A Novel Approach for Indoor Localization Using Human Gait Analysis with Gyroscopic Data

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Abstract— **Way finding is one of the main difficulties that vision impaired people face, especially in indoor environments. Although Global Positioning System (GPS) based navigation is possible outdoors, the accuracy of GPS is not sufficient for indoor navigation and way finding. Most of the existing indoor localization and path finding techniques depend on additional infrastructure deployed in the environment. This paper proposes a novel technique for indoor localization based on human gait using single-point sensors embedded in mobile devices. It involves inertial sensors and other sensors such as magnetometer, generally embedded into the mobile devices. Progress made from data collection indicates that there is a better correlation of gyroscopic data than acceleration data to the gait of the person. Data was collected in different environments with the involvement of multiple male and female volunteers with no vision impairment or motor disability. The two carrying positions considered in this experiment were in the hip-pocket (pocket of the trouser) and clipped into the belt (hip). Various positioning experiments determined that a possible optimal location for the data gathering device was in the subject's hip-pocket as compared to placement on the belt (hip region) as the movement of the thigh can be tracked when the device is placed in this position. It was also observed that the gyroscopic data can be used to identify different activities, such as walking on flat land, climbing up and down stairs and walking on inclined planes. Although the amplitude of the signal is small at the beginning and the end of the travel, the gyroscopic signal clearly identifies the step events. It is concluded that gyroscopic data gives promising results in indoor localization using gait analysis when the device is placed in the hip-pocket.**

Keywords- indoor positioning; gait analysis; inertial sensors; gyroscopic data; single-point sensors; off-the-shelf devices;

I. INTRODUCTION

Moving through an unfamiliar environment is often difficult for people with limited or no vision, particularly indoors where landmarks have limited "uniqueness" (e.g. all halls appear the same). Although Global Positioning System (GPS) based navigation is possible outdoors, the accuracy of GPS is not sufficient for indoor navigation and way finding [1]. Different techniques for indoor way finding and localization have been developed by researchers with the aid of additional infrastructure such as Radio Frequency Identification (RFID) tags [2], Ultra-Wideband (UWB) Radio Frequency (RF) signals [3], pre-installed markers in the environment [4], a pre-photographed environment [5], and WiFi networks [6]. Almost all these systems (and most of the other systems that do not use additional infrastructure) use wearable computers and sensors [7], [8], which are bulky and not very easy to use. However, few studies have been conducted in using off-the-shelf mobile devices, such as smart phones, tablets, etc. that are more portable, to analyze human gait [9]-[11], in particular, for indoor localization and way finding [12], [13]. The approaches of some indoor localization and gait analysis techniques proposed by researchers are discussed in background section including their features and drawbacks.

II. BACKGROUND

Benavente-Peces et al. [1] have compared different technologies that can be used for indoor localization, in particular, Bluetooth, WiFi, RFID, UWB and Ultrasound based systems, including their advantages and disadvantages. According to the authors, all other methods except ultrasound have interference issues. The highest accuracy of 1 cm is achievable in ultrasound based systems, while UWB being the next with an accuracy of 15 cm. Despite the accuracy, all these techniques need additional infrastructure be deployed in the indoor environment being navigated.

Kourogi and Kurata [14] have discussed an indoor personal positioning system based on locomotion analysis performed in a Kalman filter framework. The authors have analyzed data from a three-axis accelerometer and a three-axis gyroscope sensor that are attached to the hip to estimate the distance travelled by the subject. The foundation for their analysis is provided in a publication by Murray [15], in which he comprehensively discussed the movement of the human body, especially the hip, during a gait cycle. Although Kourogi and Kurata analyzed sensor data to compute the distance travelled by the subject, the absolute positioning is done using image recognition; by correlating the video stream of the wearable camera with images in an image database. This however requires large amount of processing.

Zijlstra and Hof [16] have discussed the feasibility of extracting spatio-temporal gait parameters from acceleration of the human trunk during walking. In this experiment, they have taken a sample of healthy subjects and acceleration readings were taken with a three-axis accelerometer attached to the hip, while walking on a treadmill and over ground. They have observed a clear pattern in the accelerations of the human trunk.

A gait feature extraction method using a mobile phone equipped with a triple-axis accelerometer has been discussed by Iso and Yamazaki [11]. They have recorded sensor data using two healthy subjects while carrying the phone in the shirt pocket and the pants pocket, and used these data with pseudo data derived from those data, to train their algorithm. They were able to identify gaits such as walking, running, walking fast and going up/down stairs with an accuracy of 80%. However, it should be noted that they have used only two subjects for this experiment, and also that they used pseudo data, which were derived from the same data set of the two subjects.

Tong and Granat [17] have discussed gait analysis conducted using single-axis gyroscope sensors attached to the skin of shank and thigh. They have captured both gyroscopic signals and the movement of different segments of the leg. To capture the movement of the leg, they have used a motion analysis system with reflectors attached to different segments. They were able to observe a correlation of 90% or more between these signals, from which they have concluded that there is a good correlation of the gyroscopic data to the movement of the leg. However, in this study too, the sensors are attached to the body, which is not a practically viable solution. Attaching sensors all over the body and run wires over the body to connect them to the processing device is an inconvenient arrangement while the subject is performing normal day to day life activities. This makes such arrangements to be restricted to experimental environments only.

Mayagoitia et al. have developed a system to obtain kinematics of gait using a body mounted accelerometer and a gyroscope sensors [18]. For this, they have used four single-axis accelerometers and one gyroscope sensor per each body segment and the measurements have been taken with a motion analysis system in parallel. They were able to achieve almost 100% correlation between analysis results and results of the motion analysis system in all test cases. However, their algorithms had to be executed offline because of very high computational requirements, and the system is not portable either. This type of a system is limited to be used in laboratory environments.

A comparison of the accuracy of five commercially available talking pedometers has been done by Jerome and Albright [19] using 13 adult subjects with vision impairment and 10 senior adult subjects. According to their findings, the accuracies of these systems were very poor with a minimum average absolute error value of 13%. Their conclusion was that none of those pedometers could reach sufficient level of accuracy neither for research nor for general usage. Crouter et al. [20] also concluded that the step detection of pedometers at lower walking speeds is significantly poor.

In a study conducted by Garcia et al. [21], they have evaluated the possibility of using mobile phones as pedometers. They have compared the performance of pedometer software running on a mobile phone with the performance of a commercially available pedometer. According to their observations, the mobile phone provided a competitive performance against the commercially available pedometers. Although both have performed well in normal and high walking speeds, the performance of both techniques at lower speeds was very unreliable.

Lim et al. [22] have proposed a method to detect steps using gyroscope sensors attached to the foot. However the authors do not explicitly discuss the accuracy of their method under practical usage. Zhong et al. [23] has also discussed a step identification method involving accelerometer sensors attached to the foot with the processing done in a PDA. The authors have proposed an adaptive technique of detecting steps and they were able to achieve accuracies above 90%. It should be noted that these systems also use sensors attached to the body.

III. PROPOSED METHOD

A. Introduction

This paper proposes a novel approach of analyzing human gait using single-point inertial sensors embedded to mobile devices. The work is a part of a larger project that is developing an indoor navigation system for vision impaired people using mobile devices such as smart phones and tablets. The following sections describe the results obtained in several experiments conducted in different environments with the involvement of multiple male and female volunteers with no vision impairment or motor disability, and the technique proposed based on the observations.

B. Experiment Environment

In these experiments, sensor data was collected while the subjects were performing different activities. The activities considered were walking on flat land, walking up/down stairs and walking on an inclined plane upwards and downwards. To identify the best carrying position, two positions were considered when walking on the flat land. They are the hip-pocket (pocket of the trouser) and the hip (clipped to the belt). A video was recorded to see how the subject has performed the activity, so that the data can be correlated with the video.

Data collection was performed with a specific orientation of the data collecting phone with respect to the body. When the phone is carried in the hip-pocket, it was placed in the right hand side hip-pocket with an upright portrait orientation, screen facing forward. The phone was attached to the belt on the right hand side hip with an upright portrait orientation, screen facing outward.

The reference coordinates of the sensors are illustrated in Fig. 1. X, Y and Z directions of the accelerometer are as indicated in the figure and the X, Y and Z coordinates of the gyroscopic sensor are measured around X, Y and Z axes marked on the figure. In the analysis, the vertical orientation angle was taken as 0º when the phone is kept in a vertical position.

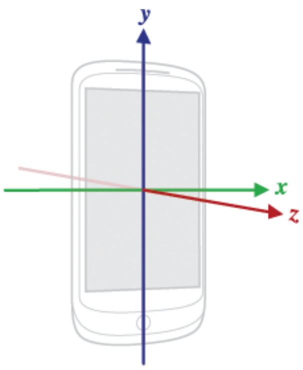

Figure 1. Reference Coordinates of Sensors [24]

C. *Empirical Observations*

It was observed that there is a closer correlation of acceleration and gyroscopic data to the gait cycle when the device is carried in the hip-pocket than when attached to the hip. This is because the sensors read the inertial parameters of the thigh.

Correlation of vertical acceleration and the roll of the device (gyroscopic x-axis) of ten consecutive steps extracted from the middle of the walk were computed. Table I shows the statistics of the computed correlations of gyro-x and vertical acceleration readings. The results indicated that there is a higher correlation of gyro-x between steps than the vertical acceleration.

It was further observed that when the gyro data is filtered with a simple sixth order Butterworth low-pass filter having a cutoff frequency of 5 Hz, the resultant waveform can be used to identify the steps very easily. Fig. 2 depicts the raw gyro-x value and the filtered version of it. Further, when the filtered version of gyro-x is plotted with the vertical orientation of the device (i.e. the orientation of the thigh), it was observed that, the gyro-x reading is closely related to the movement of the thigh (Fig. 3). Stride cycles can easily be identified with the filtered version of gyro-x data. The gyro-x reading is at the minimum or the maximum when the leg is in vertical position. The gyro-x reading gives the rolling angular velocity of the device, and hence of the thigh. Filtering is necessary to suppress noise introduced to gyro data due to the lose attachment of the device to the body, and any other noise. The filtering frequency was selected as 5 Hz to avoid vibrations occurred at different foot touching events. However, applying a filter with a larger cutoff frequency will be necessary in the future analysis.

One major issue in existing step identification techniques, both hardware based and mobile phone based, is their very poor performance in detecting steps at slow walking speeds [19]-[21]. These techniques use accelerometer reading to identify the steps. Very low values of the accelerometer reading during slow walking cause poor step identification in these methods. This can be avoided by using gyroscopic data in identifying steps. With the filtered gyro-x data, even the slow steps occurred in the beginning and the end of the walk were identified easily. Fig. 4 shows the filtered gyro-x reading of the beginning of the walk. It is clear that, by detecting the zero crossing of this signal, even the slow steps can also be recognized.

TABLE I. CORRELATION STATISTICS OF VERTICAL ACCELERATION AND ROLL OF THE PHONE BETWEEN STEPS

	Vertical Acceleration	**Roll of the Phone**
Number of steps (total/per person)	100/10	60/10
Mean correlation	0.887305	0.907205
Standard deviation	0.074488	0.055523
Minimum correlation	0.635118	0.701938
Maximum correlation	0.988070	0.976055

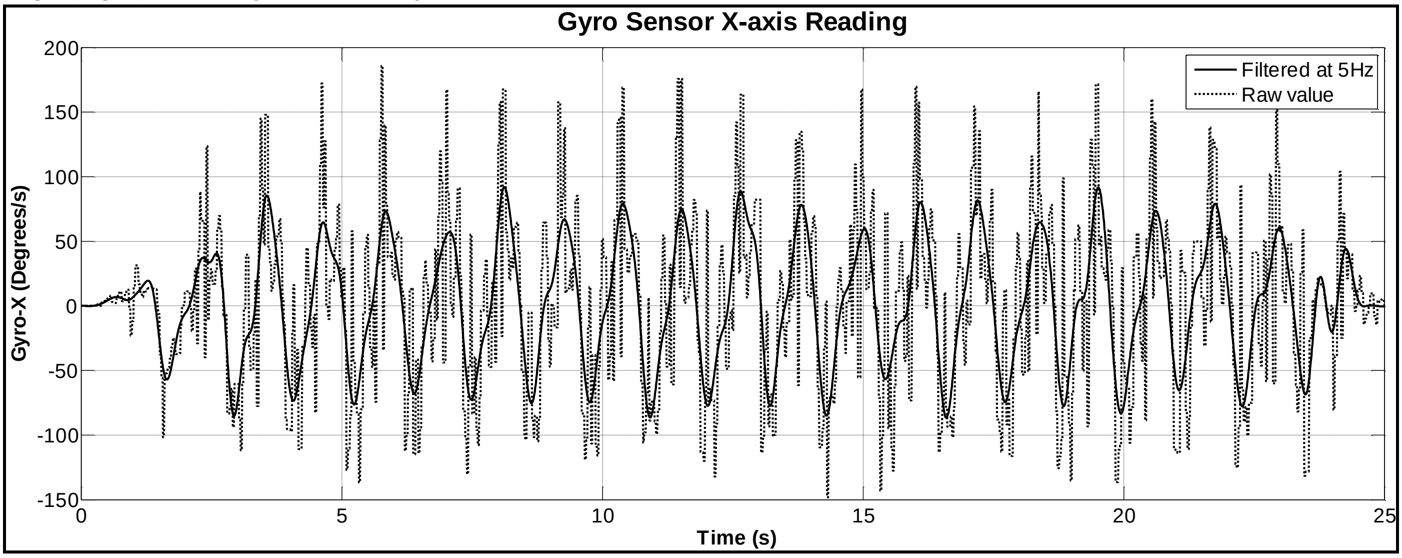

Figure 2. Gyroscopic X Axis reading (Raw Value and Filtered Value at 5 Hz)

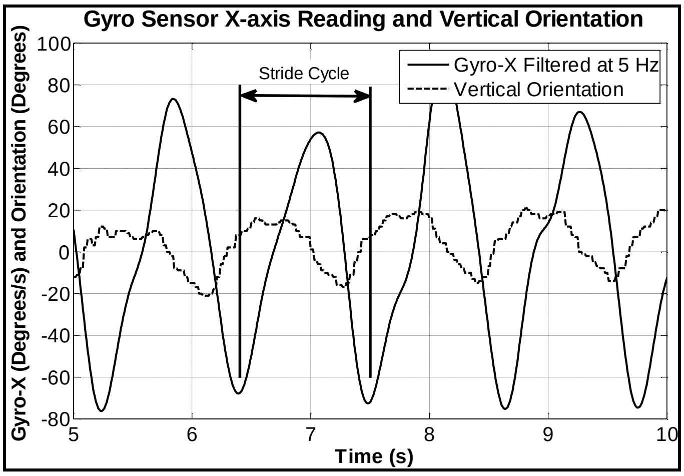

Figure 3. Gyroscopic X Axis with the Orientation of the Device

However, the slower steps cannot be clearly recognized in the vertical acceleration signal (Fig. 5). Further, the vertical acceleration reading is a combination of gravitational acceleration (g) and the vertical acceleration of the body or the thigh. Hence, g will have to be deducted from the signal in order to extract the vertical acceleration of the body or the thigh. This does not give a very accurate result without having a gravity sensor in the device. Most devices do not have an embedded gravity sensor. Further, there is a significant amount of computation involved with the estimation of the linear acceleration by removing gravity [24].

Data collected while doing different activities showed that the vertical orientation of the device, and hence the vertical orientation of the thigh varies with the activity performed. The vertical orientation was computed using gyroscopic data and the initial orientation. As the gyroscopic signal has a small drift, the raw data was high-pass filtered using a 1st order Butterworth filter with a cutoff frequency of 0.1 Hz. The plots of vertical orientation for the three activities (walking on flat land, going up/down stairs and going up/down hills) indicated that the average of the vertical orientation and the swing can be used to differentiate the activities. The average of the vertical orientation is close to vertical (0º) when walking on flat land (Fig. 6), whereas, it is close to 10º when walking on stairs (Fig. 7) and about 7.5º when walking on a hill (Fig. 8). Further, the deflection of the vertical orientation on both forward and backward directions is more-or-less similar when walking on flat land. But, the orientation fluctuates mostly in the positive direction when walking on stairs and on a hill. However, a larger swing in orientation was observed when walking on stairs. Up and down walking in both stairs and hill can be distinguished by the deflection: deflection is more when walking upwards.

D. Proposed Technique for Localization

Above observations indicate that the gyroscopic data can be easily and accurately used in finding the movement of the phone and hence the movement of the thigh when placed in the hip pocket. As the movement of the thigh is directly related to gait parameters [15], it is possible to correlate the movement of the thigh to the step size. In the proposed technique, a greater weighting will be given to the gyroscopic data in computing movement, with accelerometer data used only in computing reference coordinates. One major issue in using accelerometer data to compute motion is the large error caused in the double integration due to the drift of the acceleration reading [25]. Considering this factor, the step size is calculated solely based on gyroscopic data, with minimal use of acceleration data for verification purposes.

By relating the estimated step size, the number of steps detected and the direction of movement (heading) obtained using compass data, the distances travelled in corresponding directions will be computed and the current position is continuously updated using these results. Calibration of the system is done with the aid of GPS when the user is walking outdoors.

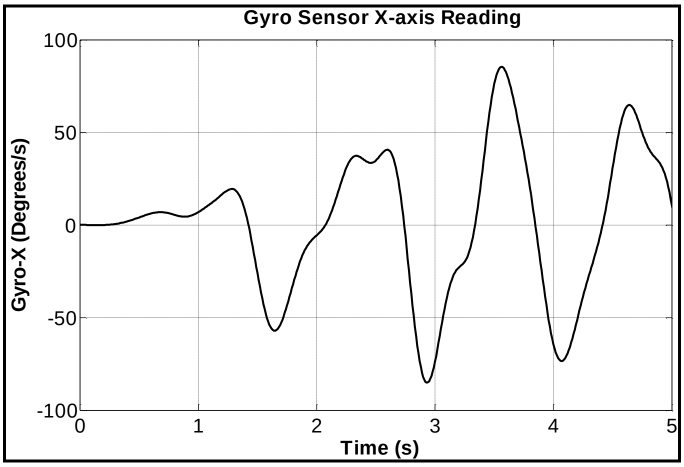

Figure 4. Filtered Gyro-X reading at the beginning of the walk

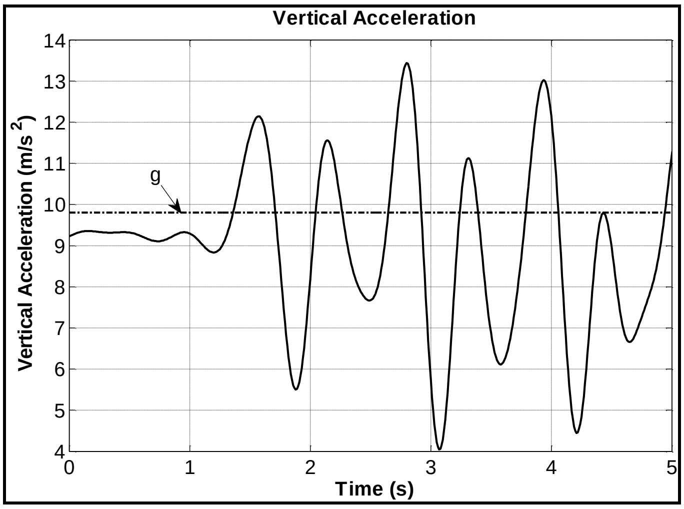

Figure 5. Filtered Vertical Acceleration at the beginning of the walk

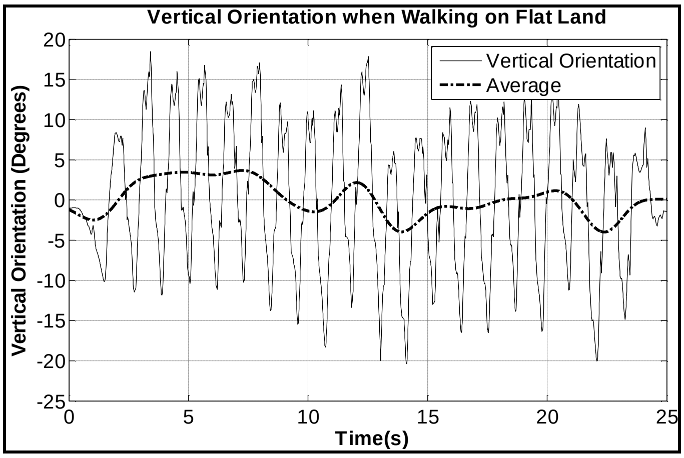

Figure 6. Vertical Orientation and its Average when Walking on Flat Land

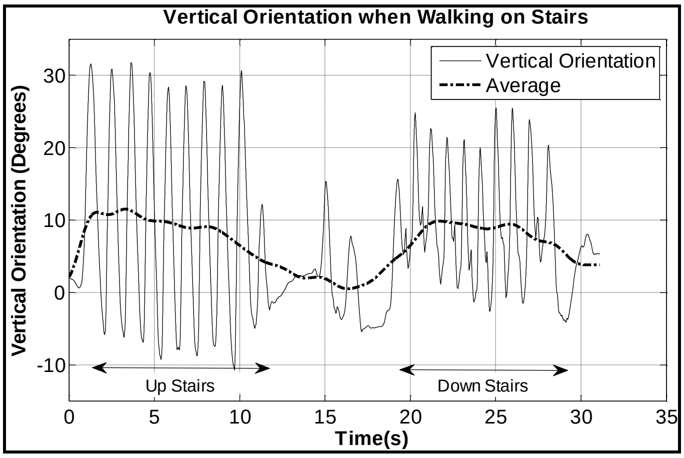

Figure 7. Vertical Orientation and its Average when Walking on Stairs

E. Advantages of the Proposed Technique

There are several advantages in using gyroscopic data in estimating gait parameters. One main advantage is the reduction of error caused in the result by the drift of the sensor. The linear acceleration is not used in the calculations, as the rotational movement of the thigh is of interest. Hence, computational load can be reduced by using gyroscopic data only, in majority of computations. In addition to those, the reaction time of the gyroscope is better than the accelerometer [25] and the gyroscope does not have a static value as in the accelerometer. This will also makes the computations faster and more accurate.

Further, the proposed method uses the inertial and other sensors embedded in modern off-the-shelf hand held devices with the processing also done in the same device. Hence, the user does not need to carry multiple devices or attach several sensors on to the body, running wires over the body or to carry heavy computers, which enables the proposed technique to be involved in practical and commercial systems. The development is mainly targeted to the vision impaired people. Hence accessibility is also considered in the developments.

F. Current and Future Work

The observations presented in this paper imply that the gyroscopic data can easily be used in characterizing human gait. An algorithm to detect steps, even at slow walking, using gyroscopic data only is being developed currently and few more tune-ups and testing is necessary to finalize the algorithm. Further experiments are to be conducted to record data necessary to build a relationship between gyroscopic data and the step size. From this data, an algorithm will be developed to combine the step identification with the step size calculation and estimate the total distance travelled with respective directions.

G. Challenges to be Faced

The major challenge to be faced in the future work is the limited computational resources available in mobile devices such as smart phones, which requires that the algorithms be demanding minimal computational resources. Hence it is advantageous to use only a single type of a sensor in majority of computations.

The experiments were conducted in controlled environments, with well defined attachment, placement and orientation of the device in relation to the body and associated movement of the body. In the practical application, the orientation of the device with respect to the body may be highly variable. For this reason, the orientation of the device with respect to the direction of the travel will also be a variable which in turn requires that a coordinate framework will have to be continuously recalculated.

Further, there will be relative movement between the device and the body due to lose attachment of the device to the body mainly in the form of vibration. This will introduce a noise component to the signals. In order to reduce the effect of noise, an estimation of contributing components will have to be performed.

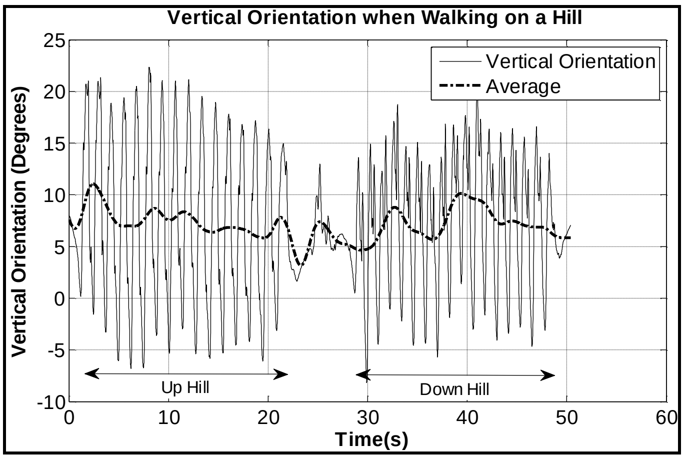

Figure 8. Vertical Orientation and its Average when Walking on a Hill

The algorithms have to be pre-calibrated with the aid of GPS while walking outdoors. It may be necessary that the calibration is performed for each user as gait patterns and parameters changes from person to person.

IV. Conclusions

This paper presented the initial findings of an experiment to determine the suitability of gyroscopic data from mobile devices in determining the step incidences as a component in the development of an indoor way finding system for people with vision impairment. From the results gathered, gyroscopic data appears to provide sufficient information in the determination of steps taken. In conjunction with various other internal sensors of these off-the-shelf devices, this offers a solution to the distance and heading components for indoor navigation.

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