Step Counting Using Smartphone-Based Accelerometer

Ms. Najme Zehra Naqvi
Department of Computer Science Engineering, Guru Gobind Singh Indraprastha University,
Indira Gandhi Institute of Technology
Delhi,110006,India
naqvizehra@rediffmail.com

Dr. Ashwani Kumar
Department of Computer Science Engineering, Guru Gobind Singh Indraprastha University,
Indira Gandhi Institute of Technology
Delhi,110006,India
dr_ashwanikumar@yahoo.com

Aanchal Chauhan
Department of Computer Science Engineering, Guru Gobind Singh Indraprastha University,
Indira Gandhi Institute of Technology
Delhi,110006,India
aanchal.chauhan16@gmail.com

Kritka Sahni
Department of Computer Science Engineering, Guru Gobind Singh Indraprastha University,
Indira Gandhi Institute of Technology
Delhi,110006,India
kritkasahni@yahoo.co.in

***Abstract*—This paper presents a method for counting the number of steps taken by a user, while walking at any variable speed, using smartphone-based accelerometer. For this purpose, the steps are detected based on a relation between frequency of step, which varies inversely with speed of motion, and the magnitude of accelerometer signal. The pattern of the forward acceleration was observed to arrive at the final relation.**

Keywords-accelerometer; step detection; step counting.

I. INTRODUCTION

A. Need for a Step Counting Algorithm

Step detection is the automatic determination of the moments in time at which footsteps occur. Step counters are becoming popular as an everyday exercise measurer and motivator, as well as a part of certain navigation systems. Accelerometers are becoming increasingly ubiquitous in commercially sold devices, such as mobile phones like the Apple iPhone or the Samsung Galaxy Ace. This paper explains a new step detection algorithm that utilises the accelerometer of a waist-mounted smartphone.

Smartphone-based accelerometer step counting is emerging as a motivational tool for people wanting to increase their physical activity. People, especially those suffering from obesity, can utilize it to count number of steps taken and hence, the number of calories burnt.

Parameters of gait, like step duration and step length are related with an increased risk of falling. Hence, phone based accelerometer scan be used as a major strategy to improve fall prevention, being of great value to older persons.

Besides these, such an algorithm can also be used for estimating the distance and hence, the position in pedestrian navigation systems (PNS) that involve multiplying the step count with the average step length.

Counting of steps involves two things: the detection of the starting point of motion, and the detection of each step. Starting point of motion is detected when standard deviation starts increasing considerably, as compared to the mean standard deviation in the quiet standing phase. This is followed by step detections, for which, a relation has been established between frequency of steps and the magnitude of the accelerometer signal.

B. Related Work

Accelerometer signals have previously been shown to be useful for step detection, especially in pedestrian navigation systems (PNS). There are three types of methods: peak detection[1,2,3], zero crossing detection[4,5] and flat zone detection using acceleration differential[6]. The peak detection method is not appropriate for detecting steps because the peak of the accelerometer output is greatly affected by the user's walking velocity. The flat zone of the signal is not detected when the accelerometer is attached to the user's waist. Zero crossing detection is not appropriate because erroneous peaks contribute to misdetection of steps in this method.

Sliding window summing[7] is another approach but it involves flat detection using the acceleration differential which itself is not appropriate. Hence, there is a need for a new approach, which is exactly what this paper explores.

II. STEP COUNTING ALGORITHM

A. Device positioning and orientation

The device is fixed near the centre of mass of the subject, as shown, so that the net external force acting on it can be detected by the accelerometer of the device. The positive x, y, and z axes point to the left of the subject (horizontal), vertically upwards, and backwards (horizontal) for the subject respectively.

B. Dataset used for analysis

Accelerometer samples from a smartphone device fixed in the aforementioned position were collected at a frequency of 100Hz. Data was collected for five people, for their slow, medium, fast and mixed pace walks, on a plane surface. Forward acceleration signal was used for the analysis.

C. Understanding the accelerometer reading

Since the accelerometer measures the external forces acting on the centre of mass, the forward acceleration should ideally be zero while standing still. But, due to certain errors creeping in (white noise or due to the inability of humans to stand still like an inanimate object), a signal with a very low magnitude and variance is obtained.

For successive sections, we define a step as the motion of a foot from the point of lift-off of its heel to the heel's touch-down, as the subject moves forward. Also, step duration, i.e., time for one step, can be defined as time between successive steps. Thus, frequency of a step is the inverse of step duration.

The graphs shown in Fig. 1 represent accelerometer readings in the direction of walking which, according to orientation of the device, represents the negative z direction. The graph on top is for a slower pace as compared to that in the lower one. To understand the pattern obtained, we analyse the forces that act on a foot while walking.

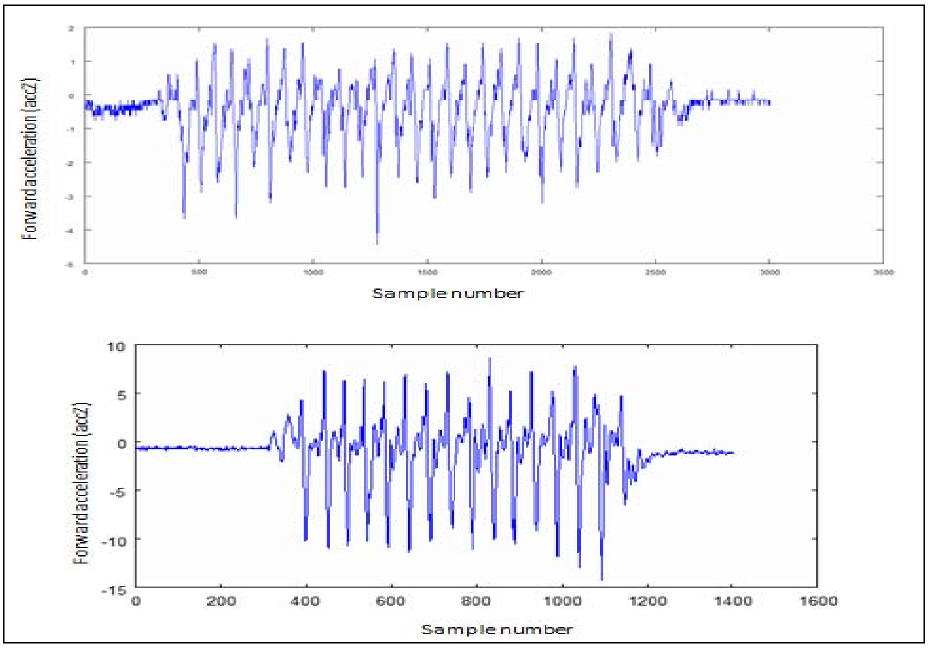

Figure 1. Accelerometer readings for forward acceleration for slow and medium pace of walking.

At the beginning of each step, one pushes back with their foot on the floor. Without friction, the foot would slide back. But, static friction opposes this motion, and is thus directed forward (in the negative z direction). Similarly, at the end of each step, one pushes forward with their foot on the floor and thus, static friction is directed backwards (in the positive z direction).

The same is evident in the graphs, as there are prominent peaks in the negative z direction at the beginning of each step. Also, positive peaks can be seen towards the end of each step.

Another important observation is that the difference in the magnitudes of these two, i.e., a positive peak and a (following) negative peak, is higher for higher speeds. Thus, it can be said that as step duration decreases with increase in speed, this difference increases. Also, frequency is variable throughout the motion of an individual.

Our approach utilizes these simple observations to count number of steps taken by a user while walking.

D. Detection of starting point

As mentioned previously, while collecting the dataset, the subjects were required to stand still for at least 5 seconds. In order to detect starting point, standard deviations were used [9].

For this, 25 contiguous non-overlapping windows of size 10 samples each were considered during the still phase. The mean standard deviation (SD) over the entire interval (mean) was calculated as well. The differences between the standard deviations of the individual windows and the mean plotted. This was repeated for different data, and from the graphs obtained (Fig. 2), the absolute difference was observed to lie below 0.07 m/s^2 during the initial still phase. Hence, a threshold of 0.08 m/s^2 was selected for the detection of the moment when walking started.

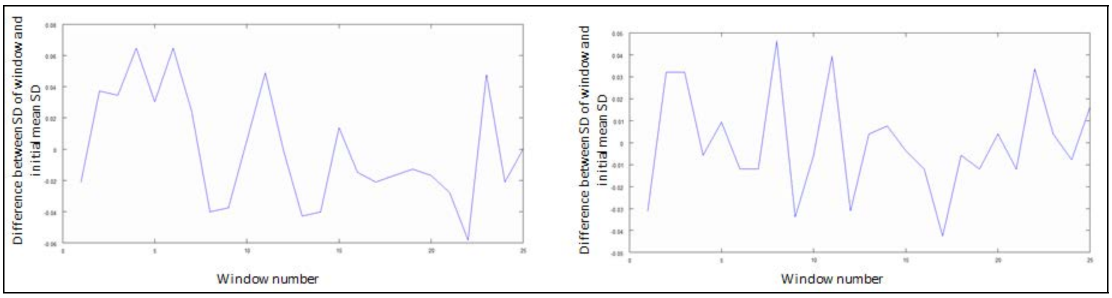

Figure 2. Plot of Difference between SD of window and initial mean SD, vs Window Number, during the initial still phase

Thereafter, standard deviation was calculated one by one for each of the successive windows, and its difference from the mean was observed. Walking was considered to be started when this difference exceeded the threshold set above. Thereafter, no more windows were taken.

E. Detection of steps

For this section, 'diff' would denote the difference in the magnitudes of the positive peak that appears towards the end of a step and a negative peak that appear at the beginning of the step in the accelerometer signal due to reasons explained previously. We plotted the frequency of steps and their respective diff, as shown in figure 3, for the actual signals corresponding to the steps taken.

We intended to find a threshold for diff, which varied according to the frequency of the step. From the graph in Fig. 3, the points that correspond to the two minimum diff values, marked in the figure, were considered to obtain the following relation between the frequency of the step and the threshold for diff:

$$th = \alpha/(i-k) + \beta$$

where,

th = threshold for current diff

i-k = tentative duration of current step

1/(i-k) = tentative frequency of current step

i = current sample number

k = sample number of sample where the previous step had been detected

a, b = constants derived from the graph in fig 3.

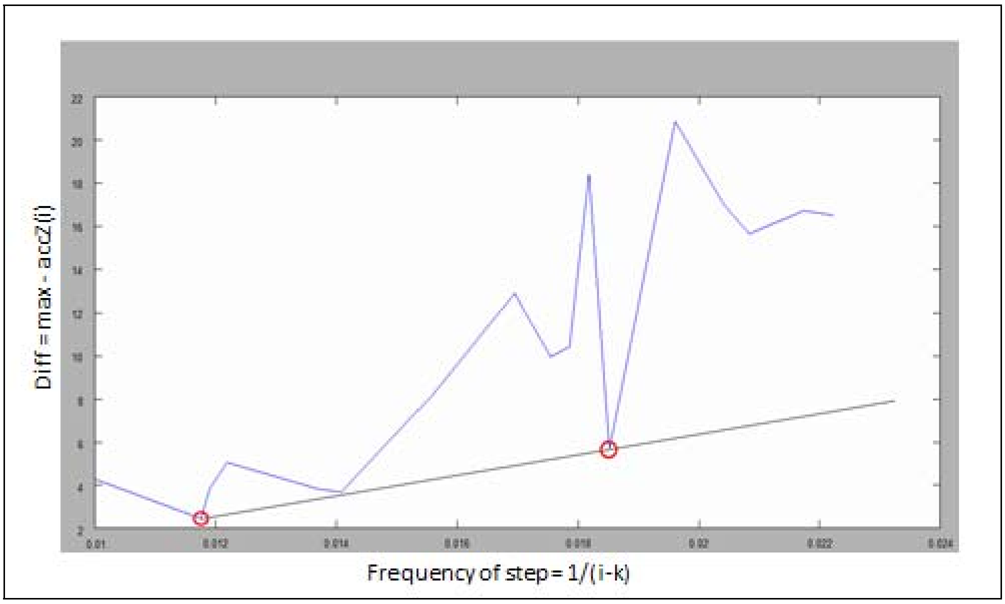

Figure 3. Plot of Diff, vs Frequency of Step. Graph was plotted from the actual steps data set, described in section 2.2.

This is the equation for the straight line shown in Fig. 3. Comparing this equation to the standard equation for a line, y = mx + c,

We have,

th → y

α → m

1/(i-k) → x

β → c

where, x, y represent the x and y coordinates of a point on the line,

m is the slope of the line,

c is the intercept formed by it on the y-axis.

The proposed algorithm for the detection of footsteps is depicted in Fig. 4. In this figure, 'accZ(i)' represents the accelerometer reading at sample number i, and, 'max' is the maximum accelerometer reading obtained since the last step. In the end, 'steps' contains the total number of steps taken.

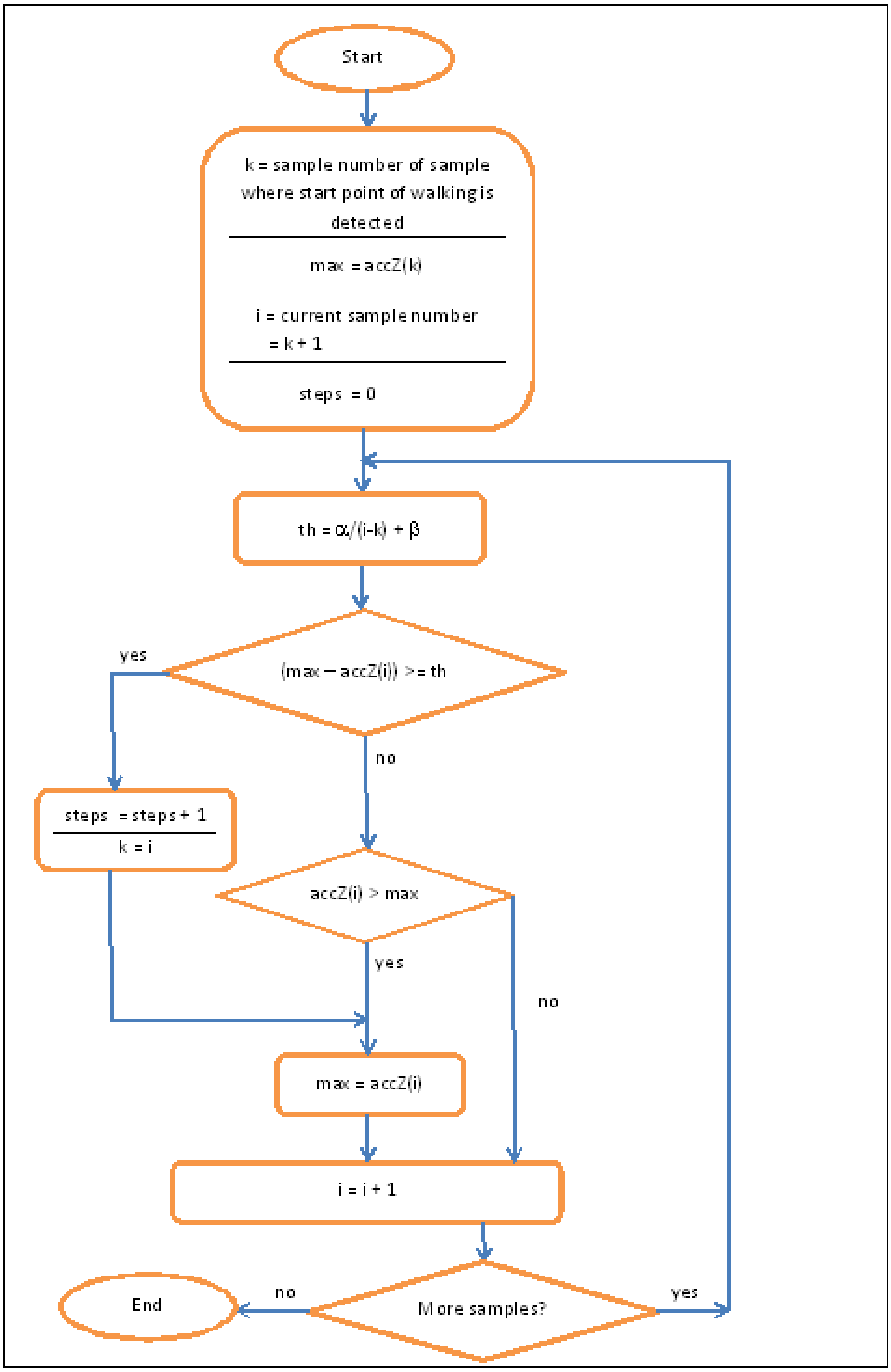

Figure 4. Step Counting Algorithm proposed.

III. RESULTS

The algorithm, based on the relation derived previously, was tested on the data using Matlab. Results, can be seen in TABLE I.

TABLE I. RESULTS FROM THE STEP-COUNTING ALGORITHM PROPOSED

steps taken	steps counted by algorithm
40	39
16	16
28	30
44	43
20	21

The results are promising. Error of 1 to 2 steps is observed due to the highly unstable pattern obtained towards the end of walk. Since, the relation that is utilized by the algorithm takes frequency of a step into consideration, hence, the method is effectively applicable to walk of any variable speed.

IV. CONCLUSION AND FUTURE WORK

This paper has presented a method for counting steps taken by a user while walking. The linear relation that was proposed to hold between amplitude of the acceleration signal and the frequency of a step, is shown to be effective in counting the steps taken, irrespective of the walking speed of the individual. This is reinforced by the results obtained.

Moreover, it was observed that the numerical value of the constant β, in the proposed relation, was found to be 3.1541 very close to π (3.1415). This may be because walking is often likened to the motion of two coupled pendula [10]. The stance leg is said to behave like an inverted pendulum moving about the stance foot, and the swing leg like a regular pendulum swinging about the hip.

In the future, we aim to verify the same. Also, we are currently working on the algorithm to consider the various walking cases such as on stairs and steep sloping roads. We also aim to investigate whether the proposed method is independent of the height and weight of the individual concerned.

ACKNOWLEDGMENT

The authors would like to thank Ms Najme Zehra Naqvi and Dr. Ashwani Kumar for the enriching discussions they had with us and their constant support and guidance.

REFERENCES

[1] R. Jirawimut, P. Ptasinski, V. Garaj, F. Cecelja, W. Balachandran,“A Method for Dead Reckoning Parameter Correction in Pedestrian Navigation System,” Proc. of the 18th IEEE Instumentation and Measurement Technology Conference, VOL. 52,NO.1, 2001,pp. 1554-1558.

[2] R. W. Levi, T. Judd, “Dead Reckoning Navigational System using Accelerometer to Measurement Foot Impacts,” United States Patent, No. 5,5583,776, 1996.

[3] Q. Ladetto, “On foot navigation : continuous step calibration using both complementary recursive prediction and adaptive Kalman filtering,” Proc. of ION GPS, 2000, pp. 1735-1740.

[4] J. Kappi, J. Syrjarinne, J. Saarinen, “MEMS-IMU Based Pedestrian Navigator for Handheld Devices,” Proc. of ION GPS, 2001, pp. 1369-1373.

[5] H. Leppakoski,“Error Analysis of Step Length Estimation in Pedestrian Dead Reckoning,” Proc. of ION GPS,2002, pp. 1136-1142.

[6] S. Y. Cho, C. G. Park, G. I. Jee, “Measurement System of Walking Distance using Low-Cost Accelerometers,” Proc. of the 4th ASCC, 2002, pp. 1799-1803.

[7] S. Y. Cho, C. G. Park, G. I. Jee, "Sensor Fusion and Error Compensation Algorithm for Pedestrian Navigation System," International Conference on Control, Automation and systems, 2003, pp. 1001-1006.

[8] S. H. Shin, Student Member, IEEE and C. G. Park, Member, IEEE, J. W. Kim, H. S. Hong and J. M.,"Adaptive Step Length Estimation Algorithm Using Low-Cost MEMS Inertial Sensors, "Sensors Applications Symposium, IEEE,2007.

[9] Vânia Margarida Cardoso Guimarães,"Phone Based Fall Risk Prediction,"Master's Thesis, FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO,2011.

[10] Arthur D. Kuo,J. Maxwell Donelan, and Andy Ruina,"Energetic Consequences of Walking Like an Inverted Pendulum: Step-to-Step Transitions,"Exercise and Sport Sciences Reviews,Vol. 33,No. 2,2005,pp. 88–97.

AUTHORS PROFILE

Ms. Najme Zehra Naqvi is a B.Tech. in Electronics and Communication with Hons. And M.Tech. in Information Technology with Hons. She is currently (2012) a lecturer at Department of Computer Science Engineering, Indira Gandhi Institue of Technology, Guru Gobind Singh Indraprastha University, Delhi, India. She has more than 8 years of experience in teaching. Her research interests include the fields of embedded systems, microcontrollers, microprocessors, operating systems, computer architecture, digital Circuits and systems, measurement, control, and microelectromechanical systems.

Dr. Ashwani Kumar is a B.E. in Electronics and Communication , Delhi College of Engineering, M.E. in Electronics and Communication, Delhi College of Engineering, Ph. D in Electronics and Communication , Delhi University and MBA (FMS), Delhi University. He has 16 Years of Research and Development experience in Centre for Development Of Telematics (C-DOT,India), Research & development Center of Ministry of communication, Govt. of India. He is currently (2012) a Professor at IGIT. His areas of interest include optical communication, digital dignal processing, strategic management, measurement, control, and microelectromechanical systems.

Ms. Aanchal Chauhan was born in 1990. She is currently(2012) pursuing B.Tech in Computer Science Engineering from Indira Gandhi Institue of Technology,Guru Gobind Singh Indraprastha University, Delhi,India (expected 2012). Her areas of interest include sensors and their applications, operating systems, data structures, measurement, control, and microelectromechanical systems.

Ms. Kritka Sahni was born in 1990. She is currently(2012) pursuing B.Tech in Computer Science Engineering from Indira Gandhi Institue of Technology,Guru Gobind Singh Indraprastha University,Delhi,India (expected 2012). Her areas of interest include sensors and their applications, operating systems, data structures, measurement, control, and microelectromechanical systems.