Development of an In-Shoe Sensor Insole for Motion Analysis, Physical Therapy, and Rehabilitation

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As the population demographics shift during the next several decades, aging and associated health risks will become increasingly important. A major health risk is falls in elders, which are a large source of morbidity and mortality, both in the general elderly population [1], as well as with persons with Parkinson’s disease [2]. Following a fall, activity is generally reduced, whether due to recovery from injury or fear of falling again, and this often results in a “downward spiral” of decreased quality of life and muscle atrophy [3]. Since falls represent such a significant safety risk, finding new methods of evaluating balance and preventing falls will be of increasing importance as the size of the elderly population grows.

Many factors can contribute to a fall, ranging from decreased vision, prescription medications, environmental hazards, to impaired balance, changes in posture, and gait changes [4]. Our focus is on the latter factors. In the clinic, assessing balance typically includes questionnaires (such as the Activities-specific Balance Confidence Scale) or function tests (such as the Berg Balance Scale or the One Leg Standing Test), including measures which can be inexpensively administered (e.g. using visual observation or a stopwatch) [5]. An additional parameter that has been shown to correlate with the risk of falling in the Parkinsonian population, is variation in stride-timing [2, 6]; however, this is difficult to assess visually, and is not widely implemented in current clinical measurements, but can be readily assessed with sensors placed on the shoe.

We have two core goals: first, to develop a device capable of robust assessment of balance and risk of falls, and second, to use the knowledge gained from this device to provide real-time feedback both for at-home physical therapy and for fall prevention. Through implementation of these goals, we hope to prevent or minimize the downward spiral by both preventing falls, and helping persons who have had a fall by restoring and maintaining self-confidence and mobility.

Previous work resulted in the GaitShoe, a wireless system worn on the shoe that measured several parameters of gait, and contained four force-sensitive resistors (FSRs), and multiple accelerometers and gyroscopes [7-8]. This system was validated by comparison to results obtained simultaneously from a vision-system motion analysis lab, and was found to be highly capable of detecting heel-strike and toe-off timing, as well as estimating foot orientation and position. In addition, the GaitShoe was used to evaluate persons with normal gait and persons with Parkinson’s disease, and detected a significant difference in variation in stride time: in 48 samples of normal gait, the standard deviation of stride time was 0.09 s (8.4%), more than double the 0.21 s (17.2%) found in 26 samples of Parkinsonian gait; stride time was determined primarily through the use of the data from the FSRs [8]. This system was also used to implement an auditory feedback system for persons with Parkinson’s disease [9].

Our recent work has split development of the in-shoe system into two components: the inertial sensing system using gyroscopes and accelerometers, to analyze motion of the foot [10], and the insole sensing system using force sensitive resistors (FSRs), to analyze the force distribution underneath the foot [11]. While both components are expected to be important for assessing balance, we have completed a preliminary investigation of using several FSRs in the insole to evaluate balance (the GaitShoe only had four). The subjects were fitted with two Dr. Scholl’s insoles, each with sixteen FSRs taped to the bottom and shrink-wrapped, and they were asked to stand with both feet flat on the floor for one minute. The results found that balance had both a frequency component and a magnitude component that varied according to the balance abilities of the subject (this preliminary study did not calibrate the FSRs, but used the same sensors across all subjects; the range of outputs of the sensors was 0-3V). In elders with no known gait problems, changes in force had a frequency on the order of 1 Hz, with a mean standard deviation was 0.029±0.016V, while in the elders with Parkinson’s disease, the resulting small tremors were readily detected in changes in force that occurred on the order of 5-10 Hz, with a mean standard deviation of 0.065±0.019V, more than double that seen in the subjects with healthy gait. In addition, we evaluated a single elder who has balance problems, but not Parkinson’s disease, and found that while the changes in force distribution occurred over longer time scales (on the order of 0.1-0.2 Hz), the mean standard deviation was 0.102±0.013V, triple that of the subjects with healthy gait [11].

Encouraged by these results, we have designed a more durable insole system, presented here, and are implementing the use of it in a larger study of the balance of elders with Parkinson’s disease. We will be evaluating elders before and after (and likely during) a 12 week high intensity training program that has been
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demonstrated to have positive results for a Parkinson’s population [12]. Our goal is to investigate the effects of the training program on balance, as measured with our system, as well as to further investigate the balance of elders with healthy gait. For this project, the FSRs will be calibrated, and a new design of the insole has been developed, shown below in Figure 1. The material used is a urethane rubber compound with a Shore hardness of 30A, chosen for the firmness and durability achieved while still maintaining the ability to easily bend the insole as needed. The sensors and wires are embedded in the insole to provide a uniform surface so that subjects who are being tested will not react to the presence of the sensors and wires. This insole is cast in two different pieces, the ball of the foot and the heel of the foot. This will allow the insole to fit a range of foot sizes by simply adjusting the position of each piece. The heel portion includes four sensors, while the ball portion contains ten sensors, including two to measure the response of the big toe. Sensors are placed to account for variances in individual foot width and length. The wires from the sensors will then be attached to the microprocessor board, which is currently connected to the outside of the shoe.

![Figure 1. A top and bottom view of the insole embedded with force sensitive resistors.](image)

This new system will be used to evaluate balance of elders, and the knowledge gained will be used to further develop a feedback device for at-home physical therapy for persons with Parkinson’s disease. Future plans also include embedding the microprocessor in the insole along with the inertial sensing components.

ACKNOWLEDGMENT

We thank Paul LaStayo and Lee Dibble of the University Rehabilitation and Wellness Clinic for their collaboration, and thank The Center on Aging at the University of Utah for their support. This work was supported by a research grant from the American Parkinson Disease Association.

REFERENCES