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An Accurate and Robust Gyroscope-Based Pedometer

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Abstract—**Pedometers are known to have steps estimation issues. This is mainly attributed to their innate acceleration based measuring sensory. A micro-machined gyroscope (better immunity to acceleration) based pedometer is proposed. Through syntactic data recognition of apriori knowledge of human shank's dynamics and temporally précised detection of heel strikes permitted by Wavelet decomposition, an accurate and robust pedometer is acquired.**

I. Introduction

WALKING is a critical necessity (such as, for commuting to work, for getting food from the fridge, etc.) and can be a popular leisure activity in our life. It represents a significant part of our daily energy expenditures [1]. Walking has been reported to reduce obesity rates, enhance bone density, improve mobility in the aged group, and lower risk to cardiovascular disease and cancers [2-7]. Studies have underlined the importance of accumulating 10,000 steps per day to confer well being [7-9]. Pedometer indices had been formulated to account for reasonable variations in different age groups and pathological groups [10]. Walking has been identified as the recommended form of exercise for secondary prevention of myocardial infarction by the American Heart Association Task Force on Risk Reduction [11].

With a low-cost pedometer, the walker can evaluate the number of steps taken relatively accurately and objectively in an ambulatory manner. Psychologically, the pedometer motivates the wearer to reach a targeted number of steps per day [7]. The pedometer is not only used for physical activity assessment in human beings, it has also been used in other research domains such as assessment of cows' reproduction optimality, sensing tool in the virtual reality world, etc [12-13].

Pedometers generally detect steps from vertical acceleration at the human trunk. The detection mechanism can be classified as either mechanical (spring, lever arm or contacts) or electrical (accelerometer). Accelerometer-based pedometers have been deemed to be more accurate and reliable as step counters [14-15]. Inaccuracies in pedometers are well-observed and compared between various major brands [15]. Study has reported that there is a greater mean absolute error in obese than non obese subjects [16]. A likely cause is the greater tissue movement of surface tissues relative to the skeleton. On the other hand, frail elderly step-counting has been observed to understate the actual number of steps [17]. Other examples of possible errors contributors are driving automobile or operating vibrating machinery (such as a lawn mower, etc.) [18].

Clearly, using an acceleration based pedometer is an erroneous approach to steps counting. Additionally, an acceleration-based pedometer is not able to discriminate explicitly whether the subject accumulates the step counts by walking, running or stair climbing. As a consequence, evaluation of energy expenditure accuracy is inaccurate.

This study proposes using a micro-machined gyroscope as a step detection counter to be attached to the shank segment of the leg. Gyroscopes have immunity to acceleration and hence should be able to eliminate the issues raised. Furthermore proper selection of wavelet detail banks should prevent artifactual acceleration sources from miscounting steps. Human gait cycles through four phases, stance (ST), toe off (TO), swing (SW) and heel strike (HS) [19]. During the heel strike phase, a significant vertical acceleration force is experienced. Although the gyroscope responds to relative orientation change, not acceleration (slight in practice), heel strike will induce a transient signal due to ground reaction forces. Such a transitory signal is significantly smaller than the higher amplitude and lower frequency angular rate signal of the shank segment's kinematics.

Wavelet decomposition has been used to extract the transitory heel strike signal and a de-noised version of the angular rate movement of the shank segment [20-21]. The de-noised angular rate signal facilitates ease of detecting the stationary points, thus eliminating any erroneous detection as a result of noise-induced local stationary points. The apriori knowledge of the shank's angular velocity during the stance and swing phases of walking dynamics is used along with the heel strike transitory angular rate signal to register each step count in a syntactic data recognition approach.

To the best of the authors' knowledge, this is the first proposed gyroscope-based pedometer in the literature.

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II. Method

A. Experimentation setup

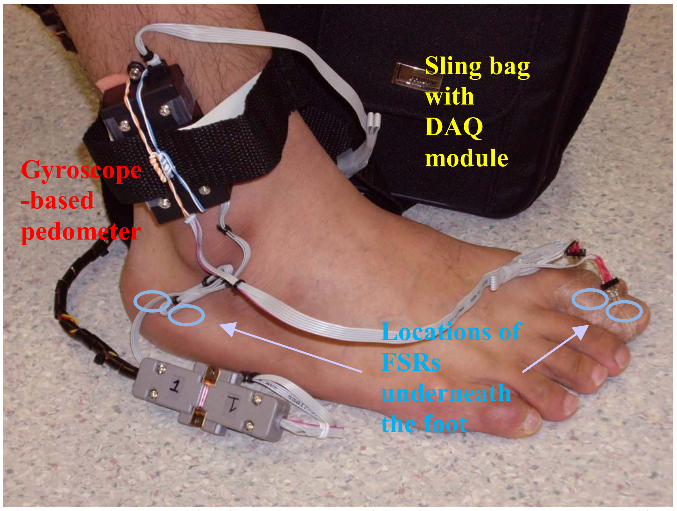

Fig. 1. A micro-machined gyroscope capable of measuring up to ±400rad/s is adhered to the right shank segment (right above the ankle joint). Connectors shown are meant for linking to the DAQ module and the FSRs. Four FSRs are adhered to strategic anatomical location underneath the right foot for gait event triggering.

A measurement range extended Analog Devices (ADXRS150) gyroscope capable of measuring up to ±400rad/s is housed in a small ABS box with its signal conditioning electronics. The ABS box also contains the electronics for interfacing the Force Sensitive Resistors (FSRs) (Interlink electronics) to the DAQ module. The FSRs are intended to serve as a temporal gait event triggers for critical validation of this proposed system.

Two FSRs are fixed underneath the hallux (big toe) and the two other FSRs are adhered to the heel of the right foot in sequence along the progression plane.

The DAQ module and the powering accessories are housed in a sling bag wore by the subject. The DAQ module is connected to a laptop via a USB link. Data are then processed in Matlab. A subject with normative gait is instructed to walk on a treadmill with paced speed of 2km/h.

B. Wavelet Decomposition based Detection of Heel Strike (HS) gait phase and de-noising of angular rate information of shank segment

In order to make this pedometer robust, there is a need to detect the transitory event that occurs during heel strike atypical in Fig. 2. The heel strike event can be closely described by a 4th order Daubechies mother wavelet. This is valid even for various velocities or weights, the presence of pathological gait traits, etc. as long as the signal can be localized in right order of time and frequency (scale) [21].

Wavelet decomposition is executed in two windowing dimensions; namely, time and scale. The Discrete Wavelet Transform (DWT) iteratively splits the current order of sampled approximate data in the next order of dyadic approximate (time) and detail (scale) using a set of complementary filters [20].

Consider the original gyroscope angular output digitally sampled, giving discrete signal, s(n). Each level of decomposition, or scale i, the approximate is denoted by $A_{2^i}s$ with time resolution down-sampled every 2^i samples for the original signal. We have the s(n) seen in (1).

$$s = A_{2^0}s = A_{2^1}s + D_{2^1}s = A_{2^i}s + D_{2^i}s + \ldots + D_{2^1}s \quad (1)$$

Inductively, we know that

$$A_{2^i}s = A_{2^{i+1}}s + D_{2^{i+1}}s \quad (2)$$

An efficient approach is to operate dyadic DWT, we iteratively pass through the current order of approximate data (N samples) into a complementary set of real filters: - low pass filter, g(n) and high pass filter, h(n). The next order of high pass filtered signal forms the next order detail signal (0.5N+1 samples) as seen in (3), and on the other hand, the low pass filtered signal (0.5N+1 samples) as described by (4), generates the approximate signal. After down-sampling by half and scaled by the mother wavelet, gives the set of next order approximate and detail signal.

$$A_{2^{i+1}}s = \sum_{k=-\infty}^{\infty} g(2n-k)A_{2^i}s \quad (3)$$

$$D_{2^{i+1}}s = \sum_{k=-\infty}^{\infty} h(2n-k)A_{2^i}s \quad (4)$$

Down sampling in DWT subjects the signal to aliasing issues and careful cancelling is necessary to prevent aliasing.

In order to evaluate the time instant at which the HS events are occurred, up-scaling of wavelet coefficients are determined by interleaving zero-paddings.

It was empirically found that the 4^{th} order Daubechies wavelet gives a good representation of the HS events. HS detection is then equated by threshold detection summation of details between bandwidth of 1Hz to 8Hz as evaluated in $A_{2^1}s - A_{2^5}s$.

C. Syntactic Data Recognition of the Phase & Swing Gait Phases

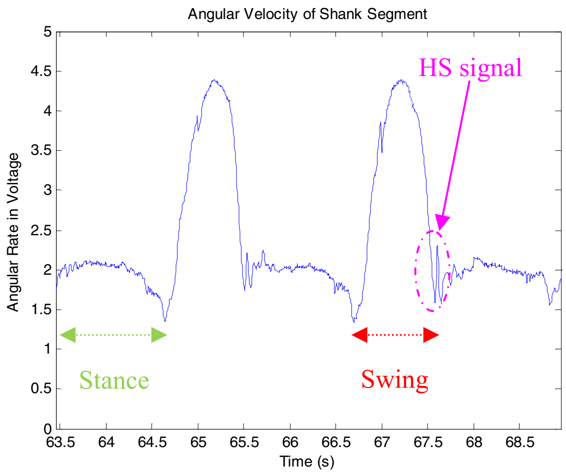

Fig. 2. Shank's angular rate signal is negative during stance and early swing positive during late swing. Salient features of interest are labeled.

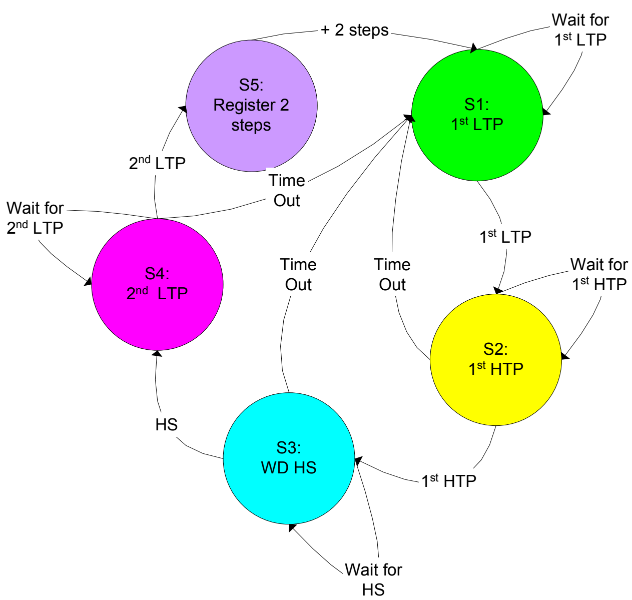

Fig. 3. State transition diagram of the syntactic data recognition performed for each gait stride. LTP – Low Turning Point, HTP – High Turning Point, WD HS – Wavelet Decomposed Heel Strike Trigger. Timeout is defined to be .5s in this study.

Human walking gait kinematics is well understood. The shank's angular velocity can be well classified into two sections. They are a small velocity (stance phase) and a large velocity (swing phase) angular rate signal as seen in Fig. 2.

Syntactic data recognition is performed to ensure the integrity of each stride (2 steps) registered. Details of the algorithm can be seen in Fig. 3. Upon wavelet de-noising, the HS transient comes before the end low stationary point. Subject's walking stride duration was assumed to be at least approximately 1 second. Local maximum turning point search is done with each 0.5 second spacing.

III. Results & Discussions

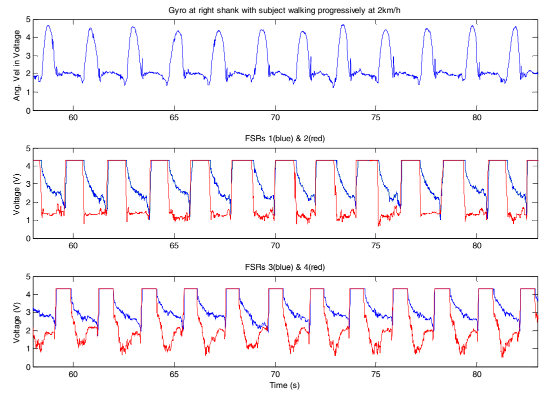

Fig. 4. FSRs outputs tally characteristics of the gyroscope's output

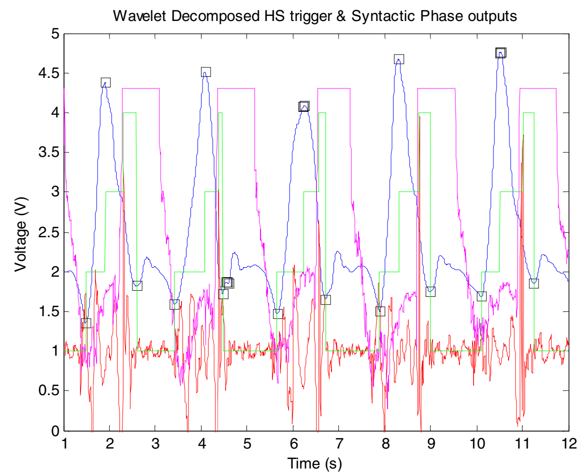

Fig. 5. FSRs outputs tally characteristics of the de-noised gyroscope's output. (Blue) – gyroscope output, (magenta) – FSR at heel end, (black) – maximum and minimum stationary points detected, (red) – wavelet decomposed HS signal, (green) output of the syntactic data recognition algorithm

A truncated plot of the gyroscope's output and FSRs (attached to subject's right shank and foot respectively) is depicted in Fig. 4. Logic high implies load on the FSR. It can be clearly seen that the 1st stationary point of the swing phase correlates to the occurrence of FSRs 2 to 1 being un-pressured. The HS can be correlated to the FSRs 4 to 3 being pressed.

The output of the syntactic data recognition algorithm can be seen in Fig. 5. The heel end FSR triggering is closely related to the wavelet decomposed HS trigger.

The experimentation results in Fig. 5 have shown this study methodology of counting is feasible. It is intuitive that vibration-related over or under estimation of steps are not like to occur here. In a preliminary test, where the subject tried to jump on the spot and rocking/shuffling his foot, no steps were being registered.

Further works are necessary to miniaturize the pedometer to a wearable scale and to test the robustness of the pedometer in an on-field basis. Such a step counting methodology also promises accurate registration of steps taken during running and stair walking with the implementation of appropriate pattern recognition algorithms.

Acknowledgment

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