Smart Shoe for Balance, Fall Risk Assessment and Applications in Wireless Health

Hyduke Noshadi, Shaun Ahmadian, Foad Dabiri, Ani Nahapetian, Thanos Stathopoulos[++], Maxim Batalin[++], William Kaiser[++] and Majid Sarrafzadeh
Wireless Health Institute, University of California Los Angeles
Email: {hyduke, sahmadia, dabiri, ani, majid}@cs.ucla.edu
[++] Email: {thanos, maxim, kaiser}@ee.ucla.edu

Abstract

A new system combining embedded networked sensing, signal processing, and state detection algorithms have been developed to create a smart shoe for individuals who are prone to falls. This system monitors walking behaviors and uses a fall risk estimation model to predict the future risk of a fall. The model incorporates variability and correlation of features extracted from walking behavior, which have been identified by geriatric motion study experts as precursors to balance abnormality and fall risk. This system provides an affordable, mobile balance abnormality detection system, which is reliable, easily customizable for individual users, context aware which can be guided by experts. This system demonstrates capabilities that meet those of dedicated gait measurement laboratories, but at a much reduced cost, with greater user convenience and with detection capability in the user environment. In addition, this smart shoe system comprises a platform that we wish to share for diverse application domains, including urban and participatory sensing, behavior analysis, and novel applications that incorporate social networking.

Introduction

Embedded networked systems and wide area cellular wireless systems are becoming ubiquitous in applications ranging from environmental monitoring to urban sensing. These technologies have recently been adopted to support the emerging work in *Wireless Health*. Wireless Health merges data, knowledge, and wireless communication technologies to provide health care and medical services, such as prevention, diagnosis, and rehabilitation outside of the traditional medical enterprise. Ever-increasing opportunities in health care have thus motivated researchers in Computer Science and Electrical Engineering to develop technologies that can be adopted in the medical and physiological fields and to serve the recently growing demand of low cost and widely accessible health care services.

Fall related injuries are among the key challenges that the health care system is facing today. Hospitalization costs of falls range from $25,000 to $75,000 per injury. While the current annual total cost of treatment is $20 billion, it is predicted to increase to an annual of $32 billion a year in the future. Even more surprisingly, direct and indirect annual costs associated with falls are $75 to $100 billion in the U.S. alone. Falls can often be caused by serious physiological problems that can lead to disability and paralysis. The elderly population is more prone to falls and fall related injuries, due to the degradation of visual, cognitive, or motor skills .[2][3][4][5].

Several methods and systems have been used to measure instability and balance [8]. Existing solutions, which typically lack a real-time feedback mechanism, are designed for laboratory use only and incur considerable operational and energy costs [10]. This paper introduces a low cost, easy to use, and customizable fall risk assessment system that operates outside a laboratory environment, which is capable of providing real-time feedback. To assess fall risk, our proposed system leverages a low power *smart shoe*, signal processing in an embedded device, and a remote repository infrastructure. In addition, the system can be used as a general platform for conducting research in a variety of application domains, in addition to Wireless Health, which would leverage the mobile sensing and signal processing platform.

Fall Risk Assessment Model

Instability is defined as a person's inability to control and maintain proper balance and orientation. The presence of instability has been identified as a primary cause of falls. Common fall risk factors include hearing, vision, and cognitive impairments resulting from aging as well as chronic conditions such as diabetes[6][7]. These conditions affect the normal ambulatory pattern which in turn alters gait parameters [8].

Our fall risk estimation model contains two major components. The first component considers the effect of a person's walking pattern and gait parameters, such as the variability and gradual shift of extracted parameters and the correlation of detected features over the time. The second component includes the effect pressure variation across the foot.

Our investigation has been conducted in close collaboration with physicians leading geriatric medicine programs at the UCLA Veteran's Administration Hospital [8]. Destabilizing forces imposed by the environment or degradation in visual, vestibular and somatosensory systems can manifest themselves in gait changes and other gait parameters. Furthermore, variability in these parameters is indicated by [9] to be of importance in predicting and assessing fall risk, and hence it is incorporated into our model. Our fall-risk formulation captures most of the factors associated with instability: physiology, cognition, vision, and environment.

System Architecture

The primary goal that guides our system design is the mitigation of the medical, economic and emotional costs of falls. We have developed a lightweight, non-invasive system for everyday use to aid ordinary individuals in assessing their fall risk. The system allows the assessment of fall risk over time in the users' home and work environment. This information, combined with supervision and assistance from physicians enables preventive action.

The proposed system is composed of the *smart shoe*, a personal device such as a PDA or cellular phone, and a remote networked computing infrastructure. The *smart shoe* contains a lightweight embedded processing device and pressure sensors. The pressure sensors are placed in the insole, so as to minimize the number of necessary sensing channels while still allowing for feature detection and extraction from walking patterns and necessary gait parameters.

As the embedded processing system in the shoe is designed for low-power operations that limit its processing capabilities, a more powerful device such as a PDA or cellular phone device is used for real-time, on-site data evaluation. The personal device, i.e. the PDA or mobile phone, performs real-time fall risk estimation through signal processing, feature extraction, pattern recognition and classification. Upon detecting a set of features that are an indication of high falling risk, the personal device is capable of sending preemptive notification to the user, a physician or a care giver. In addition, it acts as a gateway between the shoe and the backend server. The presence of more powerful devices in collaboration with backend server increases system and data reliability. The collected data is stored temporarily on the device until it is transferred to secure backend server.

A remote computing and data repository infrastructure stores parameters extracted from users over time, including balance quality and fall context. This information is considered of high value to both users and more importantly to physicians. In particular, the availability of historic data can be used to improve the fall detection model and lead to enhanced accuracy in fall risk analysis.

Vision and Future Work

The next stage of our fall risk assessment project will exploit wearable sensors that are not embedded in the shoe, to capture accurate information pertaining to the user's environment and fitness to be used when computing the fall risk. For example, it is important to differentiate if the user is walking on a flat surface or on a surface with considerable vertical variation (such as uphill or downhill). It is also important to assess if the user is fatigued due to severe temperature, pollution, high heartbeat rate, or UV exposure. High vertical variation and increased fatigue levels can produce results that resemble the effects of balance abnormality on human walking patterns and the variability of the extracted features. It is critical for our system to be able to classify an increase in variability of extracted parameters as due to balance abnormality or as due to environmental and fitness effects. We also plan to integrate subject guidance, through which the system will be able to detect the user's location and current state.

The *smart shoe* is currently customized to provide gait and balance related data. We plan to distribute the *smart shoe* platform for research and study that expands beyond fall analysis, such as urban, environmental and participatory sensing, environment monitoring, human behavior analysis and social networking. As our vision is to enable researchers from various domains to use our *smart shoe* technology, we plan to develop a public API that will allow for versatility and increased customization to meet individual needs and variety of applications requirements.

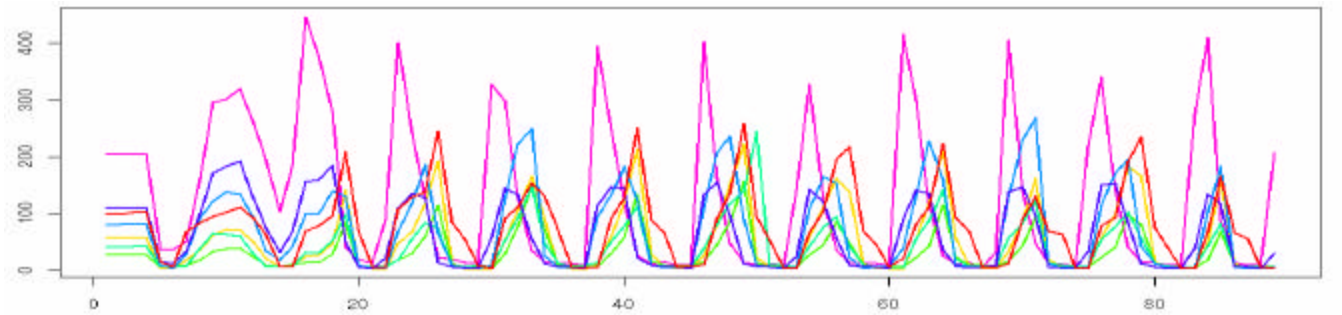

Figure 1: Data from 7 pressure sensors embedded in the Smart Shoe. The system performs signal processing, feature extraction on streamed pressure data, and incorporates results from both shoes to assess fall risk.

Experimental Results and Demonstration

We have completed preliminary investigations in fall-risk analysis and successfully demonstrated the functionality of our system. Through in-lab experiments the sensitivity of our system was validated by appropriately identifying abnormal walking patterns as having greater variance in gait parameters and smaller pressure correlation over the time.

In order to demonstrate the functionality of the system, test subjects wearing the smart shoe were asked to carry a cellular phone, containing our signal processing engine, while performing various walking patterns, such as normal gait , limping or changing the walking speed. The cellular phone examines the received signals from the smart shoe and displays stats on extracted parameters and also identifies an overall falling risk. The final fall risk assessment is presented in color coded alert levels, with green being low, orange meaning moderate and red being high.

References:

[1]. *Prospects for expanding telehealth: Multi-agent autonomic architectures*, IEEE International Conference on Computational Intelligence for Model ling, Control and Automation, 2006 and International Conference on Intelligent Agents, Web Technologies and Internet Commerce.

[2] Moreland J, Richardson J, Chan DH, O'Neill J, Bellissimo A, Grum RM, Shanks L. *Evidence-based guidelines for the secondary prevention of falls in older adults*, Gerontology 2003, 49(2):93-116

[3] *Commodore DI: Falls in the elderly population: a look at incidence, risks, healthcare costs, and preventive strategies.*, Gerontology 2003, 49(2):93-116

[4] Coogler, C.E. *Falls and Imbalance*, Rehab. Manag. (April/May), 53 1992.

[5] *Preventing Falls Among Older Adults*, http://www.cdc.gov/ncipc/duip/preventadultfalls.htm

[6] Sorock GS. *Falls among the elderly: epidemiology and prevention*, American Journal of Preventive Medicine 1988;4(5):282-8

[7] *Injury Prevention Fact Sheet: Injuries Among the Elderly*, Association of State and Territorial Health Of?cials, July 2006

[8] Yentes J, Elrod M, Perell K.L, *Predicting Fall Rist with Plantar Pressure Equipment in Individuals with Diabetes*, Clinical Rounds.

[9] Maki B.E. *Gait changes in older adults: predictors of falls or indicators of fear* Journal of American Geriatr. Soc. 45 (1997), pp. 313320

[10] Pedar, http://www.novel.de/productinfo/systems-pedar.htm