TOWARDS A SMART SYSTEM OF IDENTIFYING STEPS FOR PREDICTING FALL IN PEOPLE WITH DISABILITIES

A. K. M. Jahangir Alam Majumder[1], Sheikh Iqbal Ahamed[1], and Roger O. Smith[2]

[1]Marquette University, Milwaukee, WI 53233, [2]University of Milwaukee- Wisconsin, Milwaukee, WI 53201-0413

ABSTRACT

Advances in sensor technologies has created numerous methods to assess activity levels of people with disabilities. In this paper, we present a shoe-based sensor system (smartshoe) specifically to identify different functional postures and characteristics of steps in walking. We have designed and implemented a smartshoe with a Wi-Fi communication module to unobtrusively collect data using smartphone in any environment. The smartshoe system consists of four piezoresistive force sensitive resistors built into a flexible insole of the shoe. Analysis for discriminating the user's movements from foot pressure distribution was conducted, considering the activities of standing, walking, going upstairs, and going downstairs as a basis to eventually predict falls. With the design of insole equipped with pressure sensors, the observed foot pressure is obtained and accuracy of a standard activity can be assessed. In this paper, we present the initial results of identifying typical and atypical step characteristics with intent to predict falls for people with disabilities and people who are aging and may have balance impairments.

Keywords: Smartshoe, Smartphone, Movement, Falls, Wi-Fi Communication.

INTRODUCTION

Scientific gait analysis is the exploration of sensor patterns while walking. Gait analysis is primarily carried out in one of two ways: in a motion laboratory, 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.

Falls in the elderly are very common occurrences that can have dramatic health consequences. According to the United Nations Population Division statistics, by the end of 2009 the elderly population reached 737 million, accounting for 10.8% of the total population. In the year 2025 it is projected to account for 15% of the total population. For people of 70-75 years old, the estimated incidence of falls is over 30 percent per year [1]. Nearly half of nursing home patients fall each year, with 40 percent falling more than once [2, 12]. In order to predict the risk of falls clinical teams are often put in situations of making treatment assessments without much in the way of solid data. They may see a patient after long time, relying on memory and subjective descriptions of progress. This high risk of falling among the growing elderly population has greatly influenced research on fall detection and fall prediction; the latter, being very challenging since to prevent a fall, we first need to identify the patterns correlated with a fall for a specific person.

The cost of Smartphones has decreased and their computational capabilities have rapidly increased with improvements in mobile technology. As self-contained devices, Smartphones present a mature hardware and software environment for developing various fall detection as well as activity monitoring systems. A Smartphone-based falls 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. [3]. These integrated sensors along with the pressure sensor shoes strengthen the capabilities of the *Smartshoe*. *Smartshoe* can already automatically detect falls. Indeed other teams have already created some Smartphone-based fall detection systems [4].

This fall prediction system leverages Smartphones as a programmable platform for monitoring well-being as people go about their lives [5]. The smartphone can infer a range of behaviors on the phone in real-time. Someday this could allow users to receive real-time feedback on their movement. In addition, with the improvements in mobile technology, the popularity of smartphone app stores can make any new technology instantly widely available.

This paper concentrates on the development of a pair of shoes for user movement identification for predicting a fall. 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 to predict a fall. Our major contributions are as follows:

- *Proposed a smartphone- and smartshoe-based system to identify the quality of step activity in any environment.*
- *Developed a Wi-Fi network (my-adhoc) for the communication between smartphone and smartshoe.*
- *Provide users, health care professionals and caregivers with highly personalized health feedback.*

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

RELATED WORK

Veltink, *et al.* sensors are placed at toe or heel to recognize movements by thresholds. [6]. R.C. Luo, *et al.* explained adopting the methodology of information cognition from multisensory was regarded not only efficient but also reliable [7]. For diabetics, Morley *et al.* [8] and Maluf *et al.* [9] developed an insole-based system to quantify the conditions inside the shoe. Pappas *et al*. [10] 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. In [11], the author proposes a method that uses a network of fixed motes to provide location information about the victim after a fall has been detected. *iFall* [4] is an Android application that has been developed to detect fall events in the fall detection territory. Data from the accelerometer is evaluated using several threshold-based algorithms and position data to detect a fall.

To address the drawbacks of the above-mentioned systems, we developed a smartphone- and smartshoe based system for human movement identification to predict falls. 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.

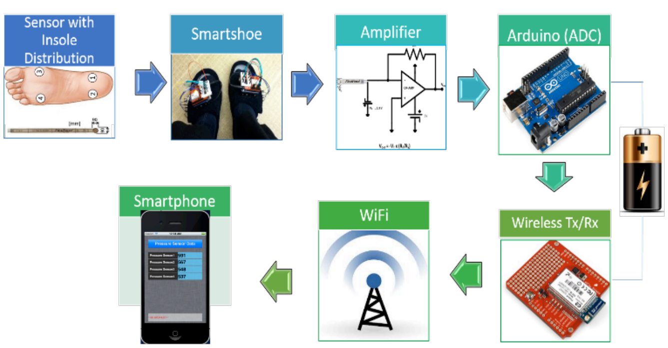


Figure 1: Overview of foot pressure sensing system

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. A human foot usually divide by three different region, Fore Foot (FF), Mid Foot (MF) and Rear foot (RF). Most of the body pressure is measured from the rear foot and from the fore foot. Considering these issues we have placed two of our sensors in the fore foot region and two of them are in the rear foot region as shown in Figure 2. We have used the flexiforce piezoresistive [13] force sensor for measuring the pressure 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.

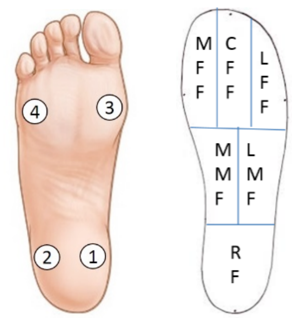


Figure 2: Insole Sensors Measurement Position

The SmartShoe is comprised of four piezoresistive pressure sensors, one arduino, and one wifly shield [13] with a battery power supply. We were using arduino, wifly shield and amplifier circuit as Wi-Fi communication module on shoe. This module would amplify the signal and convert it into digital signal. This data is transferred to the Smartphone through a my_adhoc Wi-Fi communication network.

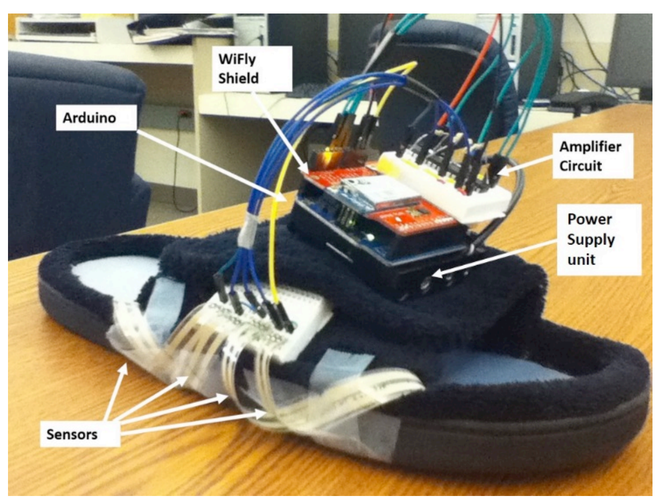


Figure 3: Early prototype of Smartshoe hardware mounted on shoe [13].

In order to process this data, the communication module has two different software tasks. One is for the arduino and another is for the iPhone. In arduino, we programmed to read an analog signal from the shoe sensors and create a data packet to convert the signal into digital form Pressure data was collected for the people over period of time and every time a subject was tested with standing, walking, going upstairs, and going downstairs.

Figure 3 portrays an early prototype with embedded sensors attached to the computational board, wifi and power components.

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 locomotor tasks, while systems simultaneously collected data.

Table 1: Summary of Subject Characteristics.

	Healthy Subject
Gender	4 males, 1 female
Age [years]	27.3 (25-35)
Height [m]	1..7(1.6-1.8)
Weight [kg]	73.4(58.2-94)

A total of 5 subjects were recruited. Characteristics for each group are summarized with means (and standard deviations) in Table 1.

Each subject first walked at his or her own self-selected natural pace for 2 to 4 trials, termed "free gait."

PRINCIPLES OF THE SYSTEM

In the system, the *smartshoe* is used to collect the foot pressure value while the subject would asked to perform four different types of movement, stand still, Walking, going upstairs, and going downstairs. After receiving the data through Wi-Fi communication we have processed it inside the mobile phone to identify the movement steps for predicting fall. 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.

Human walking is a cyclical movement, so here we use the similarity of the data between two adjacent cycles to assess the walking stability.

Stability = Similarity (C_i, C_{i+1}) ---------- (1)

Where C_i is the data of the preceding cycle, and C_{i+1} is the data of the next cycle.

The dynamic symmetry of gait is defined as the discrepancy of bilateral data in gait cycle on all symmetric attributes.

Symmetry = Discrepancy (R_i, L_i) -------- (2)

Where R_i is the data of the right-side and L_i is the data of the left-side on one attribute.

Considering stability and symmetry of walking data, we propose a walking model for our system. The impulse, I, of a step of running and walking I s given by, $= \int F\ dt$, where F is the force.

Using Newton's second Law, $F = ma$ and $a = \frac{F}{m}$

Where, a = Acceleration and m= mass.

From the foot pressure distribution and accelerations and orientation observed from Smartphone motion sensors while walking. The first simplest approximation of the signal is an impulse function. We will assume that the acceleration curve for walking is approximated by a sinc function,

$$a = \frac{F}{m} = \frac{Sint}{t} \quad \text{where, } 0 \le t \le T$$

EVALUATION AND EXPERIMENTAL RESULT ANALYSIS

Raw data on foot pressure distributions for were collected with the developed foot pressure sensing shoe (smartshoe). Variation of each kind of movement were displayed in Figure 4. The pressure level represents the output value of analog information into which voltage is converted.

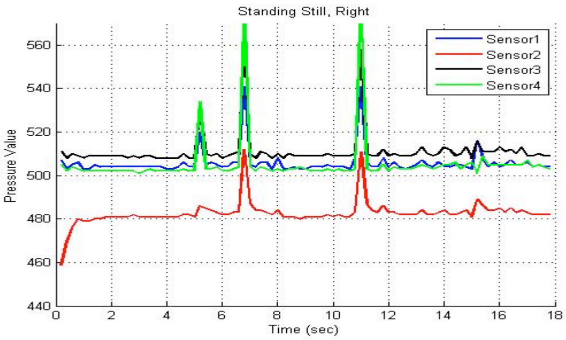
The experiment was conducted to develop an automatic measuring system for revealing the relations between human motions and collective foot pressure characteristics. With the power supply unit, foot pressure signal were gathered by piezoresistive flexi force sensors in every 18sec and transmitted to the smartphone through a Wi-Fi communication network.

According to the figure, during standing still, the values of foot pressure remain constant. In case of walking, it is observed that the patterns change in shape and the ratio of the time, which depends on the pressurization to depressurization in each step, in agreement with the way we use our feet. In case of going upstairs and down stairs, a higher pick value within each step can be observed, however the wave patterns are different for each. Therein, we are aiming at identifying these movements based on the corresponding foot pressure to predict a fall. We picked up 5 set of data samples of each moving pattern: the former 15 data set are used as a training and the latter for testing.

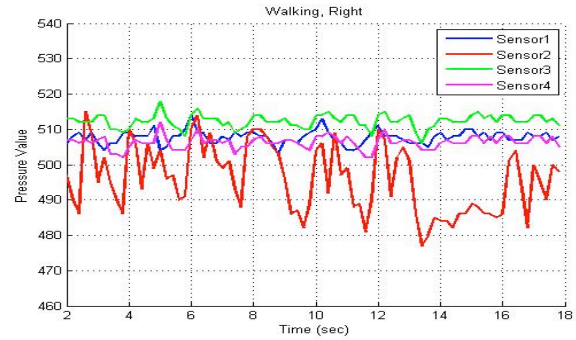
Table 2: Accuracy of different movements.

Moving Pattern	**Training Accuracy (%)**	**Testing Accuracy (%)**
Standing Still	92.0	88.0
Walking	86.1	81.3
Moving Upstairs	78.7	76.1
Moving Downstairs	93.2	88.4

The average accuracy with four sensors in each shoe is 85.5% for all four kind of movements and the identification accuracy for each moving pattern is in table 2.



(a)



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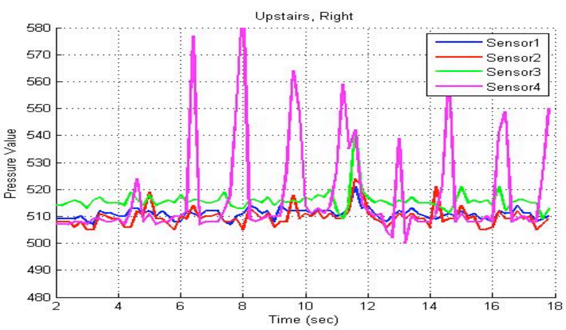

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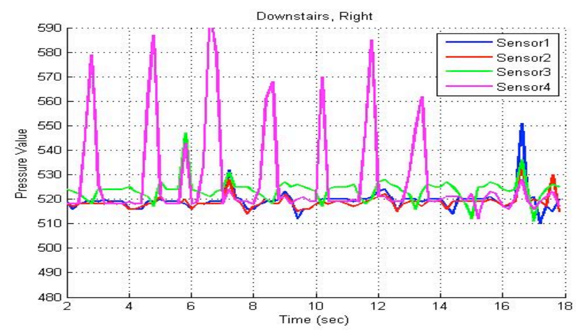

(d)

Figure 4: Right foot pressure distribution of (a) Standing still, (b) Walking, (c) Going upstairs, and (d) Going downstairs

CONCLUSIONS

In this paper we presented a smartphone- and smartshoe-based human moving pattern recognition system for predicting falls. This design was observed to collect discriminatable data. More data are needed to increase the fall prediction accuracy 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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REFERENCES

[1] United Nations,Department of Economic and Social Affairs, Population Division, "World Population Ageing 2009," pp. 66-71

[2] C. Tacconi, S. Mellone, L. Chiari. "Smartphone-Based Applications for Investigating Falls and Mobility". 5th International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth) and Workshops, pp. 258-261, 2011.

[3] N. D., Lane, Miluzzo, E., Lu, H., Peebles, D., Choudhury, T. and Campbell, A. T. "A Survey of Mobile Phone Sensing," In Proc. of IEEE Communications Magazine, Vol. 48, No. 9, pp. 140-150, 2010.

[4] F. Sposaro, G. Tyson, iFall: an Android application for fall monitoring and response. In Journal of IEEE Eng Med Biol Soc. pp. 6119-22. 2009.

[5] D. N. Lane, Emiliano Miluzzo, Hong Lu, Daniel Peebles, Tanzeem Choudhury, and Andrew T. Campbell, "A Survey of Mobile Phone Sensing", Comm. Mag., vol. 48, pp. 140–150, September 2010.

[6] P. H. Veltink, C. Liedtke, E. Droog, and H. van Der Kooij, "Ambulatory measurement of ground reaction forces," IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 13, no. 3, pp. 423–427, 2005.

[7] R. C. Luo, C.-C. Yih, and K. L. Su, "Multisensor fusion and integration: approaches, applications, and future research directions," IEEE Sensors Journal, vol. 2, no. 2, pp. 107–119, 2002.

[8] R. E.Morley, E. J. Richter, J.W. Klaesner, K. S. Maluf, andM. J.Mueller,"In-shoe multisensory data acquisition system," *IEEE Trans. Biomed. Eng.*, vol. 48, no. 7, pp. 815–820, Jul. 2001.

[9] K. S.Maluf, R. E. Morley, E. J. Richter, J.W. Klaesner, andM. J.Mueller, "Monitoring in-shoe plantar pressures, temperature, and humidity: Reliability and validity of measures from a portable device," *Arch. Phys. Med. Rehabil.*, vol. 82, no. 8, pp. 1119–1127, Aug. 2001.

[10] I. P. Pappas, M. R. Popovic, T. Keller, V. Dietz, and M. Morari, “A reliable gait phase detection system,” *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 9, no. 2, pp. 113–125, Jun. 2001.

[11] J. A. Paradiso, K. Hsiao, A. Y. Benbasat, and Z. Teegarden, “Design and implementation of expressive footware,” *IBM Syst. J.*, vol. 39, no. 3, pp. 511–519, 2000.

[12] J., Majumder, F., Rahman, I., Zerin, W., Joe, S. Ahamed., iPrevention: Towards a Novel Real-time Smartphone-based Fall Prevention System, Proceedings of ACM Symposium on Applied Computing (SAC), pp. 513-518, Portugal, March, 2013.

[13] J., Majumder, I., Zerin, M. Uddin, S. Ahamed., and R. Smith, smartPrediction**:** a real-time smartphone-based fall risk prediction and prevention system, RACS '13 Proceedings of the 2013 Research in Adaptive and Convergent Systems, Pages 434-439, Montreal, QC, Canada, October 2013.