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Framework for Real-time Auditory Display of Plantar Pressure during Walking

122 - eHealth: Gemeinsam Datencanyons überbrücken und Nutzen erzielen – oder abstürzen?

Abstract

The treatment of gait disorders and impairments are major challenges in physical therapy. The broad and fast development in low-cost, miniaturized, and wireless sensing technologies supports the development of embedded and unobtrusive systems for robust gait-related data acquisition and analysis. In addition to their applications as portable and low cost diagnostic tools, such systems are capable of use as feedback devices for retraining gait. The approach described within this manuscript applies movement-based sonification of gait to foster motor learning. This manuscript aims at presenting a framework for a prototype of a pair of instrumented insoles for real-time sonification of gait.

Keywords:

Auditory feedback · Rehabilitation · Acoustic Cueing · Biofeedback · Movement Therapy

1. Introduction

Gait is an essential motor function that forms the foundation of numerous activities of daily living. Inhibitions to gait can drastically hinder one’s ability to successfully navigate through the environment, thus affecting their independence. Therefore, gait rehabilitation is a critical issue for physical therapists due to its associated health and socio-economic implications. Currently, there are several existing methods for the diagnosis and rehabilitation of gait that range from simple visual inspection to advanced motion capture systems. Despite the advantages of these systems, several limitations still remain. Visual inspection, although affordable and practical, is highly susceptible to human error and subjectivity. At the other end of the spectrum, 3D motion capture systems are astonishingly precise in capturing and assessing human movement. However, the high accuracy afforded by these systems is accompanied by large monetary and infrastructural costs thereby limiting its widespread use. Furthermore, motion capture systems are only capable of functioning within a laboratory setting, thus limiting the amount of footsteps that are captured. With only a relatively small amount of captured footsteps, an accurate depiction of an individual’s typical locomotion may not be feasible. Recently, a widespread development of low-cost, miniaturized, and wireless sensing technologies resulted in wearable platforms for gait analysis. These platforms allow for an unobtrusive system that is capable of robust gait data acquisition over longer periods of the gait cycle.

Researchers demonstrated that sonification is an effective method for altering an individual's movement mechanics (Effenberg et al. 2011, Schaffert et al. 2012, Danna et al. 2014, Godbout et al. 2010). When implemented, sonification feedback provides the individual with a real-time auditory representation of the movement of interest. This real-time provision of augmented feedback to participants, termed continuous augmented feedback, has been a traditional method of fostering motor learning for rehabilitation in clinical settings (Schmidt and Wulf 1997). The effectiveness of providing continuous augmented feedback has been attributed to its ability in guiding the learner towards the correct motor response, minimizing movement execution errors, and reinforcing consistent behavior performance. Furthermore, the high accuracy of the human auditory system in detecting changes in sound in conjunction with its faster processing time, compared to the visual system, adds additional justification for providing auditory information as feedback (Effenberg et al. 2011).

Currently, a small number of studies exist that have implemented wearable mobile platforms as a means of providing sonification for gait rehabilitation (Baram and Miller 2007, Riskowski et al. 2009, Redd and Bamberg 2012, Maulucci et al. 2011, Rodgers et al. 2013). However, despite promising results, several limitations to these systems should be noted. For instance, Maulucci et al. (Maulucci et al. 2011) and Rodgers et al. (Rodgers et al. 2013) synthesized sounds by using spatial and temporal parameters, respectively, for outcome measurements but based their data capturing methods on expensive and large laboratory equipment. As a result, their systems are restricted to use in laboratory settings. Contrastingly, Redd and Bamberg (Redd and Bamberg 2012) or Riskowski et al. (Riskowski et al. 2009) both developed devices that are simultaneously low cost and portable (such as instrumented insoles or knee braces) but only generate basic auditory cues, such as error identification with distinct sounds. Similar shortcomings were exhibited by the system developed by Baram and Miller (Baram and Miller 2007). Their apparatus is a small, portable, ankle-mounted device for multiple sclerosis patients that generates a ticking sound each time the user takes a step. By highlighting temporal aspects of an individual's walking pattern, the participant was intended to attenuate to possible asymmetries and aberrations in gait fluency. This procedure was meant to benefit the harmonization of a non-rhythmic walking pattern. One of the strengths of this system clearly lies in its practicality and affordability for the broader population. However, the representation of a person's temporal step frequency alone may be insufficient for advances in gait rehabilitation. Considering the above-mentioned approaches and limitations in gait sonification, there is a demand for the development of a system that is unobtrusive, practical, affordable, provides the user with real-time information, and ultimately demonstrates advanced sonification procedures that incorporates more complex information such as temporal aspects, weight distribution or kinetics.

Therefore, the aim of this project was to develop a framework for sonification in gait rehabilitation. This paper will present a technical framework for a pair of wireless shoe insoles that are each embedded with 7 pressure sensors and provides the possibility for real-time sonification feedback to the user as well as its applications for gait rehabilitation for future research purposes.

2. Design and Hardware of the Shoe Insoles and Microcontroller Unit

The shoe insole device is based on two (left and right) thermoplastic resin insoles that were custom made by an orthopedic technician. The insoles were specifically designed to facilitate the placement of of the devices hardware and wiring, while simultaneously providing strong overall durability. Each instrumented insole is equipped with seven FlexiForce A401 force sensors (diameter: 25.4mm), ultra-thin (0.2mm), and flexible force sensors with a force range of 500N to sample gait plantar force distribution. The A401 model allows for a sensing area (per force sensor) from 0.71cm^2 to 5.07cm^2. The force sensors are located at the heel and continue along the lateral part of the insole to the forefoot and metatarsophalangeal joints. Furthermore, a Bosch BNO 055 consisting of a combination of an ADXL345-3-axis accelerometer (Analog Devices) and an ITG3200 3-axis gyroscope (InvenSense Inc.) allow for additional data capturing. Data from the embedded sensors are sampled by a Teensy 3.1 microcontroller (32 bit ARM Cortex-M4 72 MHz CPU). The device is powered by a 500mAh battery supply. Through the provided XBee socket for RF communication, the Teensy board is connected to a XBee module (BLEBee) based on a Bluegiga BLE 112 Bluetooth LE chip. The microcontroller along with the Bluetooth LE module allows for approximately 133Hz data sampling and transmission rate simultaneously for both feet. The device, along with its components and application scenario, is depicted in Figure 1.

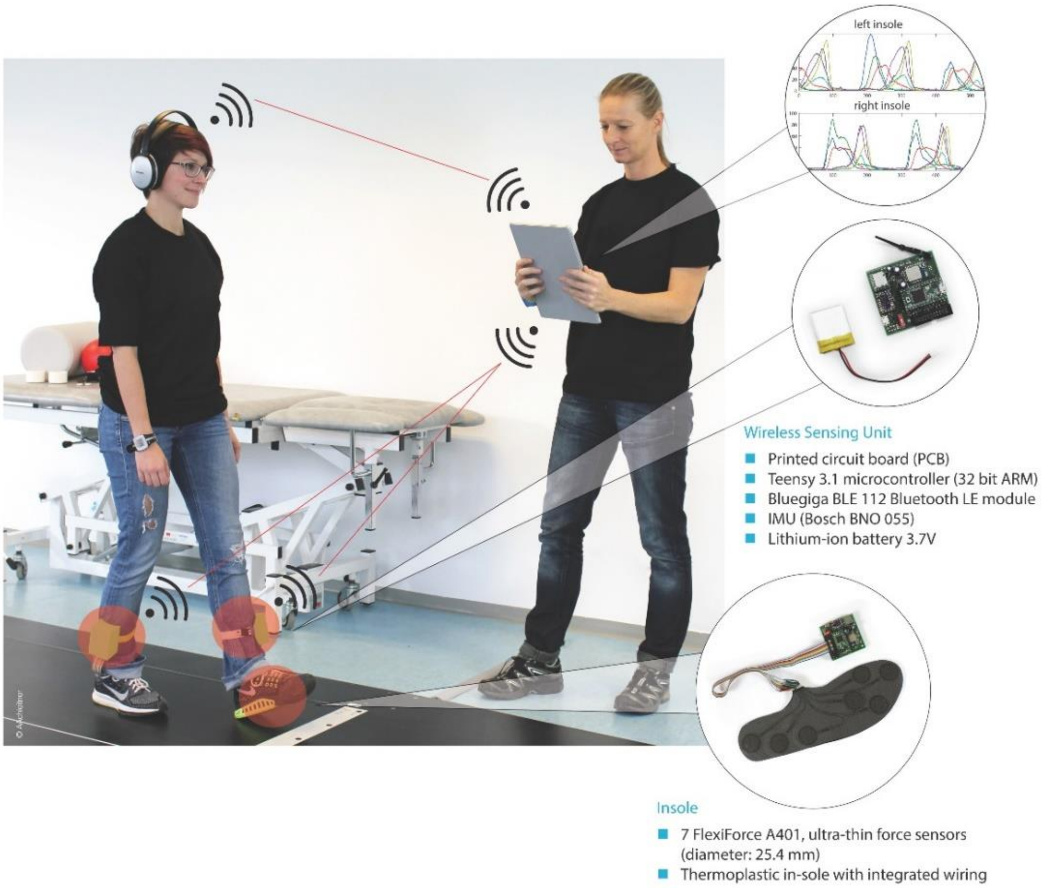

Figure 1 – Schematic representation of the sonification framework and its application in a clinical setting.

3. Mobile Device and Audio Generation

The device is designed as a portable system. Thus data processing and audio generation for real-time sonification of gait are implemented in a mobile application for Android 4.3 devices or above. A background service handles two simultaneous Bluetooth LE connections and offers a constant data stream to the PureData (PD) audio generation engine. PD accepts arbitrary numeric data (such as the force sensor data) as input from Android, synthesizes sound, and passes the generated audio data to the Android low-level audio application programming interface for immediate playback. In this way, measured force values (converted into 10 bit integers) of each sensor can then be mapped to amplitude values of corresponding sound generators. This allows for sonification of a total of seven force sensor data per foot during locomotion.

4. Discussion

Gait rehabilitation is one of the foremost challenges faced by physical therapists. Sonification has been demonstrated to be an effective method for altering participants' biomechanics (Bresin et al. 2010; Danna et al. 2013; Effenberg et al. 2011; Godbout/Boyd 2010). However, the application of sonification for gait rehabilitation is relatively novel. In a pilot study, our group (Horsak et al. 2015) developed a preliminary shoe insole that was capable of providing real-time sonification to participants on their gait parameters. The pilot data obtained indicated that when sonification was applied to healthy participants, they had a significant increase in cadence, step velocity, and step time. These findings suggest that sonification may provide additional information, in the form of real-time auditory feedback, which in turn augments the neural processes controlling gait execution. Under healthy circumstances, gait is an automatic process that requires minimal direct attention for execution. However, in populations with gait impairments, this automatic control may either be disrupted or may in fact exacerbate an existing pathology. Other researchers demonstrated similar findings when employing sonification to healthy participants for gait rehabilitation (Turchet et al. 2013; Young et al. 2013; Zanotto et al. 2013; Zanotto et al. 2014), thus sonification may offer an innovative feedback method for the purpose of gait rehabilitation. Yet, most studies were based on large obtrusive equipment that is not easily implemented outside of a laboratory setting, thus impeding research in clinical settings. To overcome these shortcomings, our group developed an unobtrusive framework for providing sonification by outfitting a pair of shoe-insoles with force sensors, which transmits data to a wireless device providing an auditory display of the participants' gait. The insoles presented in this manuscript are based on a prior prototype (Horsak et al. 2015) and were developed in cooperation with an orthopedic technician. This allowed, in comparison to the first prototype, for placement of larger force sensors to more accurately capture vertical ground reaction forces as well as for greater support for the associated wiring of the device to increase overall durability. By using larger pressure sensors, the newer prototype is better able to capture participants' pressure data during the ankle-foot roll over motion. In doing so, this prototype is able to assess more advanced gait parameters that can assist physical therapists during gait rehabilitation. The goal of our device is to provide a robust and inexpensive method for gait rehabilitation via sonification. This framework will provide a basis for upcoming research targeting the questions of whether and how sonification may be used as real-time feedback for gait rehabilitation.

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