensor concept that offers a solution to these issues. The presented sensor is a footwear based sensor that uses pressure, acceleration and temporal information to assess the user's ambulatory parameters and the incidence of falls.

The use of footwear based sensors has been investigated by various groups [8,9].[1,2] However, the main focus of these efforts has been on falls prevention through monitoring of gait and mobility parameters. Although falls risk assessment is an important aspect of the management of falls, it will never be possible to fully rule out the occurrence of a fall. Hence, the detection of the fall event itself will remain of crucial importance in any falls emergency system. The focus on falls prevention for footwear based sensors is likely for more than one reason. As the old proverb says "prevention is better than cure", but a likely further reason for the focus on falls prediction for footwear based sensors is that in this location a fall event is difficult to identify with the classical fall detection approach of measuring acceleration and impact.

In this work we propose methods to obtain accurate fall detection from the user's foot by using a state machine which allows the measured pressure and acceleration to be assessed within the context of the current user physical activity. This strategy allows for a relatively low sampling frequency, which in turn results in lower battery consumption. The sensor would be relatively cheap to manufacture and as the concept allows for a solution fully embedded in the user's footwear, is fully unobtrusive. Moreover, unlike

[1] WIISEL – Wireless Insole for Independent and Safe Elderly Living (http://www.wiisel.eu/).

[2] Balance Problems? Step into the iShoe (http://web.mit.edu/newsoffice/2008/i-shoe-0716.html).

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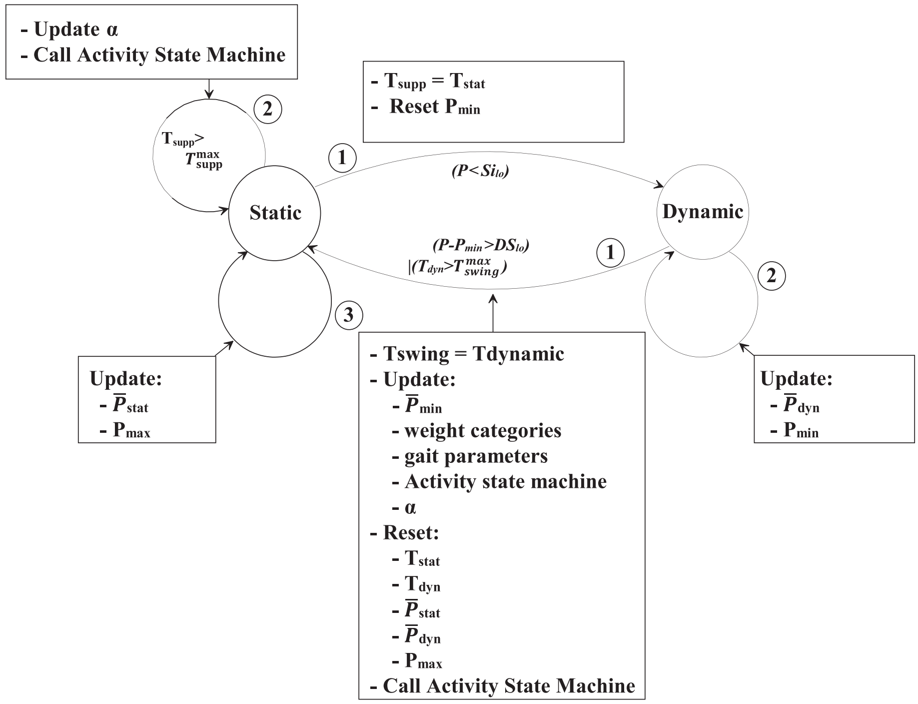

Fig. 1. Diagram of Gait State Machine.

Table 1
Support categories and their respective conditions.

Support state	Pressure condition
NoSupport (NS)	$P < Si_{lo}$
SitSupport (SitS)	$Si_{lo} \leq P < DS_{lo}$
DoubleSupport (DS)	$DS_{lo} \leq P < SS_{lo}$
SingleSupport (SS)	$P > DS_{lo}$

most other wearable fall sensors, as the concept uses knowledge on the current physical activity undertaken by the user and does not rely on impact to identify falls, the sensor is capable of detecting so called sliding falls that are hard to detect with impact based fall sensors.

2. Principle of operation

Pressure exerted by the foot and orientation of the foot (determined from acceleration) are gathered periodically and used in a state machine to determine the current physical activity undertaken by the user. With the knowledge captured in the state machine, fall events can be detected as abnormal changes in pressure and acceleration in a given state. In such a case, the fall sensor reports the fall event to a fall handler, which typically resides on a mobile phone. The fall handler can then take appropriate action, such as informing a formal or informal caretaker, or emergency services.

The fall algorithm was developed as two separate state machines. The first state machine is called the Gait state machine. This state machine has two states: Static and Dynamic. State transitions are controlled by changes in measured pressure, P, and through the use of time outs. The measured pressure is related to a Support State as listed in Table 1, where NoSupport (NS) is equivalent to the sensor being suspended in air, SitSupport (SitS) indicates a low but non-zero pressure related to the user sitting and Double Support (DS) and SingleSupport (SS) relate to both feet and one foot respectively being in contact with the ground. The thresholds used to distinguish between these support states are:

- Si_{lo} indicates the upper threshold pressure for a foot in the air and is also used as the lower threshold pressure experienced while sitting.
- DS_{lo} indicates the lower threshold pressure for two feet on the ground while standing.
- SS_{lo} indicates the lower threshold pressure experienced when standing on one foot.

State transitions in the Gait state machine are governed by parameters identified in the Gait state machine. If the current state is Static and a pressure lower than the Si_{lo} threshold is measured, the foot is assumed to be taken off the ground and the state becomes Dynamic. Upon a pressure reduction below DS_{lo}, or upon a timer running out, the state will change from Dynamic to Static. A repeated transition between these two states within certain time limits results in a non-zero gait period, support time and swing time.

The Gait state machine is depicted in Fig. 1. For brevity of the transition conditions, the numbers next to the state transitions indicate the priority of rules in case more than one transition from the current state is possible at a given time.

1. The three rules associated with the Static state are as follows: If the measured pressure is lower than Si_{lo}, the state changes from Static to Dynamic. In addition to this state change, the time spent in the Static state (T_{stat}) is recorded as the support time, T_{supp}. Furthermore the variable P_{min}, which keeps track of the minimum pressure measured by the sensor, is reset.
2. If the time spent in the Static state exceeds a threshold, it is concluded that no gait pattern is available. α, the orientation of the foot relative to gravity is recorded and the Activity state machine is called.
3. If neither rule 1 nor rule 2 applies, the Static state remains active and $\bar{P}_{stat}$, the average pressure measured in the static state, and the maximum pressure measured, P_{max}, are updated frequently.

The two rules associated with the Dynamic state are as follows:

1. If the measured pressure is greater than the threshold DS_{lo} plus the minimum pressure measured in the Dynamic state, the latter