

# Using a Three-Axis Accelerometer and GPS Module in a Smart Phone to Measure Walking Steps and Distance

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**Abstract** — In this paper we use a smart phone with three-axis accelerometer features together with a multiple judgment method to improve the accuracy of measuring both walking and running steps. In the past, using only a single characteristic for ascertaining whether there is a walking step resulted in large errors while on the other hand the multiple characteristics of acceleration variation are used to decide the presence of walking steps, thus effectively enhancing accuracy. By using a GPS module this design estimates both the user walking distance and the user path as depicted on the GPS map, and then allows the user to estimate the amount of exercise.

**Index Terms** — Smart Phone; Pedometer; Three-axis Accelerometer Sensor; GPS

## I. INTRODUCTION

The World Health Organization (WHO) has stated that the best exercise in the world is walking. The pedometer is a tool used to exchange information from data. In recent years there are more and more built-in functions in the smart phone, including a pedometer. There are many sensors in a typical smart phone, such as a magnetic field, and both orientation and accelerometer sensors.

Recently although pedometers have more and more built-in functions, many features are based on the accuracy of counting the number of walking steps [1]. The traditional pedometer must be not only installed but also fixed at the waist area in order to effectively measure both the distance and the number of steps. The pedometer application included inside the smartphone also uses acceleration sensors [2]. These sensors must be located at a suitable location such as an individual's waist or foot [3]. However the wearing location of a smartphone may affect the detection value of a sensor, thereby affecting the accuracy of the measurement, especially when fixed on a foot. Therefore we focus our research on the three-axis accelerometer in the smartphone [4]. In this paper we use the smartphone's built-in three-axis accelerometer sensor to record both the number of steps and the changes at the center of gravity when people are either walking or running. To analyze, measure and record several acceleration waveforms, we use the multiple characteristics of acceleration variation to enhance the accuracy by counting the number of the recorded acceleration waveforms used to calculate the walking or running steps. In addition, by using the GPS position our design measures the user walking distance, and

calculates the calories consumed when exercising [5]. Fig. 1 shows the architecture of the operation environment.

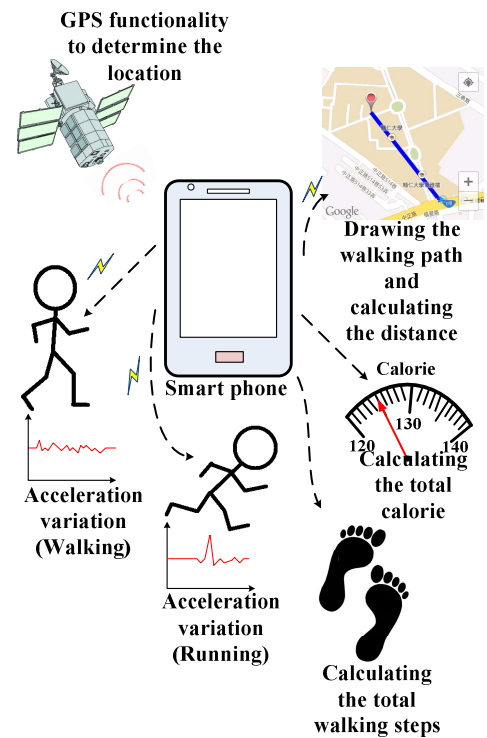


Fig. 1. The operation environment architecture.

Fig. 2 shows the three modules of our design which include the three-axis acceleration module, the GPS module, and the calories module.

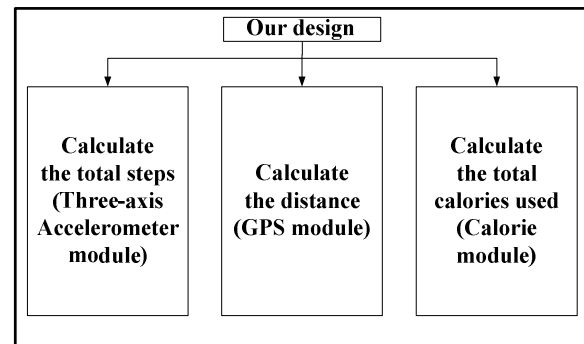


Fig. 2. The three modules of our design.

In this paper Section II describes the three-axis accelerometer placed relationship with a typical smart phone. Section III describes the judgment of walking steps and the calculation of the total number of steps. Section IV describes the walking distance calculation method utilizing a GPS. And Section V describes the calculation of the total number of calories used while exercising. Section VI shows the implementation results and our conclusions are summarized in Section VII.

## II. THREE-AXIS ACCELEROMETER SENSOR IN A SMART PHONE

One must first understand that as the placement of a smart phone which has a different impact on accelerations also contributes to the three-axis accelerometer data analysis. Therefore we must know the location of the smart phone and the relationship between the three space axes [6]. The acceleration unit is  $m/s^2$  ( $m/sec^2$ ). The function of the three-axis accelerometer sensor is to detect the X-axis ( $A_x$ ), Y-axis ( $A_y$ ) and Z-axis ( $A_z$ ) by the effects of the gravity situation. As the direction of gravity and the coordinate direction are opposite, we obtain a positive value, instead of obtaining a negative value. In our design when the phone is upright in an individual's pocket, the Y-axis ( $A_y$ ) is affected by gravity [7].

We retrieve the portrait as shown in Fig. 3 when the smart phone is placed in the pocket. At this time the Y-axis ( $A_y$ ) is affected by gravity. And we retrieve the landscape as shown in Fig. 4 when the phone is placed on the waist and the X-axis ( $A_x$ ) is affected by gravity. Fig. 5 shows the acceleration variations of the portrait [8-9].

The biggest difference of the smart phone placed in a pocket or on the waist is that as the gravity effects are in different directions, the axis shows the different characteristics of the acceleration variation. Therefore the measured data are not the same. Fig. 5 shows one of the typical acceleration variations of the stationary status in a pocket [10].

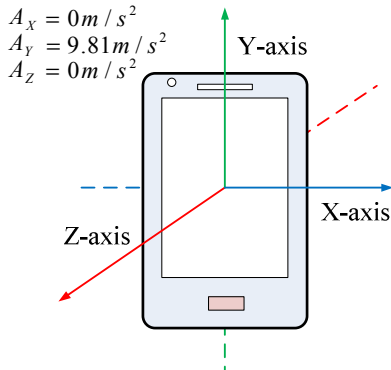


Fig. 3. Smart phone with portrait.

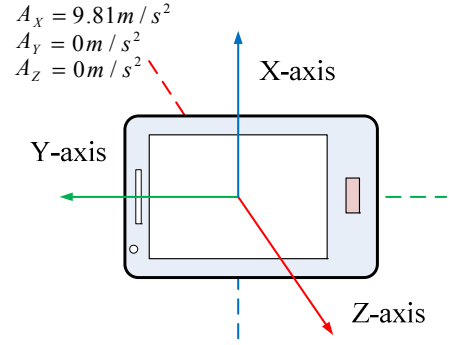


Fig. 4. Smart phone with landscape.

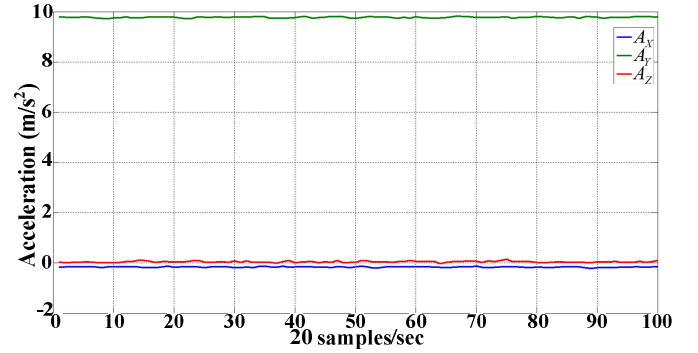


Fig. 5. The acceleration variations of a smart phone placed in a pocket.

## III. WALKING STEP MONITORING ALGORITHM

To determine whether it is necessary to complete monitoring a walking step, we need to analyze the acceleration data that has been measured and received from the three-axis accelerometer sensor. Fig. 6 and Fig. 7 shows the acceleration waveform produced as a result of two conditions: walking and running. We can see that with both walking and running, their acceleration values will have a fixed and regular change, because when a human is walking, that basic center of gravity is at the waist. Therefore in which these two statuses are different from the intensity variation of the acceleration values. An analysis of the accelerometer can be divided into three steps [11-13].

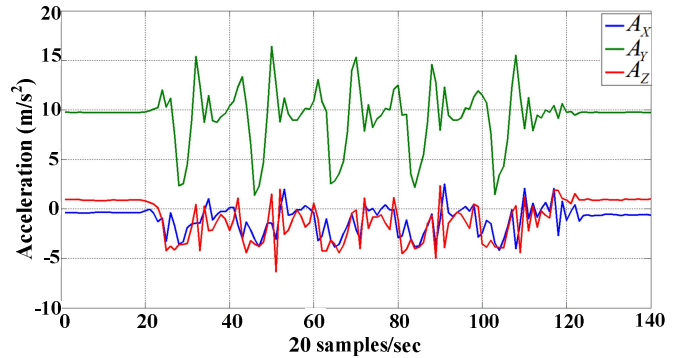


Fig. 6. Walking acceleration waveform.

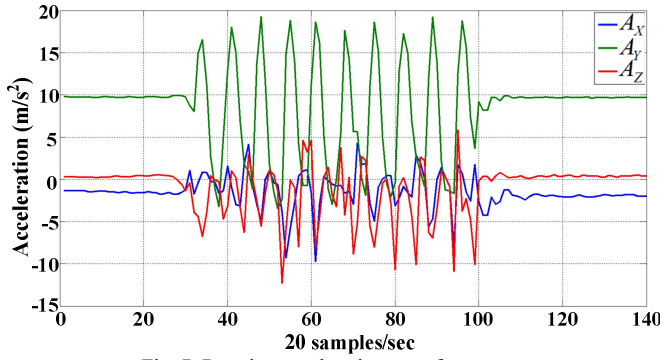


Fig. 7. Running acceleration waveform.

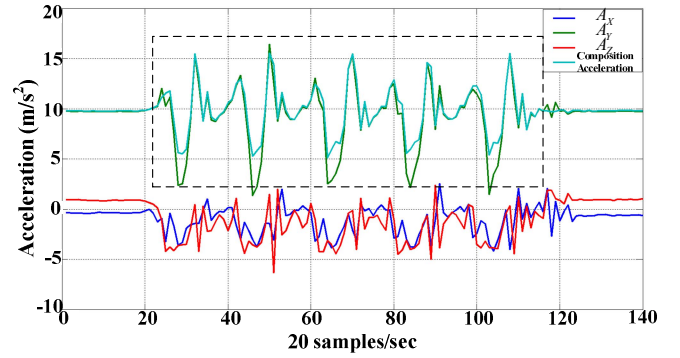


Fig. 10. A similar three-axis accelerometer waveform.

### 1. Other posture determine

To reduce the occurrence of a wrong judgment is to increase the percentage of accuracy. The sensors determine whether the waveform has a dramatic change in an instant, such as when either jumping or falling.

### 2. Sum

The sum is the magnitude of the acceleration as shown in both Fig. 8 and Fig. 9. When walking, as the center of gravity is changed by the acceleration value also, the result is a normal but yet different amount of change. By setting a threshold value, the software module can reduce any unnecessary noise, such as that caused by a mild shaking.

### 3. Individual-axis acceleration

The value of one axis is similar to the composition of a change of acceleration. As both a walking status and a running status are cycle movements, the direction and the smartphone pocket placement position, regardless of the change both of  $A_x$ ,  $A_y$  and  $A_z$  do not affect the composition of the change of acceleration. Fig. 10 shows the acceleration composition.

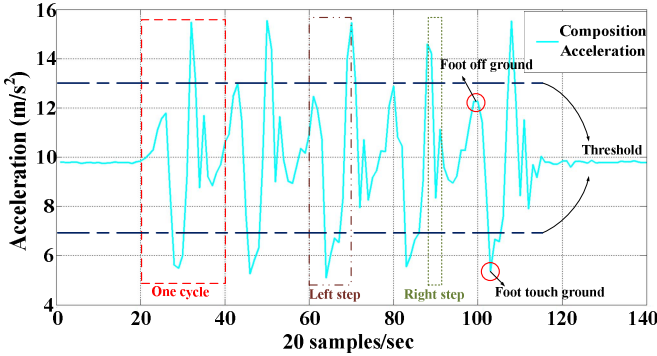


Fig. 8. Acceleration composition of a walking waveform.

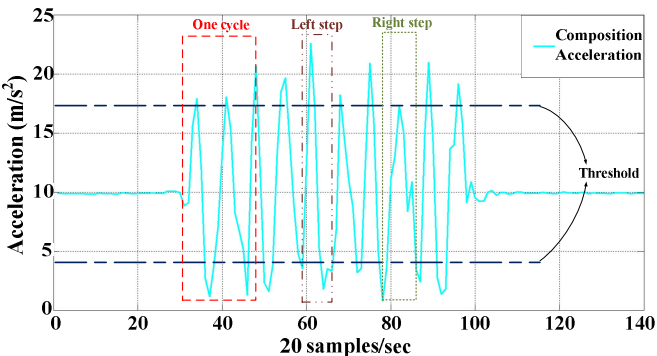


Fig. 9. Acceleration composition of a running waveform.

Fig. 11 shows the flowchart of our design which is based on the three judgment methods of the multiple characteristics of acceleration to enhance accuracy. When walking, the center of gravity of a body changes, thus resulting in an acceleration of change and a choice of the mode of moving [14-15]. By determining the status before analyzing the step flow we can improve our accuracy. We can observe that when walking and running the acceleration of change will be larger than a fixed value, as in Fig. 8 and Fig. 9. Therefore when we set a threshold and use this condition as a starting value and call it the last point, we can ignore some unnecessary noise between thresholds. When the three-axis accelerometer sensor detects the acceleration change it triggers the program to calculate the walking steps. The first step is to estimate the composition acceleration of  $A_x$ ,  $A_y$  and  $A_z$  when the user is walking. From (1) we calculate the magnitude of the acceleration and note that if this acceleration is larger than the threshold a user may have been in either a walking or a running status. In the first judgment method the continuous waveform always obtains the composition of acceleration values by including the previous subtraction. If the acceleration values meet the set points, this represents one walking step, and the last point is changed to the acceleration value. Sometimes there will be a few steps when the foot is off the ground or if the force is relatively large or small, thus causing the resulting acceleration to be also large or small. Therefore in the second judgment method the magnitude of the acceleration value must be greater or less than the threshold. A big shake may have also resulted in two acceleration values which have met our setting. Therefore, we must ensure that the acceleration must be greater than or less than the threshold to determine whether it is a walking step. From Fig. 11 we can know if we can assume whether the smart phone placement is fixed, and whether the acceleration value of one axis is similar to the magnitude of the acceleration of change. As the smart phone placement is a portrait, the  $A_y$  is affected by gravity. If an external influence pushes a human body into another direction, as the three axes change there will be one axis with a value similar to the magnitude of the acceleration of change. We apply this feature to form a third judgment method. Our program not only determines whether any walking or running exists and but also uses the multiple characteristics of

acceleration variation to determine an individual's walking step. When the acceleration value is greater than or equal to 2, the program accumulates the correct walking steps. This method successfully improves the accuracy of measurement and eliminates unwanted noise.

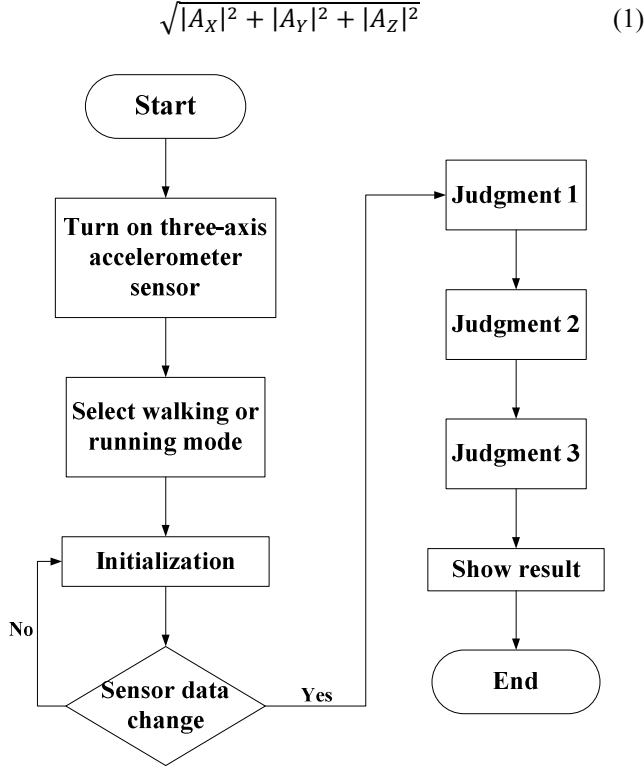


Fig. 11. Decision flowchart of the measurement of walking steps.

#### IV. DISTANCE MEASUREMENT ALGORITHM

Both in analyzing the acceleration variation and in simultaneously calculating the step, the smart phone's GPS module will obtain the user's location in real time. Furthermore, both the GPS information as well as the walking distance is displayed on the map.

Since the earth is an approximate spherical, the spherical surface distance between two points is calculated using the latitudes and longitudes. The GPS latitude and longitude of the locations has an accuracy of more than ten decimal digits in order to obtain a more accurate calculation to find the spherical surface distance. In this paper we use a Haversine equation to measure the walking distance. Because the Great-circle distance equation uses a cosine function, and the distance between two points is very short, such as a few hundred meters, the result will be a larger number of rounded errors. As the Haversine equation uses a sine function, even if the distance is small this equation can maintain sufficient accuracy. Equation (2) shows that distance  $D$  is the straight-line distance, and  $R$  is the radius of the earth. The latitude and longitude of the two points are  $(\phi_1, \lambda_1)$  and  $(\phi_2, \lambda_2)$ . The latitude and longitude in the calculation must be transferred to radians. The total distance is the sum of all samples of each segment distance from every GPS sample

in (3). Fig. 12 shows the flowchart of the distance measurement.

$$D_i = 2R \times \arcsin \left( \sqrt{\sin^2 \left( \frac{\phi_2 - \phi_1}{2} \right) + \cos \phi_1 \cos \phi_2 \sin^2 \left( \frac{\lambda_2 - \lambda_1}{2} \right)} \right) \quad (2)$$

$$D = \sum_{i=1}^n D_i \quad (3)$$

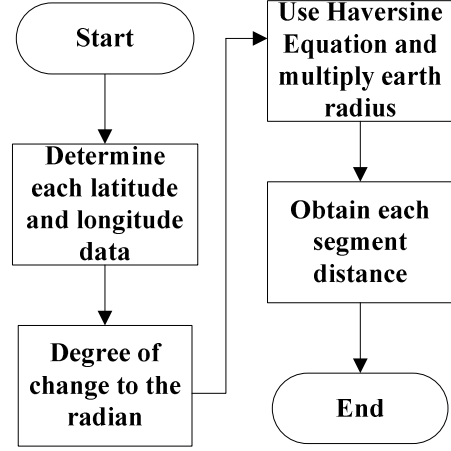


Fig. 12. Flowchart for the walking distance measurement.

#### V. CALCULATE THE AMOUNT OF EXERCISE

In a modern busy society, people have no time and energy to exercise after work. This lack of exercise is the main cause why a person's weight gradually increases. Generally, walking is a good way to begin to exercise. The benefits of exercise are weight loss, release of emotions, lower blood pressure, better blood circulation, and an improvement of both one's heart and lung functions. Long-term, regular exercise can improve a person's physical function, reduce both the incidence of illness and delay aging. Exercise also can promote an increased metabolic rate. If the exercise matches a person's diet, one's weight loss efficiency will be improved. Experts suggest at least 30 minutes of exercise each day or a total per a week of 150 minutes, in order to have a significant effect. Calculating the amount of exercise is a means to estimate the use of calories while exercising. Fig. 13 shows the flowchart for calculating calories [16-18].

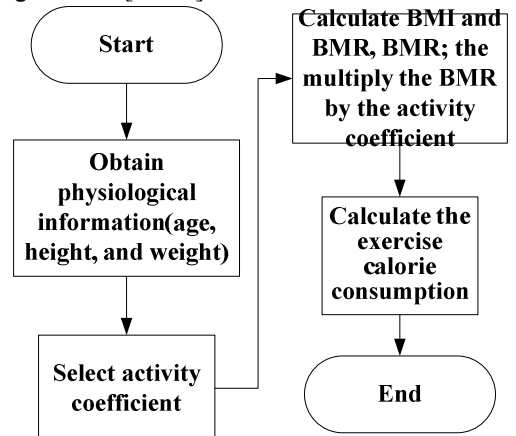


Fig. 13. Flowchart for calculating calories.

The first step requires the user to enter physiological information and select the activity coefficient. The daily number of calories required for everyone will vary with the amount of activity. Therefore, the activity coefficient must be included, in order to determine the correct number of calories needed for each day. The second step calculates both the body mass index (BMI) and the basal metabolic rate (BMR). Then the BMR is multiplied by the activity coefficient to obtain the value of the user [19].

The BMI is a simple tool for calculating whether or not a person is overweight. The BMI is defined as (4). The weight is  $w$ , and the unit is kg. The height is  $h$ , and the unit is m. The BMI unit is  $\text{kg/m}^2$ . The normal range  $18.5 \leq \text{BMI} < 24$ .

$$\text{BMI} = \frac{w}{h^2} \quad (4)$$

The basal metabolic rate (BMR) is the minimum required not only to maintain the calorie consumption of a body for one day, but also to maintain the minimum standards required for a healthy life. Equation (5) and (6) is the BMR formula for men and women. The BMR unit is kcal, the weight unit is kg, and the height unit is cm.

For men:

$$66 + (13.7 \times \text{weight}) + (5 \times \text{height}) - (6.8 \times \text{age}) \quad (5)$$

For women:

$$655 + (9.6 \times \text{weight}) + (1.7 \times \text{height}) - (4.7 \times \text{age}) \quad (6)$$

According to one's target a special amount of exercise is recommended in order to complete a simple exercise management system. By paying attention to one's BMR the required daily calorie needs of an individual can achieve weight control.

Table I shows the activity coefficient. Different types of work and different amounts of exercise have different coefficients.

TABLE I  
ACTIVITY COEFFICIENT

	Coefficients
Office type (little or no exercise)	1.2
Light type (exercise 1-2 times per week)	1.375
Moderate type (exercise 3-5 times per week)	1.55
Heavy type (exercise 6-7 times per week)	1.725
Manual labor type (Heavy exercise per day)	1.9

Table II shows the three amounts of exercise recommended for different requirements.

TABLE II  
AMOUNT OF EXERCISE RECOMMENDED

	Times
Reduce the incidence of chronic disease	At least 30 minutes per day
Want to lose weight or maintain weight	At least 60 minutes per day
Still want to continue to lose weight after weight loss	At least 60~90 minutes per day

Table III shows the calorie consumption of different exercises. Examples are given for one hour of exercise for two

individual's weighting 60 kg and 70 kg respectively.

TABLE III  
CALORIE CONSUMPTION OF DIFFERENT EXERCISES

	Calories burn rate (kcal/kg/hr)	60kg/1hr	70kg/1hr
Walking (4km/hr.)	3.1	186	217
Running (8.7km/hr.)	9.4	564	658

## VI. IMPLEMENTATION RESULTS

Fig. 14 (a) and Fig. 14 (b) shows the user interface of our design on which the smart phone records both the walking steps and the walking distance and calculates both the BMI and the BMR. The software module also shows a recommended number of steps total based on the BMI. In addition, the user interface also draws a distance path on the map with a resolution of about 10 meters. Our design is designed to record when if one first goes from point A to point B and then return back to point A, which represents the summation of the distance from point A to B and point B to A.

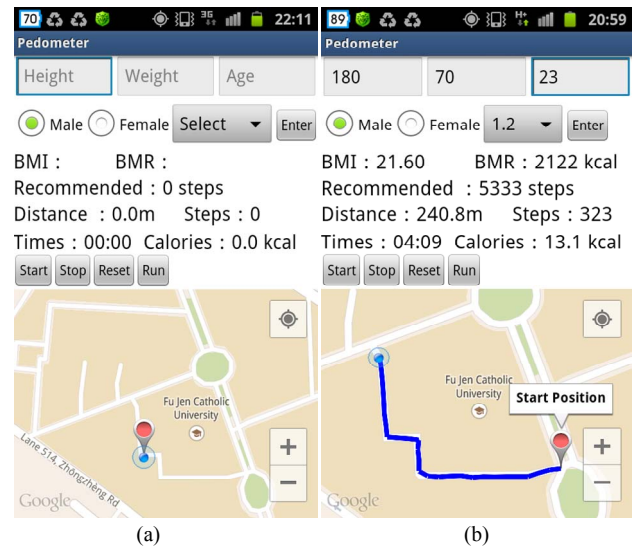


Fig. 14. User interface of our design.

Table IV and Table V show the measurement results of our design. Five persons were used both to test and to count the total walking steps in comparison with the results shown by pedometers. The smart phone, when placed on the waist, provides the highest level of accuracy for a general traditional pedometer like Design A. Design B is currently on the market and can be downloaded using specific application. We test three designs at the same time. Our design has the highest accuracy rate when utilizing the multiple characteristics of acceleration variations. Design A also has a high rate of accuracy when walking, but it must be placed on the waist. If not, there will be errors in calculating the total results. For example, tester 2 is wearing baggy pants. In Table V, when measuring the running status, our design can maintain a certain level of accuracy, especially with tester 2. When a person is running, with a smart phone the result is a bigger



error than when walking, because the smart phone dynamically moves up and down and the waist center of gravity changes are more dramatic.

TABLE IV

A COMPARISON OF OUR DESIGN WITH OTHERS FOR THE MEASURING OF WALKING STEPS

Tester	Actual steps	Design A	Design B	Our Design	Our error rate
1	300	297	372	296	-1.33%
2	300	224	323	317	+5.67%
3	300	319	351	314	+4.67%
4	300	285	341	295	-1.67%
5	300	299	369	280	-6.67%
Average value	300	284	351	300.4	-
Standard deviation	0	32.3	18.2	13.6	-

TABLE V

COMPARISON OF OUR DESIGN WITH OTHERS FOR THE MEASURING OF RUNNING STEPS

Tester	Actual steps	Design A	Design B	Our Design	Our error rate
1	300	258	317	287	-4.33%
2	300	602	746	217	-27.67%
3	300	262	294	321	+7%
4	300	301	435	352	+17.33%
5	300	274	411	306	+2%
Average value	300	339.4	440.6	296.6	-
Standard deviation	0	132.2	161.8	45.1	-

## VII. CONCLUSION

In this paper we use the three-axis accelerometer sensor of a typical smart phone to calculate the total walking steps. In addition, we use the GPS module in the smart phone to calculate the walking distance and display the result on a map. From the experimental results which can be confirmed by the use of the three-axis accelerometer we can effectively measure the user's walking steps. Our design is based on the smartphone which can be carried anywhere, including out of doors. We also use the multiple characteristics of the acceleration variation to enhance our measurement accuracy.

## REFERENCES

- [1] Hui-Huang Hsu, Kang-Chun Tsai, and Zixue Cheng, "Posture Recognition with G-Sensors on Smart Phones," 2012 15th International Conference on Network-Based Information Systems (NBIS), pp. 588-591, Sept. 2012.
- [2] J. C. Alvarez, R. C. Gonzalez, D. Alvarez, A. M. Lopez, and J. Rodriguez-Uria, "Multisensor Approach to Walking Distance Estimation with Foot Inertial Sensing," 29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2007, pp. 5719-5722, Aug. 2007.
- [3] Chi-Chung Lo, Chen-Pin Chiu, Yu-Chee Tseng, Sheng-An Chang, and Lun-Chia Kuo, "A Walking Velocity Update Technique for Pedestrian Dead-Reckoning Applications," 2011 IEEE 22nd International Symposium on Personal Indoor and Mobile Radio Communications PIMRC), pp. 1249-1253, Sept. 2011.
- [4] Kose Alper, Cereatti Andrea, and Croce Ugo Della, "Estimation of traversed distance in level walking using a single Inertial Measurement Unit attached to the waist," 2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, pp. 1125-1128, Sept. 2011.
- [5] J. Babic, and I. Podlubny, "Software application for GPS devices using Google Maps," 2011 12th International Carpathian Control Conference (ICCC), Velké Karlovice, Czech Republic, pp.1-5, 25-28 May 2011.
- [6] T. Tamrat, M. Griffin, S. Rupcic, S. Kachnowski, T. Taylor, and J. Barfield, "Operationalizing a wireless wearable fall detection sensor for older adults," 2012 6th International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth), pp. 297-302, May 2010.
- [7] O. Aziz, and S. N. Robinovitch, "An Analysis of the Accuracy of Wearable Sensors for Classifying the Causes of Falls in Humans," IEEE Transactions on Neural Systems and Rehabilitation Engineering, pp.670-676, Dec. 2011.
- [8] Zhang Zhanli, Guo Shijun, Wang Hengdi, and Deng Sier, "A New Acceleration and Deceleration Algorithm and Applications," 2012 Second International Conference on Intelligent System Design and Engineering Application (ISDEA), pp.121-124, 6-7 Jan. 2012.
- [9] Yongwon Jang, M. W. Jung, Jaemin Kang, and Hee Chan Kim, "An Wearable Energy Expenditure Analysis System based on the 15-channel Whole-body Segment Acceleration Measurement," IEEE-EMBS 2005, 27th Annual International Conference of the Engineering in Medicine and Biology Society, pp.3834-3836, 2005.
- [10] Y. Tsuruoka, and M. Tsuruoka, "Walking stability using portable acceleration measurement system," IEEE International Conference on Systems, Man and Cybernetics, 2009, pp.504-509, 11-14 Oct. 2009.
- [11] K. Sagawa, H. Inooka, and Y. Satoh, "Non-restricted measurement of walking distance," 2000 IEEE International Conference on Systems, Man, and Cybernetics, pp.1847-1852 vol.3, 2000.
- [12] Wu Shyi-Shiou, and Wu Hsin-Yi, "The Design of an Intelligent Pedometer Using Android," 2011 Second International Conference on Innovations in Bio-inspired Computing and Applications (IBICA), pp.313-315, 16-18 Dec. 2011.
- [13] Ying-Wen Bai, Siao-Cian Wu and Cheng-Lung Tsai, "Design and Implementation of a Fall Monitor Using a Smart Phone 3-axis Accelerometer," The 16th IEEE International Symposium on Consumer Electronics, Harrisburg, Pennsylvania, USA, pp. 143-148, 4-6 June, 2012.
- [14] Wang Hongman, Zhu Xiaocheng, and Chang Jiangbo, "Acceleration and Orientation Multisensor Pedometer Application Design and Implementation on the Android Platform," 2011 First International Conference on Instrumentation, Measurement, Computer, Communication and Control, pp.249-253, 21-23 Oct. 2011.
- [15] K. Tumkur, and S. Subbiah, "Modeling Human Walking for Step Detection and Stride Determination by 3-Axis Accelerometer Readings in Pedometer," 2012 Fourth International Conference on Computational Intelligence, Modelling and Simulation (CIMSIM), pp.199-204, 25-27 Sept. 2012.
- [16] P. Buddharaju, and N. S. C. P. Pamidi, "Mobile Exergames - Burn Calories While Playing Games on a Smartphone," 2013 IEEE Conference on Computer Vision and Pattern Recognition Workshops (CVPRW), pp. 50-51, 23-28 June 2013.
- [17] S. Kasim, and F. A. Zakaria, "Daily Calorie Manager for basic daily use," 2013 Third International Conference on Innovative Computing Technology (INTECH), pp. 437-442, 29-31 Aug. 2013.
- [18] Mi-hee Lee, Hyoung-Ki Lee, Kiwan Choi, SeokWon Bang, Jaywoo Kim, and Sangryong Kim, "Method of Measuring Calorie Consumption for Portable Apparatus," IEEE 27th Annual International Conference of the Engineering in Medicine and Biology Society, 2005, pp. 5203-5206, 17-18 Jan. 2006.
- [19] M. M. Hassan, M. A. Hossain, Y. Aldukhayyil, A. Alamri, M. Al-Qurishi, M. S. Hossain, D. T. Ahmed, and A. El Saddik, "Health monitoring of obese people through a cloud-based serious game framework," 2013 IEEE International Conference on Multimedia and Expo Workshops (ICMEW), pp. 1-4, 15-19 July. 2013.