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A Gyroscopic Data based Pedometer Algorithm with Adaptive Orientation

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Abstract— **Orientation of an Inertial Measurement Unit (IMU) relative to earth is a critical factor to the step detection in gyroscopic data based pedometer algorithm. The orientation of the IMU will be often subjected to change while using the small scale electronic pedometers. Existing fixed axis gyroscopic data based pedometer algorithm may not be suitable to implement in the modern small scale embedded pedometer applications. In this paper we have developed an advanced version of the gyroscopic data based pedometer algorithm which can dynamically adjust for the changing orientation of the IMU. Step detection component of the proposed algorithm is based on the gyro readings and the orientation detection is based on accelerometer readings. The algorithm employs the gravity vector and linear acceleration vector of the pedestrian to identify the orientation of the IMU. The active gyroscopic data axis for the pedometer algorithm is chosen based on the orientation.**

I. INTRODUCTION

Pedometers are extensively used in healthcare related applications and fitness tracking [1]–[3]. Most of the modern smart phones come with built in pedometer algorithms and the ability to predict the daily fitness statistics of the user. Pedometers can also be used in indoor and outdoor navigation applications [4], [5]. Most of these applications use accelerometer data with threshold detection [6]. It has been highlighted in [7] that the pedometer algorithms based on accelerometer data is less accurate at slow walking speeds and gyroscopic data based pedometer algorithm has been proposed instead.

The work in this paper is inspired by the work done by researchers in [7]. Their gyroscopic data based pedometer algorithm detects the zero crossings of the gyro signal and uses corresponding positive and negative peaks of the gyro signal for step counting. The mobile phone always has to be placed in the trouser pocket according to their implementation. The limitation of this approach in pedestrian tracking applications is the loss of stride data in case if the user takes the mobile phone out of the pocket while walking. Hence the tracking device (Pedo Tracker) shown in Figure 1 was developed for the implementation of the new algorithm. The tracking device was designed to be as small as possible for the convenience of the user to carry in the front trouser pocket. The device weighs 5.5 grams and dimesions are $46 \times 24 \times 6\ mm$. The tracking device tends to topple inside the pocket due to its smaller size and the axis of walking relative to the sensor changes consequently.

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Fig. 1: Pedo Tracker

The novel algorithm developed in this paper could identify the walking axis of the user relative to the sensor and switch the axes dynamically when the tracking device topples. This algorithm was developed as a component of a pedestrian tracking system based on continuous step length estimation.

The paper is organized as follows. A literature review is reported in Section II. Section III describes the methodology that was followed to test and implement the algorithm. Section IV provides concluding remarks.

II. BACKGROUND

The indoor/outdoor navigation system developed in [4] uses a smart phone to obtain pedometer data. The pedometer data is fed into a Fuzzy Decision Tree along with the inertial sensor data of the mobile phone. Their system consists of an indoor mobile mapping system for map generation in indoor environments. They have identified step length and heading to be two major error sources in pedestrian dead reckoning (PDR) systems. They state that the gyro-heading is also affected by the dynamic disorientation between sensor body frame and pedestrian.

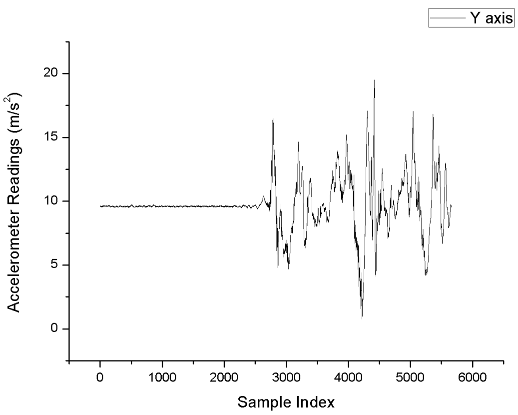

Fig. 2: Accelerometer Reading of gravity axis while kept stationary and then walking

A wearable augmented reality system for navigation using positioning infrastructures and a pedometer is presented in [5]. Their main technique of localization is using RFID tags and IrDA markers. The pedometer is used as an alternative localization method when the infrastructure is absent in a particular area. They use a USB compatible IMU with accelerometer based pedometer to perform dead reckoning. Their approach consists of an infrastructure based navigation and they have used an expensive standalone IMU for the pedometer. They have very bulky setup which the pedestrian has to wear while using their system.

A precise IMU based localization technique for smart phone users called PILoT has been developed by researchers in [8]. The system utilizes Kalman filter in combination with Continuous Wavelet Transform (CWT) for localization. It fuses the accelerometer and magnetometer readings with gyroscope readings to accurately localize the subject. The proposed system PILoT has achieved a mean accuracy greater than 99% in step detection. However, their system does not seamlessly adjust for the orientation changes in the IMU. Instead it can only adjust and switch its reference axis between x-axis and z-axis based on the assumption that the user keeps the mobile phone in the pocket or in the hand respectively. Any other orientation will cause the system to generate false results.

A researcher has used the gyroscopic data based pedometer algorithm in [7] for human gait modelling in vision impaired indoor navigation [6]. His work extends to step detection, step length estimation and gait phase classification using a single thigh mounted IMU. He has emphasized the importance of a pedometer algorithm which adapts dynamically for the changing orientations of the IMU in his thesis.

The researchers have identified the weaknesses in existing pedometer algorithms and their inaccuracies to be used in PDR systems. It is understood that the main drawbacks in developing an IMU based PDR navigation system is the inaccuracy of the pedometers and the heading estimation. The pedometer algorithms need to be independent from any infrastructure and must employ low cost hardware with a small form factor. The Pedo Tracker was designed to overcome these difficulties and the approach took by the authors in compensating for dynamic orientation change is discussed in the following sections of this paper.

III. Algorithm Development

The novel pedometer algorithm is an advanced version of the Gyroscopic Data based Pedometer Algorithm presented by the researchers in [7].

Gyroscopic Data Based Pedometer Algorithm with Adaptive Orientation

1) Capture accelerometer readings: ax, ay, az
2) Pass ax, ay, az through a low pass filter based on complementary filter.
3) Detect gyroscopic data axis for pedometer: $min(filtered\{ax, ay, az\})$
4) Read gyroscopic data from the detected data axis.
5) Feed gyroscopic data from the detected data axis to the Gyroscopic Data Based Pedometer algorithm in [7].

A. Orientation Detection

Adaptive orientation was acquired by tracking the gravity vector and linear acceleration vector of the pedestrian. This approach would be simple and straightforward if the IMU was kept stationary. Almost all the existing orientation detection algorithms were developed based on the assumption that the IMU was held stationary. This approach becomes a bit more complicated, since the Pedo Tracker performs a periodic motion while it resides inside the trouser pocket. Figure 2 shows the accelerometer reading of the gravity axis where the IMU was first held stationary and then started walking.

It could be seen that the sensor reading stays around 9.8 ms^{-2} when the device was kept stationary and it varies from -7 to $+20$ ms^{-2} while walking. This makes it difficult to detect the gravity vector direction while walking. Figure 3 shows the accelerometer readings from all the three axes in above scenario.

With the interference from other two axes, it would be more difficult to identify the gravity direction. Two approaches to overcome this problem was tested out.

1) Calculating Cumulative Average of the signal
2) Applying a Low Pass filter to the signal

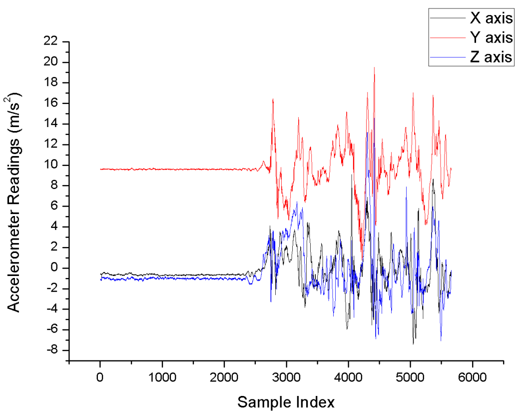

Fig. 3: Accelerometer readings of all the 3 axes while kept stationary and then walking

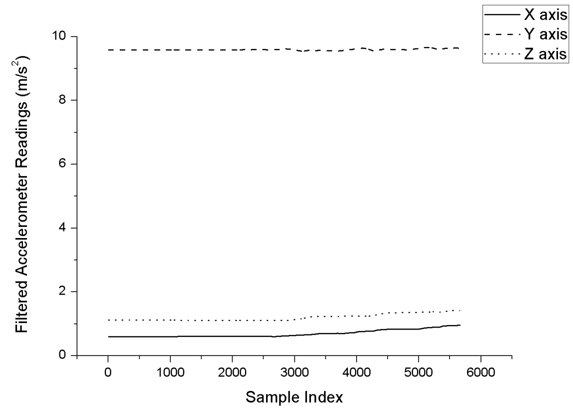

Fig. 4: Low Pass Filtered version (at 2Hz cutoff) of accelerometer signals corresponding to waveforms in Figure 3

The first approach was tested and implemented using Pedo Tracker. Even though the larger fluctuations are disappeared after obtaining the cumulative average, the resulting signals are still found to be vulnerable to larger fluctuations of the leg movement.

The second approach was to pass the signal through a low pass filter to obtain the steady signal. The acceleration vectors were distorted by the periodic movement of the leg. This distortion could be filtered out, because the leg movement is periodic. The signal was filtered by a low pass filter with 2 Hz cutoff frequency and resulting waveform is shown in Figure 4.

The low pass filtered version of the signal is found to be more stable than the cumulative averaged version. Hence the low pass filtered signal could be used to identify the gravity vector, heading direction vector and gyroscopic data axis for obtaining stride cycle. The highest acceleration component holds the gravity vector. The absolute value of the acceleration of a walking pedestrian in the direction of walking is non-zero. Hence the median acceleration component of the readings must provide the walking direction. Hence the minimum acceleration componhent must account for the gyroscopic data axis for the pedometer. Therefore, this technique could be used to dynamically switch the sensor coordinates to earth coordinates.

There are six possible gyroscopic data axes which could be detected by this approach:

1) Stride cycle around $+X$ axis
2) Stride cycle around $-X$ axis
3) Stride cycle around $+Y$ axis
4) Stride cycle around $-Y$ axis
5) Stride cycle around $+Z$ axis
6) Stride cycle around $-Z$ axis

The sensor coordinate system is rotated to earth coordinate system after detecting the sensor orientation out of above

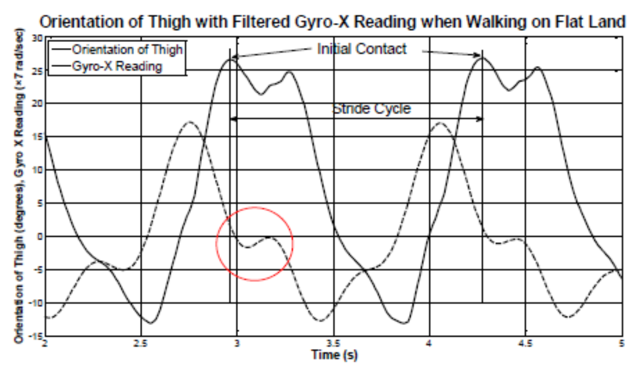

Fig. 5: Typical Human Stride Cycle [6]

six cases. This algorithm was implemented on Teensy 3.2 microcontroller.

B. Step Detection

The basic principle of gyroscopic data based step detection is to exploit the shape of the typical human gait cycle. Figure 5 shows the typical shape of human gait cycle by observing the gyro reading [6].

The gyroscopic data from the selected axis is used in step detection. There are two noticeable positive peaks in the waveform after each positive going zero crossing. The first peak is the higher peak which corresponds to the upward moving phase of the leg (initial contact). The Second peak accounts for the jerk occurred when the leg returns to ground. Thereafter the negative going zero crossing will occur, which is followed by the negative peak. The highest positive peak and the negative peak of the waveform are tracked to count the number of steps.

A single threshold was used to detect both the peaks in the gyroscopic data based pedometer algorithm in [7]. This technique was replaced by using two separate thresholds to detect the positive and negative peaks separately. The positive peak of the stride waveform is higher than the negative peak as shown in Figure 5. Therefore, the latter procedure was found to be more accurate than the original thresholding mechanism.

C. Results and Observations

Five test subjects were made to walk 100 steps on a flat land while the device was placed randomly in the pocket of each subject. The stepping speed of each subject was approximately 100 steps per minute. A sample result set from one of the subjects is listed in Table I.

TABLE I: Test results from one test subject

Trial ID	Actual Step Count	Predicted Step Count
1	100	92
2	100	88
3	100	94
4	100	93
5	100	87
6	100	92
7	100	91
8	100	87
9	100	93
10	100	91

The accuracy of the algorithm was found to be 90.8% based on the tests conducted. The accuracy of the gyroscopic data based pedometer algorithm developed by researchers in [7] was 96.84% and 98.77% while walking in slow (50 steps/min) and fast (150 steps/min) on flat lands respectively. This shows that the integration of adaptive orientation into the pedometer algorithm has not significantly affected the accuracy in [7].

D. Future Work

The accuracy of the novel algorithm decreases when an orientation switching event occurs while walking. The loss of stride data during an axis switching event accounts for this decrease in accuracy. A proper methodology to avoid this data loss occurring at each switching event would help to increase the accuracy of the proposed algorithm under dynamic orientation chanegs.

This algorithm only considers the accelerometer data to predict the sensor orientation. Gyroscopic data could also be used to determine the axis orientation of the sensor to a certain extent. The current algorithm could be further developed by combining gyroscopic data into the orientation detection process.

IV. Conclusion

The accuracy of the pedometer algorithm was above 90% based on the collected experimental data. This recorded accuracy might be further increased if more trials were conducted to test the algorithm performance. The accuracy of the pedometer algorithm in [7] was not significantly decreased upon the introduction of the adaptive orientation. An axis switching event takes place when the Pedo Tracker topples inside the trouser pocket. Gyroscope signal data corresponding to one or two steps would be lost during each of these transitions. This scenario causes the decrease in accuracy of the step detection when the orientation changes occurs dynamically. The gyroscopic data axis for the pedometer algorithm could be detected only for a limited number of orientations. The axes of the sensor must be perfectly aligned with the axes of the earth frame during the detectable orientations. When the Pedo Tracker is at an intermediate orientation, it will snap the orientation to the most fitting orientation known.

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