TOWARDS A LOW POWER WIRELESS SMARTSHOE SYSTEM FOR GAIT ANALYSIS IN PEOPLE WITH DISABILITIES

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ABSTRACT

Gait analysis using smart sensor technology is an important medical diagnostic process and has many applications in rehabilitation, therapy and exercise training. In this paper, we present a low power wireless smartshoe system to analyze different functional postures and characteristics of gait while walking. We have designed and implemented a smartshoe with a Bluetooth communication module to unobtrusively collect data using smartphone in any environment. With the design of insole equipped with four pressure sensors, the observed foot pressure is obtained and accuracy of a standard activity can be assessed. With our proposed portable sensing system and effective low power communication algorithm, the smartshoe system enables detailed gait analysis. Furthermore, pervasive gait analysis using our system can be extended in many potential applications such as fall prevention, life behavior analysis and networked wireless health systems.

Keywords: Smartshoe, Smartphone, Gait, Low Energy, Bluetooth Communication.

INTRODUCTION

Shoe-based activity or gait monitoring systems are gaining widespread popularity in research and in the commercial market place. Shoe-based sensors are being used in applications ranging from studies of obesity to post-stroke rehabilitation, from energy expenditure studies to training activities in sports. Scientific gait analysis is the exploration of sensor patterns while walking, and its results have plenty of applications in medical programs [1], physical therapy [2], and sports training [3]. For example, with detailed gait feature analysis, therapists can quantify the rehabilitation progress of the patients after surgery, and the corresponding treatment and training can be customized according to an individual's status [4]. With full analysis of the motion of body segments using highly accurate computer based force and optical tracking sensors, or in an office with the clinician making visual observations. The first method is expensive, the second method is inexpensive but requires substantial time and clinical expertise.

There are several prior research work on wearable devices for human gait analysis in the past. Bae et al. [5] presented a Force Sensing Resistive (FSR) sensor array based system for gait analysis. Recently, Xu et al. [6] developed a Compressed Sensing based algorithm with a single accelerometer for accurate human activity recognition. All these works are helpful to understand the human locomotion and walking status. However, they cannot comprehensively and accurately address all gait features used in actual medical applications. There is indeed a demand of a portable system for professional level gait analysis.

The cost of Smartphones has decreased and their computational competences have rapidly increased with improvements in mobile technology. A Smartphone-based gait observation system can function almost everywhere, since mobile phones are highly portable. Currently, most Smartphones have sensors to observe acceleration, location, orientation, ambient lighting, sound, imagery, etc. [7]. These integrated sensors along with the pressure sensor shoes strengthen the capabilities of the *smartshoe*. The smartshoe system can monitor all types of activities in free living without troubling the normal life of the subject.

This paper concentrates on the development of a low energy wireless shoes for user gait abnormality identification. Foot pressure signals can identify behavior of human gait and posture as reflected in foot pressure distribution. Many studies describe foot pressure as a detection system, but few have used smartphone and a *smartshoe* for the analysis. We report on a new smartphone and *smartshoe* used for gait analysis. Our major contributions are as follows:

- *Development of a low energy wireless smartshoe*
- *Proposed a smartphone- and smartshoe-based system to analyze gait in any environment.*
- *Development of a low energy Bluetooth communication between smartphone and smartshoe.*
- *Provide users, health care professionals and caregivers with highly personalized health feedback.*

Our system targets gait abnormality detection among people with impairments that affect balance, predisposing individuals to falling. These include common rehabilitation diagnostic groups and elderly populations, but also may eventually help identify gait disorders among children, behavior analysis and be helpful in environment monitoring.

RELATED WORK

Hessert *et al*. designed a type of wearable force sensor based on a photo elastic triaxial force transducer to measure GRF in gait analysis [8]. Force sensors based on the optical fiber matrix were developed to detect the shear and compressive force during human walking [9, 10]. Veltink, *et al.* sensors are placed at toe or heel to recognize movements by thresholds. [11]. R.C. Luo, *et al.* explained adopting the methodology of information cognition from multisensory was regarded not only efficient but also reliable [12]. Mathie *et al.* [13,14] reviewed the use of accelerometer-based systems in human movement, such as monitoring a range of different movements, measuring physical activity levels and identifying and classify movements performed by subjects, and discussed a real-time human movement classifier using a triaxial accelerometer for ambulatory monitoring. For diabetics, Morley *et al.* [15] and Maluf *et al.* [16] developed an insole-based system to quantify the conditions inside the shoe. Pappas *et al.* [17] used a pattern recognition algorithm to define the changes during the gait cycle using their device comprising of three force-sensitive resistors (FSR) located on an insole (one under the heel, and two at the first and fourth metatarsal heads), and a gyroscope. The system was tested on two subjects with incomplete spinal injury and was used to trigger functional electrical stimulation (FES), with demonstrated benefit for both subjects.

To address the drawbacks of the above-mentioned systems, we developed a smartphone- and smartshoe based system for human gait analysis to predict fall related injuries. Moreover our design is highly secure and inexpensive because it requires only a smartphone with low cost smartshoes.

SYSTEM DESCRIPTION

Primary features of the foot pressure sensing shoes are its unobtrusiveness and portability. The wearable nature of shoes allows it to collect user's motion signal freely. The schematic of the pressure sensing system is presented in Figure 1.

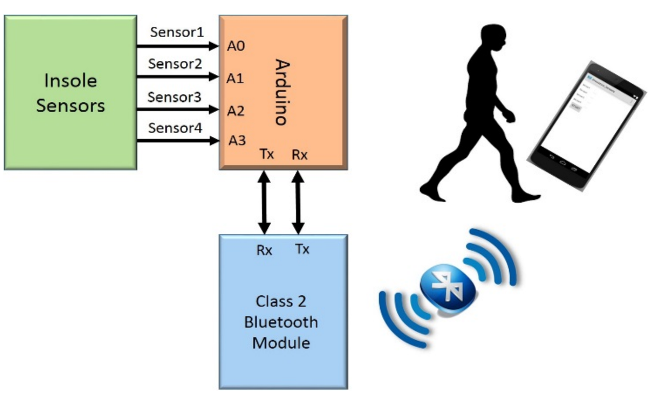


Figure 1: Overview of a foot pressure sensing system

For the analysis of the kinematic motion of the foot, four piezoresistive pressure sensors were placed at the bottom of the shoe to assess the timing parameter and pressure distribution. Most of the body pressure is measured from the rear foot and from the fore foot regions. Considering them we have placed two of our sensors in the fore foot region and two of them are in the rear foot region as describe in table 1. We have used the piezoresistive pressure sensor for measuring the force while walking. The resistance of this sensor changes with the change in pressure. The harder you press, the lower the sensor's resistance. Resistance changes only when pressure is applied to the round area at the end of the sensor, but the resistance does not change while being flexed.

Table 1. Insole Sensing Position

Position Number	Name
Sensor 1	Posterior Metatarsal
Sensor 2	Heel (Hind foot)
Sensor 3	Great Ball (Forefoot)
Sensor 4	Little Ball (Forefoot)

With of four pressure sensors the smartshoe is comprised one arduino, and one class 2 Bluetooth module with a battery power supply. We were using arduino, low power class 2 Bluetooth device and amplifier circuit as wireless Bluetooth communication module on shoe. This module would amplify the signal and transferred to the Smartphone through a Bluetooth communication network.

The class 2 Bluetooth device is a small form factor, low power, highly economic Bluetooth radio for original equipment manufacturer (OEM's) adding wireless capability to their products. This device supports multiple interface protocols, is simple to design in and fully certified, making it a complete embedded Bluetooth solution. With its high performance on chip antenna and support for Bluetooth® Enhanced Data Rate (EDR), the device delivers up to 3 Mbps data rate for distances to around 70 feet.

In order to process the pressure data, the communication module has two different software tasks. One is for the arduino and another is for the Android. In arduino, we programmed to read an analog signal from the shoe sensors and buffered the signal that send to the smartphone through a serial port as string. Pressure data was collected for the people over period of time and every time a subject was tested with different types of walking.

Volunteers were recruited for the validation of the smartshoe system. The testing involved placing the smartshoe instrumentation on the subjects' own walking shoes. Each subject was asked to perform a series of walking tasks, while systems simultaneously collected data and measure the power consumption of the smartphone battery.

Table 2. Summary of Subject Characteristics.

	Healthy Subject
Gender	3 males, 3 female
Age [years]	27.3 (25-35)
Height [m]	1..65(1.5-1.8)
Weight [kg]	73.4(58.2-94)

A total of 6 subjects were recruited. Characteristics for each group are summarized with means (and standard deviations) in table 2. Each subject first walked at his or her own self-selected natural pace for 2 to 4 trials, termed "free gait.” Then asked them to walk with propulsive gait (a stooped, stiff posture with the head and neck bent forward) and Spastic gait (a stiff, foot-dragging walk caused by a long muscle contraction on one side).

PRINCIPLES OF THE SYSTEM

In the system, the *smartshoe* is used to collect the foot pressure value while the subject would asked to perform different types of walking. After receiving the data through Bluetooth communication we will have processed it inside the mobile phone to identify the abnormality in walking pattern. At that moment, the system detects a high-risk gait pattern and enables a warning to the subjects through an audio message and vibration, to alert them about an imminent fall related injuries.

WIRELESS COMMUNICATION ALGORITHM FOR SMARTSHOE

In order to develop the application we have used the algorithm shown in figure 2 to establish the Bluetooth connection between smartshoe and the smartphone. At first the algorithms search the device that supports our proposed communication features. The application will move forward to execute the next operations after accurately detect the correct devices. Enabling the Bluetooth device we initiated an action button to discover the available Bluetooth devices around our device. Among the available devices, the algorithm looked for our target device (smartshoe Bluetooth device) by its name. Subsequently getting the target device name and address, we are checking for whether the device is bonded or not. If the device is not bonded or paired the application will do that with pair code. Then we began a thread to receive and transmit the sensor data through a class 2 Bluetooth module embedded in smartshoe. Here the connections are peer-to-peer communication. We used the Bluetooth Socket to plug in the connectivity. We also have created a thread to listen always from the connected device. Thenceforth the socket was fully ready for receiving and transmitting the input and output stream.

On the other part we have programmed the Arduino with four sensors. We read the analog input data and sent it serially to the Bluetooth device of smartshoe. Smartphone Bluetooth has received these data as string. Then we displayed the data on the Android device with corresponding sensors.

As we have described earlier the application started with saving individual patient personal information. We have recorded the sensor data with respect to individual patient. We saved the data in order to train out system for individual patient. Later on by analyzing these information of individual patient we could identify their walking pattern or classify between normal and abnormal gait pattern.

Raw data on foot pressure distributions were collected with the developed foot pressure sensing shoe (smartshoe). The pressure level represents the output value of analog information into which voltage is converted. The experiment was conducted to develop an automatic measuring system for revealing the relations between human motions and collective foot pressure characteristics. With the power supply unit, foot pressure signal were gathered by piezoresistive flexi force sensors in a time span and transmitted to the smartphone through a Bluetooth communication network.

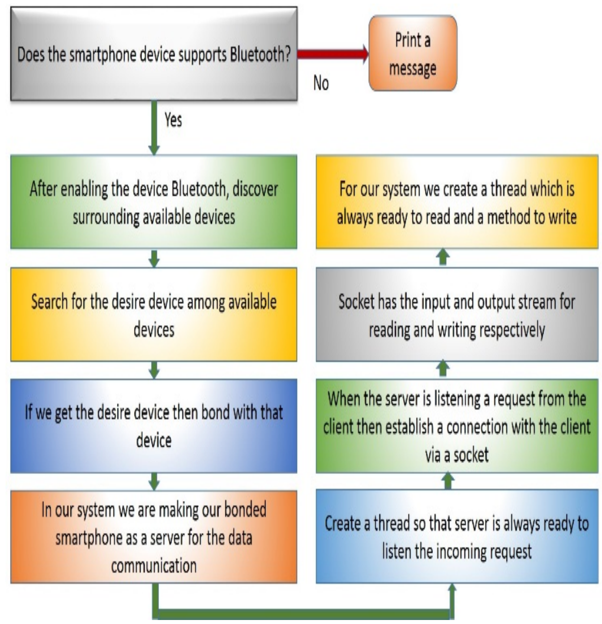


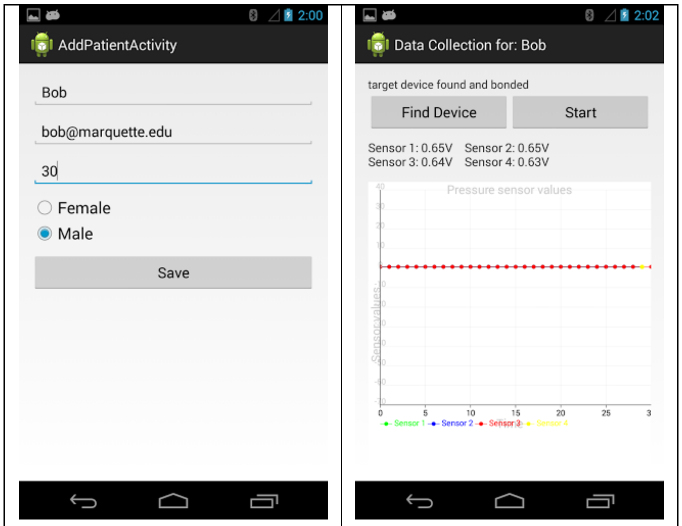
Figure 2: Algorithm on Smartphone

DESIGN AND EVALUATION OF THE SYSTEM

In our application we were saving each patient’s personal information in the Android database SQLite. The patient name would automatically show up in the patient list. Then we can select individual patient to collect the smartshoe sensor data.

As an example, in figure 3, first we were saving Bob’s information in our SQLite database and then collecting pressure sensor data from smartshoe with regard to him. Starting of this user interface a toast would show up to notify “Bluetooth is on”. Afterward we pressed the “Find Device” button to get the target device. If it could find the desire device a text message would show up at the above that “target device found and bonded”. If the desire device is not bonded we have bond that manually by pairing the code. Now the application is ready to receive sensor data from smartshoe. To get those data we need to press “Start” button and sensors data would start showing up continuously. The corresponding graph would show up below the sensor data. We are still working on displaying the corresponding graph for each walking pattern on smartphone. We saved those data against each patient for further experiments.

Our target is to save those data for individual patient to train our system to identify each patient’s normal and abnormal gait pattern. We also observed the smartphone battery usages during our data collection process. It is noticed that the smartphone battery life using our Bluetooth communication algorithm with class 2 Bluetooth device is improved than that of general Wi-Fi or other communication system. The system has a power consumption of about less than 26µA at sleep mode, 3mA at connected situation and 30mA during data collection.



(a) Patient Activity | **(b) Sensors Data**

Figure 3: Screenshots of android based data collection

CONCLUSIONS

In this paper we presented a smartphone- and smartshoe-based human gait recognition system with low energy communication. This design was observed to collect distinguishable data. More data are needed to increase the accuracy and smartphone battery drainage for a wider variety of people and better target the intended population. This work, however provides a solid conceptual and demonstrable foundation for the next phase of design.

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