Adaptive Step Detection Algorithm for Wireless Smart Step Counter

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***Abstract*—we had designed and implemented a smart step counter with adaptive step detection algorithm that can enhance the accuracy of step detection using step amplitude. This algorithm can pick step count out over 99% of accuracy through the adaptive step detection algorithm. To prove the effectiveness of the new algorithm, we made a noise filtering process with the amplitude threshold from the amplitude of energy value that found out the detection error was increasing, and it's the key idea of the variable amplitude threshold that can be adapted on the continuous data evaluation. The experiment results shows that the adaptive step detection algorithm can catch the average step count accuracy up to 98.9% at 10 Hz sampling rate and 99.6% at 20Hz sampling rate.**

Keywords—Adaptive Step Detection; Peak Threshold; Amplitude Threshold; Step Count

I. INTRODUCTION

Many ubiquitous devices such as smart phone and smart applications has been developing for human's real life based on the expansion of ubiquitous sensor network and mobile techniques. Most of all, the u-healthcare area is one of the fast expanded application area. Many mobile devices for measuring usual healthcare information and information services for analyzing healthcare information have been studied to help us giving effective healthcare guide with their enhanced mobility and usability [1]. The ubiquitous step counter is one of the typical devices for personnel healthcare.

Walking is the most frequent usual activity in human's life and it is real physical exercise including very complicate mechanism on many parts of human body [2]. Many people have been used a kind of step counter during personnel exercises or indoor/outdoor sports activities for measuring their quantity of motion. There had been many kinds of mechanical step counter but not so much precise as need. Today, MEMS (Micro Electro Mechanical System) based digital mini-accelerometer can make us CPU assisted step counter. This type of step counter, the accuracy of the step counts depends on the step detection algorithm built in the device. Many step detection algorithms had been studied and developed to make sure the accuracy of step detection, and the sampling rate of digital accelerometer is one of the major factors of the accuracy. In this study, we proposed an adaptive step detection algorithm that can count the step in another way of previous works. To prove the effectiveness of the proposed algorithm, we developed the Bluetooth based 3-axes accelerometer sensor module, measured x, y, z data and analyzed the accuracy of the step detection.

II. RELATED WORKS

A step detection and step count application is one of the most interest smart phone applications so that many researchers has been studied and developed various step detection algorithms on accelerometer. Moving average algorithm used 2-axes accelerometer on 50Hz sampling rate and got 91% step count accuracy [3]. Some algorithm used very strict rule that accepts as a step only when data passes 4 stages of motion from the 2-axes accelerometer tied on ankle. It can detect the step with 97.2% accuracy at walking, 92.5% accuracy at running and slow walking [4]. Several studies adopted a kind of adaptive threshold based step count algorithm and detected step count with 98.6% accuracy for walking, slow walking and running [5]. Mobile health monitoring system has real-time cognition applications on user's activity by using GMM(Gaussian Mixture Model) and HMM(Hidden Markov Model) so as to count steps and paces by using MEMS sensor [6, 7]. Most of these studies attempted to detect the step with peak threshold. In this study, we attempt to adopt variable step amplitude on peak threshold based step detection algorithm and showed its effectiveness on step detection for various walking types.

III. CONCEPT OF SMART STEP COUNTER

A. System Design and Implementation

In this work, we had designed and implemented the smart step counter to measure the detail step count connected with user's smart phone application. The experimental version of the smart step counter can be attached on a human body anywhere. This module basically has BMA250 3-axial accelerometer sensor and CSR BlueCore4-External for MPU and Bluetooth functions [8, 9]. The MPU includes our own step count algorithm, 1MB EEPROM I^2C control for 3-axes

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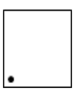
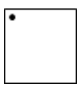
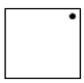
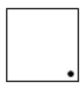
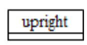
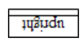
data, Bluetooth communication control and real time control as well as the adaptive step detection algorithm in the form of embedded firmware. The Bluetooth communication control can transmit the accumulated 3-axies data from EEPROM on the Bluetooth network in write-back..

The BMA250, a kind of motion cognition 3-axial accelerometer sensor from BOSCH, can give the each of x, y, z directional acceleration data as raw outputs. The sensitivity of BMA250 can be adjusted as 2g, 4g, 8g and 16g. Each output for x, y, z axis can be varied according to the sensor position on one's body as shown on Table I. For example, if one takes the sensor module on his/her waist and walks around with 1g(gravity), the 3-axial accelerometer sensor's direction would be concentrated on direction 2, and its output shows x = 1g, y = 0g and z = 0g.

TABLE I. BMA250 OUTPUT SIGNALS FROM SENSOR ORIENTATION

Sensor Orientation (gravity vector ⇩)	1 	2 	3 	4 	5 	6 
Output Signal x	0g / 0 LSB	1g/256 LSB	0g / 0 LSB	-1g/-256 LSB	0g / 0 LSB	0g / 0 LSB
Output Signal y	-1g/-256 LSB	0g / 0 LSB	1g/256 LSB	0g / 0 LSB	0g / 0 LSB	0g / 0 LSB
Output Signal z	0g / 0 LSB	0g / 0 LSB	0g / 0 LSB	0g / 0 LSB	1g/256 LSB	-1g/-256 LSB

B. Measuring and Data Processing

The LSM sends 3-axes data stored in EEPROM to a mobile smart device via Bluetooth data communication mechanism. The smart mobile device, like a smart phone or smart pad, processes the data at every Bluetooth data transfer. For the fast data processing, we transform a set of 3-axes data into a single representative data through the time domain *t* to get a step data instead individual axe data processing. This single representative data can be regarded as an energy value *E(t)* from SVM(Signal Vector Magnitude) algorithm as equation (1).

$$E(t) = \sqrt{|x(t)|^2 + |y(t)|^2 + |z(t)|^2} \qquad (1)$$

To get the walking data, we picked up 5 men with height 168~183cm and weight 45~81kg range as testers. Each tester walked with LSM on his waist with three walking types (Slow walking, Normal walking and Jogging) at 4g and 8g, totally 72 times repeated.

IV. STEP DETECTION ALGORITHM

A. Step Detection with Peak Threshold

In previous works, the peak threshold is a very important factor for step detection algorithm. It is defined as a minimal peak energy value *E(t)* that can be accepted as a step from energy value waveform. The step count would be varied along with the peak threshold. Increasing the peak threshold, the step count is decreased and vice versa. Therefore, to get the precise step count, an appropriate peak threshold should be applied on the step detection algorithm.

As a result of pre-analysis on comparing measured x, y, z values with default values on datasheet, we got 0.950 ~ 1.050 energy value at a stationary state. So, the peak threshold should be over 1.050 to get the step count at moving or walking state. We had set the peak threshold from 1.050 to 1.2 at 0.025 intervals, and analyzed the step counts with 10Hz and 20Hz sampling rate. At the case of the peak threshold goes over 1.2, the step detection accuracy drops down under 60% so as to ignore the pre-analysis results. Table II shows the pre-analysis results that count the steps with various peak thresholds and sampling rates.

TABLE II. AVERAGE STEP COUNT WITH PEAK THRESHOLD

Sampling rate	Sensitivity	4g			8g		
	Peak Threshold	Slow walking	Normal walking	Jogging	Slow walking	Normal walking	Jogging
10Hz	1.075	104.20	103.23	103.03	108.20	104.88	104.35
	1.100	101.78	101.78	102.25	102.45	101.15	101.58
	1.125	98.93	100.83	101.95	100.28	100.28	101.18
	1.150	95.25	99.53	101.70	94.55	98.90	101.00
	1.175	90.20	98.30	101.60	88.18	97.55	100.85
	1.200	84.53	96.80	101.45	83.78	95.78	100.80
20Hz	1.050	119.69	109.19	109.06	117.81	110.81	111.06
	1.075	108.13	103.19	101.31	110.50	108.38	104.69
	1.100	104.69	101.69	99.38	103.75	101.81	102.44
	1.125	102.44	101.44	99.06	103.44	101.63	102.00
	1.150	99.00	101.19	98.94	98.44	101.00	101.69
	1.175	94.56	101.00	98.69	96.75	100.75	101.56
	1.200	90.00	100.75	98.69	93.56	100.50	101.50

At the case of 10Hz sampling rate, the step counts approached 100 steps at 1.10 ~ 1.15 peak threshold and 99% step detection accuracy that can give enough precision less than 10Hz sampling rate. At the case of 20Hz sampling rate, the step count was slightly increased by noise increasing result from the high frequency and approached 100 steps within 1.050 ~ 1.175 as like 10Hz sampling rate. These results show that the step detection algorithm can catch the step counts with 99.4% accuracy within 1.100 ~ 1.125 peak threshold at 10Hz, and within 1.150 ~ 1.175 peak threshold at 20Hz.

B. Average Amplitude

Almost of previous step detection algorithms had detected and counted steps based on peak threshold. But they also have another characteristic on step data as a form of *E(t)*. And these algorithms could not catch the walking types well and have low step count accuracy at low sampling rate. That's why these algorithms have a little bit step count gap according to the walking type and sampling frequency.

Most of the current digital sensors communicate with CPU through built-in I^2C or SPI interface to transfer the sampled data and the sampling rate depends on the interface bandwidth. Almost the low-cost digital sensors have 5~50Hz even for BMA250 on our LSM. So the step detection algorithm has to take another factor to compensate this gap for low sampling rate. In this work, we adopted amplitude value on step detection algorithm as another step detection factor and checked if the improved step detection algorithm can makes effective step counts. To choice the appropriate amplitude, we examined the average amplitude for all case of walking types, sensitivities, peak threshold values and sampling rates. Table 3 shows the average amplitudes from step detection process with peak threshold.

From the Table III, we found that jogging has high amplitude at high energy value with 1.100 ~ 1.150 peak threshold at 10Hz and 20Hz than normal and slow walking. This fact shows that the average amplitude can be used as another effective factor for checking the walking type or step detection. And we can regard this average amplitude as amplitude threshold.

TABLE III. AVERAGE AMPLITUDE FROM STEP DETECTION WITH PEAK THRESHOLD

Sampling rate	Sensitivity	4g			8g		
	Peak Threshold	Slow walking	Normal walking	Jogging	Slow walking	Normal walking	Jogging
10Hz	1.050	0.61	0.77	2.05	0.56	0.82	2.11
	1.075	0.64	0.81	2.13	0.59	0.83	2.15
	1.100	0.65	0.81	2.15	0.61	0.85	2.20
	1.125	0.66	0.82	2.15	0.61	0.86	2.20
	1.150	0.67	0.83	2.16	0.63	0.87	2.21
	1.175	0.68	0.83	2.16	0.65	0.87	2.21
	1.200	0.70	0.84	2.16	0.66	0.88	2.21
20Hz	1.050	0.54	0.82	2.41	0.59	0.83	2.42
	1.075	0.59	0.86	2.56	0.62	0.85	2.54
	1.100	0.61	0.87	2.61	0.65	0.89	2.59
	1.125	0.62	0.87	2.62	0.66	0.89	2.60
	1.150	0.63	0.87	2.62	0.68	0.89	2.61
	1.175	0.65	0.87	2.62	0.68	0.89	2.61
	1.200	0.66	0.88	2.62	0.69	0.90	2.61

C. Adaptive Step Detection

Everybody has different step and amplitude along with one's physical factors and walking type. If we detect the step with just a single value of amplitude threshold, step detection accuracy could be dropped. So we need variable amplitude threshold that can be varied along with the energy value *E(t)* to get more accurate step count. In this work, we designed an adaptive step detection algorithm with variable amplitude threshold that continuously update the amplitude threshold according to the previous data history.

In adaptive step detection algorithm, the amplitude threshold can be updated at every $Peak_i$ position as the harmonic average of 5 consecutive amplitudes ($Amplitude_i$) which is the difference between $Peak_i$ and Low_i values. For example, the amplitude threshold at current position can be calculated with 5 data from Peak1 to *Peak5* at Figure 1. Table 5 shows step count with the variable amplitude threshold algorithm. It also shows that the step count accuracy enhanced up to 98.9% at 10Hz sampling rate and 99.6% at 20Hz sampling rate.

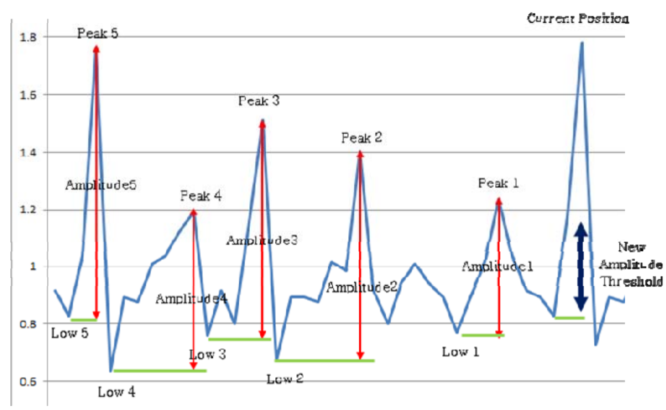


Fig. 1. Peaks, Amplitudes and Amplitude Threshold from *E(t)*

Table IV shows step count with the variable amplitude threshold algorithm. It also shows that the step count accuracy enhanced up to 98.9% at 10Hz sampling rate and 99.6% at 20Hz sampling rate.

TABLE IV. AVERAGE STEP COUNT WITH VARIABLE AMPLITUDE THRESHOLD

Sampling rate	Sensitivity	4g			8g		
	Peak Threshold	Slow walking	Normal walking	Jogging	Slow walking	Normal walking	Jogging
10Hz	1.100	100.93	100.98	100.63	100.85	100.48	100.28
	1.125	98.48	100.33	100.55	99.13	99.75	100.15
	1.150	94.93	99.13	100.45	93.88	98.65	100.10
20Hz	1.100	100.69	101.06	97.56	100.75	100.38	99.44
	1.125	100.00	101.13	97.50	100.81	100.31	99.63
	1.150	97.81	100.81	97.50	97.31	100.25	99.81

V. CONCLUSION

In this work, we developed LSM for measuring the movement of 3-axes accelerometer and designed new adaptive step detection algorithm that can match up the step detection accuracy not depend on the walking type under low sampling rate using variable amplitude threshold. Although the existing step detection algorithm can catch the step with accuracy over 99% on fixed peak threshold, it also has high error rate under the 10Hz sampling rate according to the walking types. Therefore, we have to improve the previous step detection algorithm using amplitude threshold at the cases of walking types under the 10Hz frequency.

When we checked step count from amplitude of $E(t)$ after noise filtering, the step count error rate increased because everyone has different step and amplitude along with the walking types. In adaptive step detection algorithm, we used the variable amplitude threshold that can adapt over continuous data observation and enhanced the step count accuracy up to 98.9% at 10Hz and 99.6% at 20Hz sampling rate. Therefore the proposed algorithm can enhance the step detection accuracy under various walking types and can be applied on the low-cost step count device that has to be designed with low sampling frequency caused by sensor connectivity such as I^2C or other circuit limitation.

In further work, we are going to design and develop the health activity monitoring system based on this work. The monitoring system would be closer with a smart mobile device such as smart phone or smart pad, and could check the walking type and total activity automatically by amplitude analysis of $E(t)$.

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