DERIVATION OF BASIC HUMAN GAIT CHARACTERISTICS FROM FLOOR VIBRATIONS

Majd Alwan, Siddharth Dalal, Steve Kell, Robin Felder

Medical Automation Research Center
University of Virginia
Charlottesville, VA

INTRODUCTION

This abstract describes a passive unobtrusive gait-monitoring device, based on a highly sensitive optic fiber floor vibration sensor. Long-term in-home gait monitoring provides a measure of a person's functional ability and activity levels, which can help 'evaluate' a person's health over a long period of time. Such a passive gait-monitoring device can be useful for assessing healing/deterioration following therapeutic interventions. It can also contribute to the detection of general health problems early. The ability to distinguish between normal walking and limping or shuffling, which may be precursors to a fall, as well as detecting falls, is of utmost value to elder populations. Elders, who represent 12% of the population, account for 75% of deaths from falls [1]. The considerable cost involved in the treatment and hospitalization of fall injuries and even death due to falls could be greatly reduced if falls could be predicted and avoided through appropriate intervention.

BACKGROUND

Current gait analysis techniques broadly fall under three categories depending upon the type of device used: wearable devices, walk on devices and visual gait analysis tools and techniques. These gait laboratory equipment and analysis techniques yield excellent and detailed gait characteristics and enable clinicians to prescribe an appropriate intervention. However, the equipment required is extremely expensive, in the range of tens of thousands to a few hundred thousand dollars. The computational power required for the image based analysis make longitudinal in-home gait monitoring using these technologies impractical.

THE GAIT MONITOR SYSTEM

The gait monitor described in this abstract is passive, can transmit acquired data wirelessly, and obtains gait data from sensing floor vibrations. Passive monitoring obviates the need to wear anything, walk on special surfaces or be observed by cameras. In clinical settings, we envision the deployment of such a device in a corridor where a person's gait is evaluated as he/she enters the clinic and the analysis report becomes available to the clinician by the time the patient walks into the examination room.

We have designed a system to process the raw vibration signal of the optic fiber sensor system, extract features of significance and analyze the extracted data to provide basic gait characteristics. Our preliminary analysis algorithms were able to differentiate between normal walking, limping and shuffling, to measure step count and calculate cadence with good accuracy when the gait is normal. Figure 1 shows a block diagram of the system.

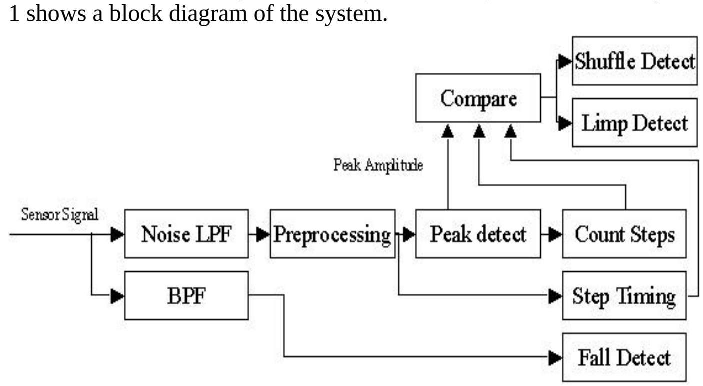

Figure 1: Block Diagram of the Gait Monitor System

For step timing, limp and shuffle detection, the original signal is filtered through a specially tuned Low-Pass Filter (LPF). The filtered signal is processed to derive a large signal that corresponds to the footfalls of the walking person. The processed signal is passed through a peak detector to detect negative peaks in the signal, corresponding with footfalls.

The fall detector consists of a Band-Pass Filter (BPF), tuned to block frequencies generated by different walking modes and falling objects. The filter output feeds into an amplifier followed by a comparator to detect falls; the comparator threshold is tuned to detect a low weight human falling about ten feet from the sensor, yet insensitive to falling objects.

RESULTS

The system design was simulated on Matlab and Simulink. Real raw sensor data, recorded from a set of experiments carried out on carpeted and uncarpeted wooden floors with a person walking towards and away from the sensor, was input into the simulation model. The results in figures (2, 3 and 4) depict the outputs of the step timing (upper waveform in yellow) and the peak detector (lower signal in purple) modules. Original sensor signals, along with outputs of the various signal processing stages can be found in [2].

Normal Gait

In figure 2, the amplitude of the detected peaks, corresponding to footfalls, consistently increased when the person walks in a normal gait towards the sensor, and decreased when the person walks away. Counting the detected peaks reflects step-count and we can calculate cadence by simply measuring the time period. It is clear from the graph that the step-timing signal was fairly regular for normal gait.

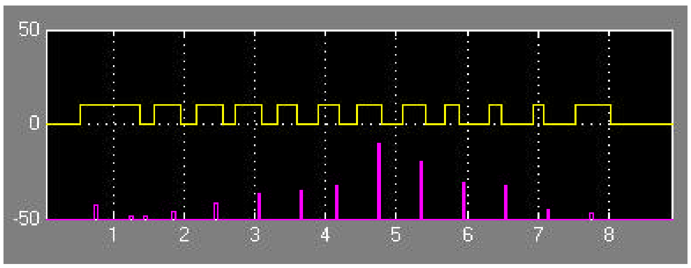

Figure 2: Normal Gait

Limping

Figure 3 illustrates signals derived from data of a limping person. An alternating pattern for the amplitude of the peaks, high-low-high or low-high-low was observed which reflects the difference in pressure applied to the floor by both feet. The amplitude of the peaks still shows an overall trend of increase with the person walking towards the sensor and decrease when walking away from it. However, the difference in alternating amplitudes is higher than the increase or decrease due to proximity to the sensor. From the figure, we can clearly observe irregular and skewed step timing in case of limping.

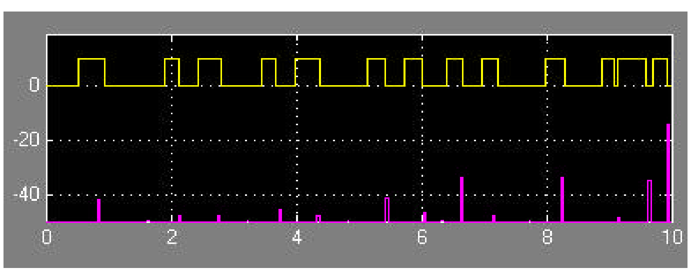

Figure 3: Limping

Shuffling

Figure 4 depicts the signal derived from data generated by a shuffling subject. From shuffling data, we observe a large number of low amplitude peaks that have no correlation with each other or with proximity to the sensor. In case of shuffling, irregular and skewed step timing signal is also noticed.

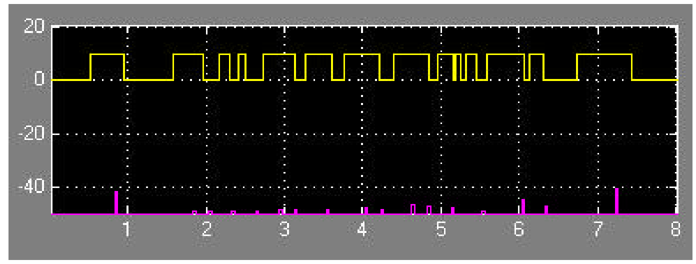

Figure 4: Shuffling

Falls

Figure 5 shows the output of the fall detector (lower spike in yellow) successfully triggered by a person, weighing 175lb., falling 9 feet away from the sensor on a carpeted area of a wooden floor. The upper signal (in purple) represents the output of the falls BPF filter.

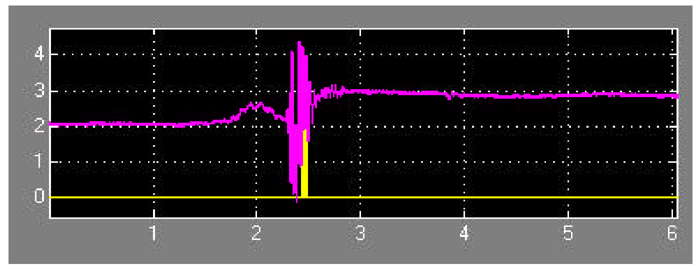

Figure 5: Falling Person

CONCLUSION AND FUTURE WORK

The simple device and algorithms described here can provide various basic gait parameters including step count, cadence, and step duration, in addition to the ability to distinguish between normal, limping and shuffling gait modes. However, this gait monitor may be augmented with additional sensors to estimate the distance of walking subjects and evaluate average walking velocity; this would enable the calculation of additional gait characteristics such as average step length and average stride length. These parameters can be used to detect various gait anomalies [3].

We built a hardware prototype implementing these models and intend to deploy this prototype in different settings to collect longitudinal data. Data analysis techniques will be applied to derive gait characteristics that are common among frail fall-prone elders. These characteristics will be used in building a predictive model for falls. The device could be installed in eldercare or physical rehabilitation facilities and people's homes.

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REFERENCES

1. George F. Falls in the Elderly. American Family Physician, Apr. 2000.
2. Alwan M., Dalal S. and Kell S. Passive Unobtrusive Gait Monitor: An Economic Device to Detect Gait Anomalies and Falls, Poster Paper, CBI Steps to Success Conference, Roanoke, VA (2002).
3. Classification of Gait Abnormalities. http://guardian.curtin.edu.au/cga/faq/classification.html