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Human Activity Recognition Using Thigh Angle Derived from Single Thigh Mounted IMU Data

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***Abstract*—Accurate human activity recognition is a challenging topic of research in many areas. A common approach to activity recognition is to use accelerometers and/or gyroscopes to detect trunk or leg movement. This paper present a novel approach to detect human activities based on thigh angle computed using data from a single thigh mounted Inertial Measurement Unit (IMU). As this work forms a component of a system under development to assist the vision impaired in indoor navigation, activities common in indoor pedestrian tracking such as sitting, standing and walking were considered in the development of the algorithm. This algorithm uses simple signal processing techniques including peak detection, zero crossing detection and timers to identify the activity based on the thigh angle computed by fusing accelerometer and gyroscope. This allows implantation of the algorithm in a general purpose low end microcontroller. To reduce the number of input parameters to the algorithm, it was assumed that accelerometer y–axis is aligned with the thigh such that gyroscopic x–data represents angular velocity of the forward and backward movement of the thigh. The algorithm has shown above 78% accuracy in detecting standing, above 92% accuracy for walking and no measured errors for sitting, in a test conducted with a limited number of samples with ideal testing conditions. These results indicate that this less computationally intense algorithm gives promising results in activity detection in indoor pedestrian navigation applications.**

Keywords*—Human gait analysis; activity recognition; inertial sensors; indoor navigation

I. Introduction

Accurate human activity recognition plays a significant role in making pedestrian tracking accurate. Although many different activities are performed by people during navigation, the three main activities found in indoor navigation are standing, sitting and walking. Additional activities may include walking on stairs, going on an escalator or a travelator ramp and going in an elevator.

Researchers have used many approaches to detect different human activities. In most of these techniques, a 3–axis accelerometer is used to measure the acceleration of the trunk [1] or a section of a leg [2]. This paper proposes a novel approach for human activity detection using the thigh angle derived from a single thigh mounted Inertial Measurement Unit (IMU). This paper also presents the outcomes of preliminary activity detection algorithm. The activities considered in the data collection are standing, sitting and walking. Minimal computational demand was the main aim when developing the algorithm. Therefore, no filtering was used in the algorithm in addition to any filtering happening in the sensor level.

Some existing work on human activity detection are discussed in the “Existing Work” section of this paper while the experimental results, proposed algorithm, experimental setup and results of algorithm implemented on test data are presented in the “Indoor Activity Detection Algorithm” section. The implementation and testing plan of these algorithms are discussed in the “Discussion and Future Work” section of this paper.

II. Existing Work

the majority of the existing work on human activity detection use 3–axis accelerometers to measure the trunk or the leg movement while some work use a gyroscope in conjunction with the accelerometer. Bocksch et al. [1] have discussed an activity classification method that uses a 9–degree of freedom IMU. They detect standing, running, walking, in car, lying, cycling and falling in their system. The magnetometer is used to detect the car entry and exit, where as the other inertial sensors are used to detect other activities. The device is placed on the belt (hip mounted) and they could detect walking, running, throwing and lying with 100 % accuracy and standing, entering a car and cycling with 92 %, 76 % and 72 % accuracies respectively. However, their algorithms are computationally intensive and may require high processing and memory capabilities in the device.

Kwapisz et al. [2] have discussed an activity recognition system using the accelerometer data of a mobile phone placed in the pocket. In this system, they have processed the average, standard deviation, average absolute difference, average resultant acceleration, time between peaks and binned distribution of acceleration data. They have considered the activities walking, jogging, ascending stairs, descending stairs, sitting, and standing. They could achieve detection accuracies above 90 % for walking, jogging, sitting and standing, but 61.5 % accuracy for walking upstairs and 55.5 % accuracy for walking downstairs. Their technique too, require higher computational capabilities.

Most of these existing techniques use threshold detection of the accelerometer to detect the activities, which performs less accurately in slow walking speeds and stair climbing.

Further, they need intense computations to be performed, which is not favorable for low cost devices. The main concerns of developing a navigation aid for vision impaired people were low cost devices which leads to the requirement of less computationally intense algorithms and less error. With these main constraints in mind, in [3], the authors discussed the possibility of using thigh mounted IMUs and the thigh angle in vision impaired pedestrian navigation purposes. The work discussed in this paper is based on that proposal and is a part of a research that develops a model for human gait that can be used to estimate step length in real–time based on a thigh mounted IMU data for the purpose of vision impaired indoor navigation.

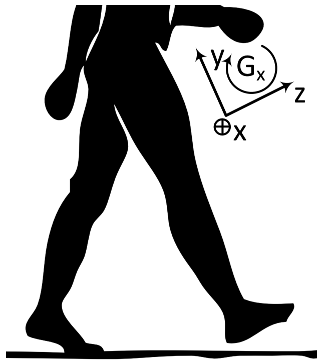

Fig. 2. Reference axis of IMU data

III. Indoor Activity Detection Algorithm

A. Observations

The indoor activities considered in this study are walking, standing and sitting as they are the most common indoor activities performed by vision impaired people. Movement of the thigh was captured using an IMU built in-house using MPU-9150 9–axis sensor. The IMU was strapped to the subject's thigh while performing a "stand, sit and walk" activity chain. Measurements were taken for standing posture with the test subject in slight motion, i.e., whist changing the supporting leg. Fig. 1 shows the thigh angle computed for a trial of stand-sit-stand-walk-stand-sit-stand activity chain.

Thigh angle was computed by fusing accelerometer and gyroscope data. If the total acceleration read by the accelerometer is close to gravitational acceleration, then the thigh angle is calculated by taking *arctan* of the ratio $^{Az}/_{Ay}$ where Az and Ay are the z–axis and y–axis (as shown in Fig. 2) readings of accelerometer. Gravity is the most significant component of this reading in this case and hence the angle calculated from acceleration is accurate. Otherwise, the thigh angle is calculated by integrating gyroscopic x-axis reading because the accelerometer reads body acceleration in addition to gravity, hence angle calculated from accelerometer data is not accurate.

B. Data Processing and the Algorithm

The indoor activity detection algorithm is based on the envelope of the thigh angle and steps detected. As shown in Fig. 1, the thigh angle is less than 20º when standing, larger than 70º when sitting and the peak of thigh angle lies in between 20º and 70º when walking. Detection of steps is used to confirm if the subject is walking. Steps are detected by checking the delay between zero crossings of the thigh angle. If the delay is between 0.2 s and 1 s, then it is considered as a stride is detected. These times were selected to accommodate slow gait of 1.5 steps per second as published in [4].

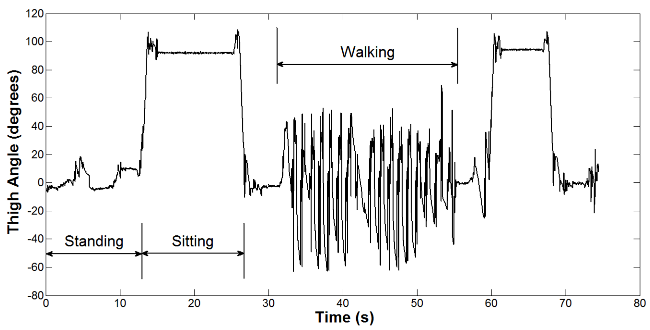

Fig. 1. Thigh angle while standing, sitting and walking

The envelope of the thigh angle is computed using a peak-hold mechanism. The positive peak of the thigh angle is taken as the envelope till the next positive peak is detected. Zero crossings of the thigh angle are detected simultaneously. Sitting is distinguished from standing and walking if the envelope of the thigh angle is larger than 70º. If the activity is not standing, then if the envelope is less than 20º and walking is not detected, then the activity is taken as standing. Else the activity is considered as walking. Finally, this activity state is sent through a timing mechanism to avoid the activity state being switched to a different state for a very short period. Slow walking speed is in the range of 1.5 steps per second [4] and slow gait is observed in most of indoor navigation situations particularly for people with vision impairment in unfamiliar surroundings. Therefore the duration of the timer is set as 2 s, hence the activity is detected with a delay no more than one stride. The indoor activity detection algorithm is shown in Fig. 3. Thigh angle computation is excluded in the figure for simplicity.

Fig. 4 depicts the envelope detected by the algorithm and Fig. 5 shows walking detected by the algorithm. For illustrative purposes, zero indicates that walking is not detected and 90 indicates areas where walking is detected. Fig. 6 shows the final activity output (after the delay mechanism) of the algorithm. Each activity was represented by a value as shown in Table I for demonstrative purposes. The delay seen in the activity plot of Fig. 6 is due to the delay timer in the algorithm.

C. Experimental Setup

The experiment was conducted with the participation of two young females and two young males, all known to have no disability or impairment. Observations were recorded with the IMU attached to each thigh with two trials per each thigh.

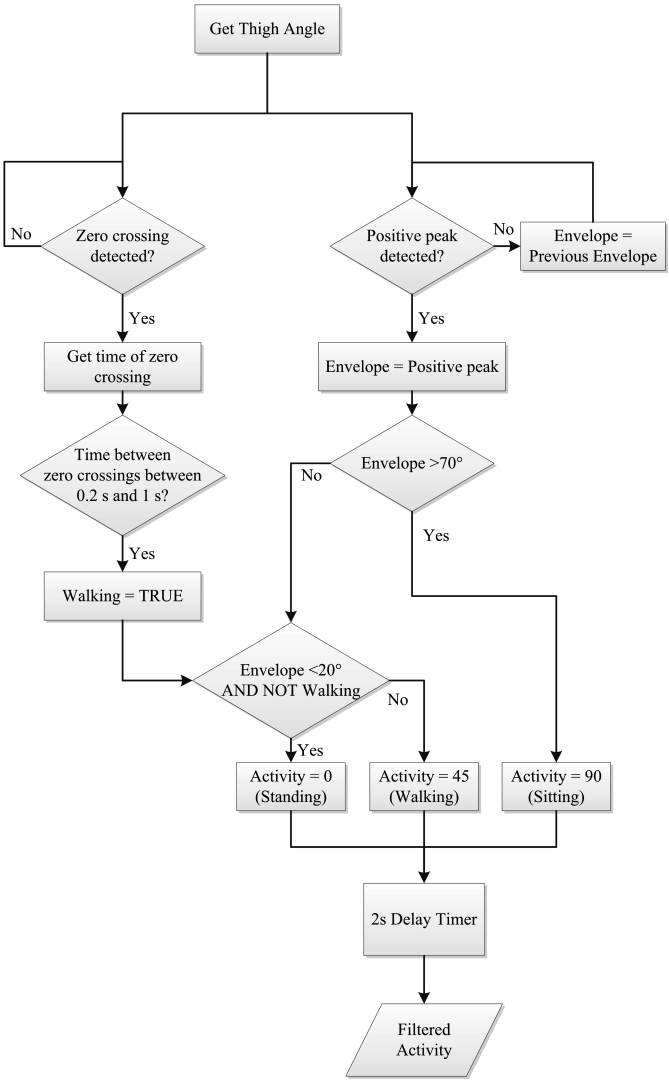

Fig. 3. Indoor activity detection algorithm

Subjects were asked to perform standing, sitting and walking activities. While standing, they were asked to behave naturally without conscious attempts to remain stationary and changing the support limb as they wish. In sitting posture, subjects were requested to move normally. Walking was done with medium and slow gait.

The IMU used for this experiment is developed in-house using MPU9150 sensor, which consists of a 3-axis accelerometer, a 3-axis gyroscope and a 3-axis compass in a single chip. The IMU samples all sensors at 50 Hz and sends them to the computer through a wireless link. The nRF24 radios were used for the wireless link instead of Bluetooth.

Table I
VALUES ASSIGNED FOR ACTIVITIES

Activity	Value
Standing	0
Walking	45
Sitting	90

Table II
ACTIVITY DETECTION RESULTS AS A PERCENTAGE WHEN THE IMU IS MOUNTED ON LEFT THIGH

Activity Performed	Activity Detected			Activity Count (n)
	Standing	Sitting	Walking	
Standing	78.26	0.00	21.74	23
Sitting	0.00	100.00	0.00	8
Walking	0.00	0.00	100.00	11

Table III
ACTIVITY DETECTION RESULTS AS A PERCENTAGE WHEN THE IMU IS MOUNTED ON RIGHT THIGH

Activity Performed	Activity Detected			Activity Count (n)
	Standing	Sitting	Walking	
Standing	90.00	0.00	10.00	20
Sitting	0.00	100.00	0.00	8
Walking	7.14	0.00	92.86	14

D. Results

The activities performed and activities detected by the algorithm were recorded by observing the thigh angle and the output of the algorithm. 78.26 % of standing activities were detected as standing when the IMU is mounted to the left thigh and the rest were detected as walking. Walking and sitting activities were detected with no errors for the trials performed with IMU mounted to the left thigh.

When the IMU is mounted to the right thigh, standing was detected by the algorithm with an accuracy of 90 % and walking with an accuracy of 92.86 %. Some standing activities were detected wrongly as walking and some walking activities as standing. However, for this case too, sitting activities were detected without errors for the trials recorded.

The difference of accuracies of the algorithm for two legs will have to be further studied.

IV. DISCUSSION AND FUTURE WORK

The simulation results of the algorithm indicates that it gives promising results. However, the activities identified in this algorithm are limited to sitting, standing and walking. Some of

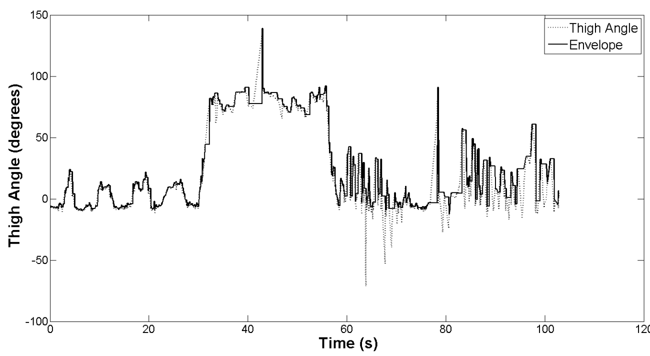

Fig. 4. Envelope detection

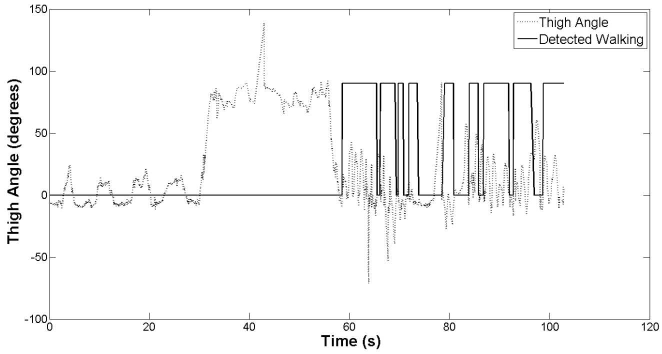

Fig. 5. Walking detected by the algorithm

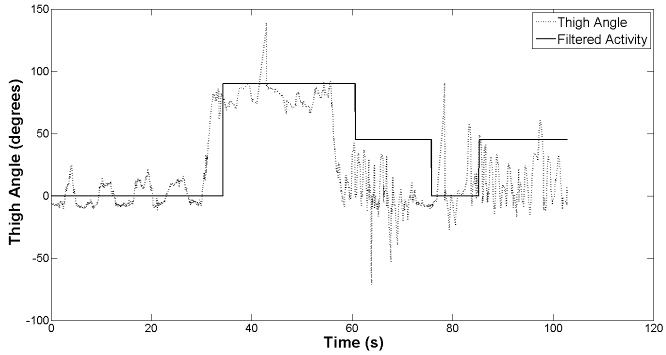

Fig. 6. Activities detected by the algorithm

the errors in detecting the activities are due to nonsmooth thigh angle waveform because of packet losses between the IMU and the computer because of the signal drops of the radio. There were some occasions where the delay between two samples received were 1 s. Accuracies of the algorithm may improve when the algorithm is implemented in an embedded device as there will not be any missing samples.

The activities found in indoor navigation in addition to the activities considered in this algorithm are walking on a travelator ramp or a stair case, going on an escalator and going in an elevator. Preliminary observations of an experiment performed using a Nexus 5 smartphone indicated that the pressure sensor reading in combination with the above algorithm may be used to identify these activities. Fig. 7 shows the pressure variation when walking on stairs while keeping the phone in the trouser pocket. The algorithm detects the activity as walking when walking on stairs too, but no major pressure change was observed when walking on level surfaces. Therefore, combining

Table IV
TOTAL ACTIVITY DETECTION RESULTS AS A PERCENTAGE

Activity Performed	Activity Detected			Activity Count (n)
	Standing	Sitting	Walking	
Standing	83.72	0.00	16.28	43
Sitting	0.00	100.00	0.00	16
Walking	4.00	0.00	96.00	25

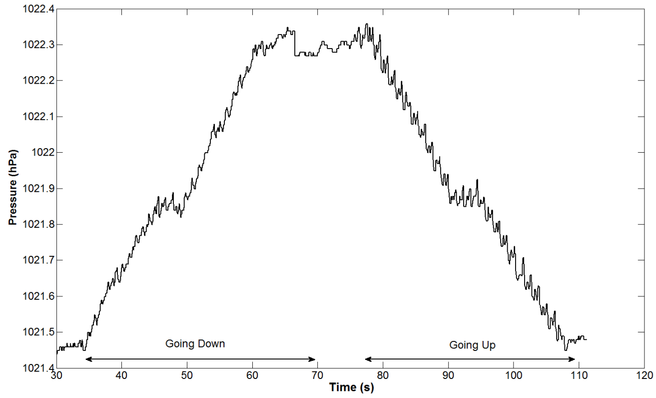

Fig. 7. Pressure Reading when Walking on Stairs

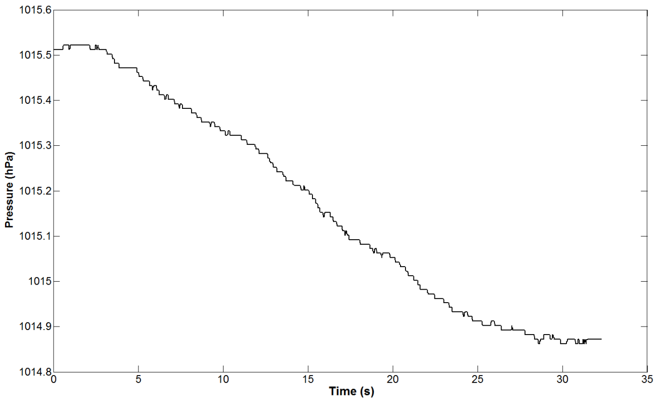

Fig. 8. Pressure Reading when Going on an Escalator

pressure data and the aforementioned algorithm may be used to identify walking on stairs and distinguish it with walking on level surfaces. The pressure readings when going on an escalator and a travelator ramp are shown in Fig. 8 and Fig. 9 consecutively. In both these cases, the algorithm detects them as standing as there is no leg movement. Therefore, the algorithm in combination with the pressure reading may be used to detect going on an escalator or a travelator ramp.

Pressure reading when going in an elevator is shown in Fig. 10. Although a gradual pressure change was observed when going down, a sudden pressure drop was observed when going up. This was observed in all the trials conducted. This may be because of the characteristics of the air flow in to and out of the elevator. However, a significant pressure change is read when going in the elevator and the algorithm will detect this as standing. Hence, the algorithm in combination with the pressure reading may also be used to identify traveling in an elevator.

Further testing on the pressure data will have to be conducted to check if the pressure readings are consistent in repetitive measurements and over time. Once this is established, pressure input can also be taken into the algorithm and the algorithm can be improved to detect all possible indoor activities.

The next step of this work will be implementation of these algorithms in conjunction with the pedometer algorithm dis-

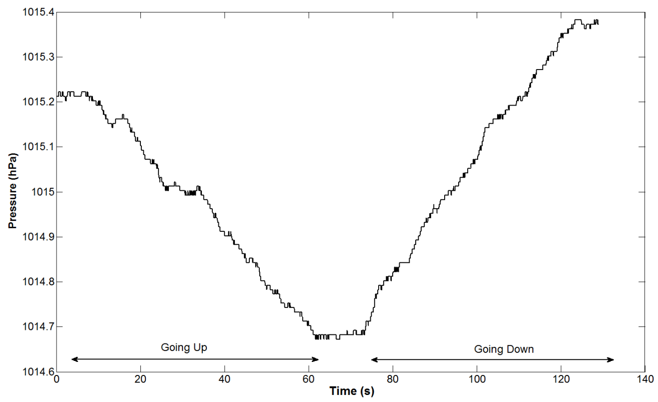

Fig. 9. Pressure Reading when Going on a Travelator Ramp

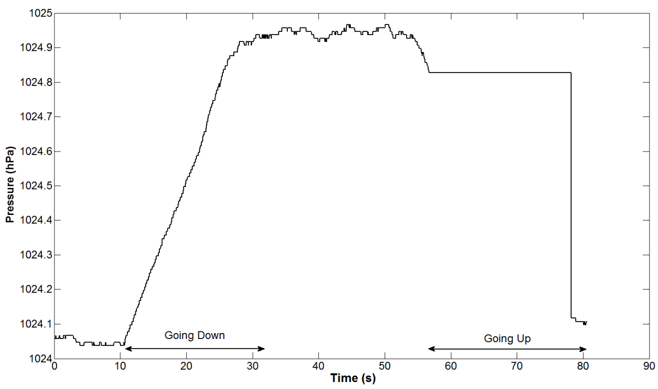

Fig. 10. Pressure Reading when Going in an Elevator

cussed in [5] on an Android based Smartphone or an embedded device and test them in real-time with the participation of an additional larger number of subjects. The implemented algorithms will be tested on both vision impaired subjects as well as nonvision-impaired subjects to test the accuracy. The parameters of the algorithms may need to be fine tuned depending on the test results to achieve higher activity detection accuracies. The indoor activity recognition algorithm will then be used to identify activities in an indoor navigation system for vision impaired people.

V. Conclusions

This paper proposed a human indoor activity detection algorithm with minimal computational demands. It was observed that the algorithm detects activities with accuracies above 78 % although it demands lower processing and storage requirements. However, the activities detectable by the algorithm are limited to walking, sitting and standing.

Preliminary observations of possibility of using pressure data to detect walking on travelator ramps, escalators, stairs and in elevators were also presented. Results indicated that pressure input may be effectively used to improve the algorithm to detect all possible indoor activities.

The algorithm is to be extended combining pressure input and the pedometer algorithm and tested and tuned for real-time activity detection. It is concluded that the thigh angle can be used for indoor activity detection with computationally efficient techniques and the pressure data may be used to improve the algorithm to detect all possible indoor activities.

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