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Instrumented Shoes for Real-Time Activity Monitoring Applications

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Abstract. Activity monitoring in daily life is gaining momentum as a health assessment tool, especially in older adults and at-risk populations. Several research-based and commercial systems have been proposed with varying performances in classification accuracy. Configurations with many sensors are generally accurate but cumbersome, whereas single sensors tend to have lower accuracies. To this end, we propose an instrumented shoes system capable of accurate activity classification and gait analysis that contains sensors located entirely at the level of the shoes. One challenge in daily activity monitoring is providing punctual and subject-tailored feedback to improve mobility. Therefore, the instrumented shoe system was equipped with a Bluetooth® module to transmit data to a smartphone and perform detailed activity profiling of the monitored subjects. The potential applications of such a system are numerous in mobility and fall risk-assessment as well as in fall prevention.

Keywords. Activity monitoring, wearable sensors, inertial measurement unit, force sensing insole, real-time

1. Introduction

Frailty can be defined as a gradual physiological degradation that results in detrimental outcomes in older adults, especially when reacting to environmental stimuli [1]. As a result, a notable worsening of mobility and social activity is perceived in frail older adults [2]. Approximately 35-40 % of community-dwelling, healthy older adults aged 65 or more experience at least one fall every year, and the fall incidence rate increases with age [3]. Fear of falling is manifestly prevalent within older adults with up to 65 % in some populations, leading in many cases to a significant decline in activity levels [4]. Consequently, increased activity avoidance can lead to a reduced quality of life. Certain activities accompanied by well-suited exercise programs have shown potential in maintaining balance, strength, endurance, bone density and functional ability; which in turn can lead to a better quality of life and reduce the risk of falling [5].

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Furthermore, such interventions can be tailored for every individual based on their mobility and activity levels. Traditionally, clinical assessment of motor function in elderly people is mainly based on questionnaires, which are considered subjective and suffer from poor recall. Technology-based assessment of functional mobility, e.g. gait and balance, generally utilizes stationary stereophotogrammetric motion capture tools and force plates. This limits the assessment to the small volume of the lab and does not provide actual activity of the subject during daily conditions. Thus, monitoring time and space volume are limiting factors, insufficient to characterize daily life. With recent progresses in communication systems and smartphones, motion sensors have witnessed a considerable boom in research. Miniature inertial sensors such as accelerometers and gyroscopes are integrated in light box designs that can be placed on the body and collect movement data autonomously for up to several days. However, the devices currently existing on the market or in research laboratories can only perform the recognition of a few types of activity, although more detail on lack of mobility and balance is needed for monitoring elderly subjects, e.g. the detection of transfer between postures, ability to avoid obstacles, climbing and turning. Furthermore, accurate classification of activity is accompanied by a high number of sensors, hindering the movement of the elderly person wearing them. Additionally, only a handful of systems have been validated for real life monitoring of elderly individuals.

In this context, we propose a wearable device consisting of an inertial sensor and a force-sensing insole that will be placed entirely at the shoe level to provide comfort and unobtrusiveness. The device will be used to monitor the daily-life movements of the user and accurately recognize the type of activity, its duration, frequency and intensity (FITT principle [6]). The data from all sensors will be transmitted from the shoes to a smartphone for online activity profiling and further conveyance to geriatric care units.

2. Methods

2.1. Instrumented shoe system

The development prototype of the instrumented shoes consists of the Physilog® (Gaitup, CH) inertial sensing and data logging unit, and the plantar pressure insole (IEE, LU) shown in Figure 1. The system contains 3D accelerometers, 3D gyroscopes, barometric pressure sensor, and 8 plantar pressure cells at relevant anatomical locations under the foot: medial and lateral heel, lateral arch, $1^{st}/3^{rd}/5^{th}$ metatarsals, hallux and the remaining toes. All signals are logged on the Physilog device and can be transferred via USB to a laptop. An electronics box is used to digitize and amplify the pressure sensor data. The system additionally includes a magnetometer and can incorporate a GPS unit. Our concept is innovative in its design and the fact that it can be worn in the shoes during daily life without hindering the user. Recently, a Bluetooth module was added to the system (incorporated within the Physilog box) enabling real-time data transmission of all the sensors to a smartphone or PC.

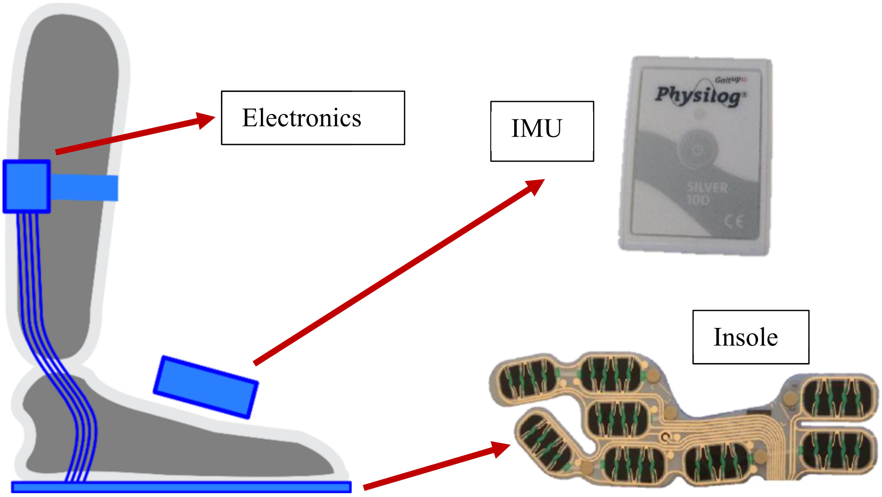

Figure 1 – Instrumented shoe system: Physilog® inertial sensor placed on the shoe, insole inserted inside the shoes and converting electronics placed above the ankle.

2.2. System architecture

The proposed system architecture is oriented towards collecting data from the instrumented shoe in real-time and perform online activity classification and characterization (e.g. gait analysis of locomotion periods and postural transition analysis). Data from all sensors is also stored on a memory card to prevent data losses when the subject is out of smartphone or PC range. Dedicated algorithms will be implemented on the smartphone to perform the analysis and send relevant outcome parameters to a geriatrician including postural allocation, spatio-temporal gait parameters and other information such as symmetry and variability. In turn, the clinician can provide feedback for the user on their mobility levels via the smartphone interface. The system architecture is detailed in Figure 2.

2.3. Activity classification

We have previously validated an activity classification algorithm and its initial in-lab results were described in [7]. The algorithm was based on a biomechanical model and achieved a global accuracy of 97% in detecting activities such as sitting, standing, and level walking as well as stairs, ramps, and elevators, in offline mode after data collection.

The data collected in real-time from the sensors could be used in a similar fashion, i.e. applying a decision tree where the activity types are classified based on the biomechanical model. However, some aspects of the decision tree might not be applicable online because of the need to post-process the data. Alternatively, machine learning techniques could be implemented to recognize the activity in real-time [8]. A short time window (e.g. 5 seconds) would be selected and signal features during this window calculated to provide the activity class.

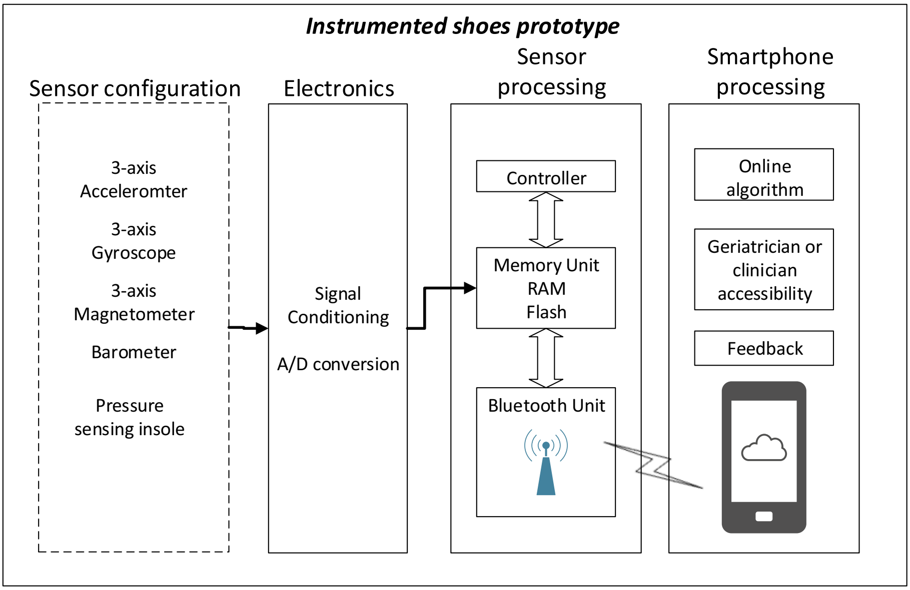

Figure 2 – Final prototype technical architecture

3. Results

Preliminary testing of the real-time Bluetooth data transmission was completed during different activities (sitting, standing, in-place stepping, and level walking). Data were collected wirelessly on a PC. A custom plotting interface was implemented in C++ to visualize the data in real-time. The data collection could be achieved with no losses for the two feet sensors simultaneously as compared to the data that was logged on the memory card for each IMU.

4. Discussion

In this study we proposed an instrumented shoe system for real-time activity monitoring. The preliminary testing of real-time data transmission from the sensors to a PC and smartphone proved to be satisfactory. The next step would be to implement the real-time classification algorithm on the smartphone to provide online activity monitoring and daily logging of the activity profile. Several considerations must be accounted for, including power consumption and algorithm performance tradeoff.

Real-time activity monitoring could have major implications on health assessment in community-dwelling older adults. Postural allocation could inform about sedentary periods, which could be fragmented to increase health benefits [9]. Gait analysis of locomotion periods would be used to output parameters such as stride velocity and foot clearance which have been associated with frailty and fall risk [10], [11]. Thus, the system architecture offers geriatricians several tools with which to assess mobility and provide prompt and tailored feedback to older adults. The current prototype could also be miniaturized to provide maximum comfort to the user.

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