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Pedometer Development Utilizing an Accelerometer Sensor

Ling-Mei Wu, Jia-Shing Sheu, Wei-Cian Jheng, and Ying-Tung Hsiao

***Abstract*—**This paper develops a pedometer with a three-axis acceleration sensor that can be placed with any angle. The proposed pedometer measures the number of steps while users walk, jog or run. It can be worn on users' waistband or placed within pocket or backpack. The work address to improve on the general pedometers, which can only be used in a single direction or can only count of steps without the continuous exercise judgment mechanism. Finally, experimental results confirm the superior performance of the proposed pedometer.

***Keywords*—**Accelerometer sensor, Angle estimation, Pedometer.

I. Introduction

ACCORDING to the National Health Interview Survey in Taiwan [7], from the department of Health, R.O.C. (Taiwan), physical exercise condition of residents in Taiwan is generally insufficient, 46.47% of residents don't have good exercise habit. Under this circumstance, pedometer has become a very good tool for testing exercise volume. As long as wearing a pedometer on the body, the number of daily walking steps can be detected. The users can calculate whether they get enough exercise or not, through automatically accumulated steps to achieve the proper exercise and health management.

From now on, pedometers can be generally divided into mechanical pedometer and electronic pedometer. The principle of a pedometer is to utilize upward and downward oscillations when the user is walking. And these oscillations will drive the balancing mechanism in the pedometer, of which the movement of waist is most obvious.

The mechanical pedometer utilizes a spring coil to suspend a lever arm and to provide stress for its upward and downward movements. The lever arm will move upward and downward for every walking step, and determining the walking steps, but the disadvantage is that detection can only be measured in a single direction. And this direction must be vertical ground surface.

The electronic pedometer utilizes an accelerometer to detect the changes of acceleration in different directions. From now on, the commercial products still use a criterion with continuous movement for preventing a misjudgment. For example, the steps will be calculated into correct steps only after continuously walking for a few seconds or continuously walking a few steps, so the disadvantage is that all short walks will be treated as an error message, and it will be ruled out.

In this paper, we used a three-axis accelerometer to implement an electronic pedometer can be placed at any angle, so that users can carry out detection of walking steps through wearing it on waist or arbitrarily placing it in pocket or backpack, without the limitation of a general mechanical pedometer which must be worn on waist. And at the same time an algorithm is used to calculate acceleration changes vertical to ground surface, such that at any placement angle it can accurately detect vertical oscillation of human body while walking. It does not need to use the continuous movement anti-misjudgment mechanism which was used by old products, and also enhanced the accuracy of counting steps.

II. Related Work

The accelerometer can detect changes in acceleration. Along with the development of Wiimote of game console Wii to today's smart phones, three-axis accelerometer has been widely used, no matter in gesture recognition, vehicle navigation, pedometer application, fall detection, etc. There are many different methods to use the accelerometer.

In the hand gesture movement trajectory recognition system [9], according to the movement of the hand, user can carry an acceleration sensor on hand to record the acceleration values of movement trajectory, and then use different algorithms to conduct signal processing and sum up different patterns of behavior.

In applications of vehicle navigation system [3], the positioning is mainly determined by using an accelerometer and a gyroscope, and coupled with GPS. For example, in integrated system of GPS (global positioning system) and INS (inertial navigation system), the INS is an auxiliary navigation system, it uses an accelerometer and a gyroscopes to measure the acceleration and rotation of an object, and uses a computer to continuously estimate the position, posture and speed of the moving object.

In the fall detection system, M. J. Mathie et al [5] proposed signal vector magnitude (SVM), and judged the occurrence of falls based on using SVM as a threshold. Chia-Chi Wang et al [1] considered that in the normal case the movement magnitude of head is lower than other parts of body, so they set up sensor on right ear to carry out detection. Xing-Han Wu [8] calculated the inclination angle of sensor according to the relationship between gravity and three-axis accelerometer. Jiang-Peng Dai et al [4] proposed a detection method of vertical displacement through using the accelerometer in a mobile phone and based on two rotations of coordinate system.

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With regard to pedometer application, Chien-Chung Shih proposed [2], based on that numerical curve of *G* value would be significantly oscillated while in walking or running. So the number of times of the user's body movements can be confirmed by way of finding partial highest and lowest points of the curve, and the dynamic threshold can be adjusted depending on differences of user to carry out the detection of the number of steps.

III. Architectures and Algorithms

A. Hardware Architecture

The experimental device used in this paper is a three-axis accelerometer ADXL330connected to the MPC82G516, which is an 8-bits MCU, as shown in Fig. 1, and used its ADC analog-to-digital signal conversion to detect the acceleration changes in three axes. The system flow chart is depicted in Fig. 2. The hardware consists of MCU and Sensor.

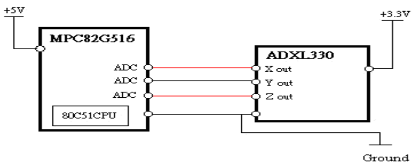

Fig. 1 Hardware architecture

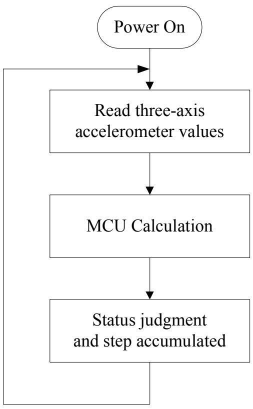

Fig. 2 System operation flow chart

B. Figures Data Smoothing Methods

The output of the accelerometer ADXL330 used in this device is an analog signal, it will inevitably generate some error due to noise coupling through wired to ADC Port of the MPC82G516. In order to eliminate the error on signals, this paper had used a hamming filter [6] to carry out smoothing process, as shown in (1). The *y(t)* indicates the value of the signal after smoothed, *x(t)* indicates the value of original signal at time *t*. After smoothing process, the error of the digital signal can be reduced, its value can be stabilized, and therefore it is more conducive to identify the user's behavior.

$$y(t) = \frac{1}{4}\left[x(t) + 2x(t-1) + x(t-2)\right] \tag{1}$$

The signals captured by the MPC82G516 are shown in Fig. 3. The data in Fig. 3 are the acceleration changes for a total period of 2.5 seconds, the vertical axis indicates the acceleration values, and the horizontal axis indicates time in seconds, it can be seen that the numerical values have unstable oscillating circumstance, the result after smoothing processing through (1) is shown in Fig. 4, it indeed can effectively reduce errors and capture stable signal variations.

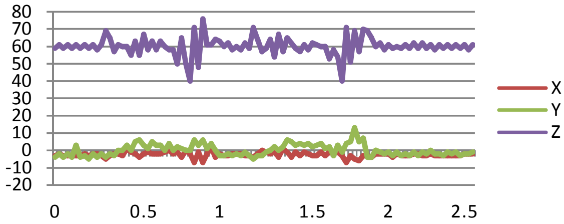

Fig. 3 Original data signal

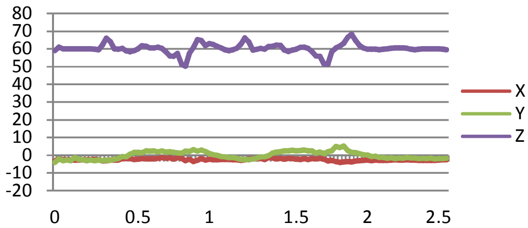

Fig. 4 Data signal after smoothed

C. Calculating the Inclination Angle

According to the relationship of gravity force component and rotation angle (shown in Fig. 5, taking x-axis as an example), it can be seen that the gravity force component *0.5G* is equal to *Sin(30°)*, so the angle of inclination is equal to the *ArcSin* value of gravity force component, as shown in the following (2), where x is the angle of inclination, a_x is the gravity force component sensed in X-axis, a_g is the numerical value measured out by sensor when gravity acceleration is *1G*.

$$\begin{cases} Sin(x) = \dfrac{a_x}{a_g} \\ x = ArcSin(\dfrac{a_x}{a_g}) \end{cases} \tag{2}$$

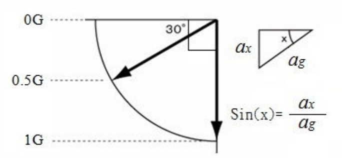

Fig. 5 The relationship diagram of gravity and inclination angle

Each of the inclination angles can be obtained according to Fig. 5 and (2), and the gravity force components sensed in the axis are shown as in Table I.

TABLE I
THE RELATIONSHIP OF INCLINATION ANGLE AND GRAVITY

Angle (degree)	Sin(Angle) (gravity *G*)
0	0
10	0.173648178
20	0.342020143
30	0.5
40	0.64278761
50	0.766044443
60	0.866025404
70	0.939692621
80	0.984807753
90	1

Fixed inclination angle of the device is experimented. The sensor with a fixed angle is placed, used (2) to calculate the inclination angle, and then conducted verification with actual placement method. All errors are within 5 degrees as shown in the actual test results in Table II. The experimental environment is shown in Fig. 6.

TABLE II
ACTUAL CALCULATE THE INCLINATION ANGLE

Actual angle (degree)	Sensed gravity (G)	*ArcSin* conversion (radial degree)	Converted angle (degree)	Error angle (degree)
0	0	0	0	0.00
10	0.2173	0.2191410	12.56	2.56
20	0.3913	0.4020485	23.04	3.04
30	0.5652	0.6006967	34.42	4.42
40	0.6739	0.7394924	42.37	2.37
50	0.7826	0.8988454	51.50	1.50
60	0.8913	1.1002138	63.04	3.04
70	0.9565	1.2748334	73.04	3.04
80	0.9782	1.3619023	78.03	1.97
90	1	1.5707963	90	0

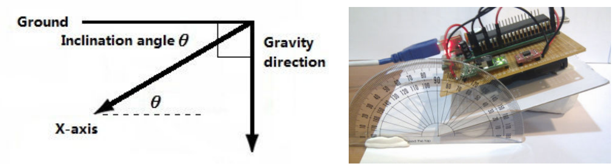

Fig. 6 The relationship diagram of X-axis inclination of θ degrees and the direction of gravity

D. Vertical Ground Acceleration

Chien-Chung Shih [2] explained that the waist and the human body will have the displacement's variations which are vertical ground when human is walking. This direction is the same as the direction of gravity. In order to obtain the acceleration changes in this direction, as shown in Fig. 6, take X-axis as an example, inclined by θ degrees relative to the horizontal plane, (3) can be derived.

$$a_g = a_x Sin\theta \tag{3}$$

In (3), where a_g is the acceleration in the direction of gravity, a_x is the acceleration sensed in the direction of X-axis, θ is the angle between X-axis and horizontal plane, according to Fig. 6, it can be obtained that a_g is equal to product of a_x and $Sin\theta$. While in sensing the axis inclination angle θ, it can be calculated out that $Sin\theta$ is equal to the gravity force component acted on the axis, so the calculation of the inclination angle can be omitted from substituting it into the (3), and the acceleration changes in the direction of gravity can be directly calculated out from component force of gravity, as shown in (4).

$$a_g(t_n) = a_x(t_n)\frac{a_x(t_1)}{a_G} \tag{4}$$

In (4), taking X-Axis as an example, $a_g(t_n)$ is the acceleration in the direction of gravity at time t_n, $a_x(t_n)$ is the acceleration in the direction of X-Axis at time t_n, while $a_x(t_1)$ is the sensed gravity force component at still time t_1, and a_G is the full gravity acceleration *1G*.

In the setting of a three-dimensional space with three axes, the acceleration changes acted on three axes can be obtained by the sensor. Then added Y-axis and Z-axis to (4), and the following (5) can be obtained.

$$a_g(t_n) = \begin{cases} a_x(t_n)\dfrac{a_x(t_1)}{a_G} \\ a_y(t_n)\dfrac{a_y(t_1)}{a_G} \\ a_z(t_n)\dfrac{a_z(t_1)}{a_G} \end{cases} \tag{5}$$

In (5), $a_g(t_n)$ is the acceleration in the direction of gravity at time t_n. $a_x(t_n)$, $a_y(t_n)$, $a_z(t_n)$ are respectively the accelerations sensed in the direction of three axes at time t_n, while $a_x(t_1)$, $a_y(t_1)$, $a_z(t_1)$ are respectively the sensed gravity force components in three axes at still time t_1, and a_G is the full gravity acceleration *1G*. Therefore, the acceleration changes in the direction of gravity can be obtained through using the accelerations in the direction of gravity respectively sensed in three axes.

E. Vertical Movement Tests of Different Inclination Angles

In order to separate walking signals from other noises, we had placed the experimental device at different angles to make it generate upward and downward movements in vertical direction, and forward & backward and leftward & rightward movements in horizontal direction, and targeted on the changes of sensed values of the three-axis accelerometer, as well as the acceleration a_g in the gravity direction obtained from (5) to analyze the difference of the data between vertical and horizontal movements.

In the experiment, the experimental device was respectively placed in horizontal position, 45 degree inclined to X-axis, and 54.7 degree inclined to each axis, used to verify at different angles, whether the sensor can identify vertical and horizontal movements according to changes of acceleration a_g in the direction of gravity.

First, the experimental device was placed in a horizontal position, and the data line chart is shown as in Fig. 7. In the initial state the gravity force components in *X* and *Y* directions are close to zero, the gravity force component in *Z* direction almost exclusively occupies the whole gravity. The vertical movements are indicated by changes in the level of Z-axis values, while the horizontal movements are represented by changes of values generated in X-axis and Y-axis. And a clear distinction between vertical and horizontal movements can be seen from the changes of a_g below.

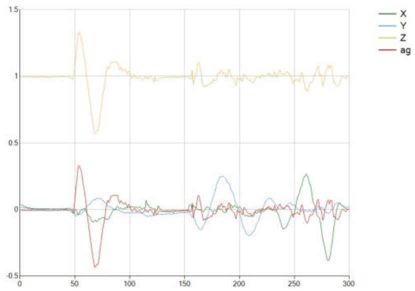

Fig. 7 Data signal of horizontal position

Second, the experimental device was placed in a position inclined to X-axis by about 45 degree, and the data line chart is shown as in Fig. 8. The ratio of gravity force components acted on X-axis and Z-axis is about 1:1. When in vertical movement, the values in X-axis and Z-axis have significantly same amplitude of change. Then in horizontal movement, a single numerical value change exists in the *Y* direction, and opposite numerical value changes occur in the *X* and *Z* directions. And the same as in the horizontal position, the vertical and horizontal movements can be distinguished by the changes of a_g.

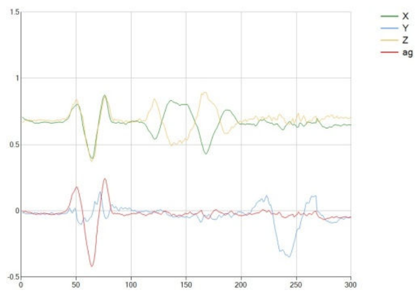

Fig. 8 Data signal of inclining to X-axis by about 45 degree

Next, the experimental device was placed in a position inclined to each of three axes by about 54.7 degree, the ratio of gravity force components acted on three axes is about 1:1:1, and the data line chart is shown as in Fig. 9. Since the gravity force components acted on three axes are the same, so when in vertical movement significantly same amplitude of changes in value exists in all three directions, while the changes in value have different directions in the horizontal direction. And same as above stages, in this stage the vertical and horizontal movements can also be distinguished by the changes of a_g.

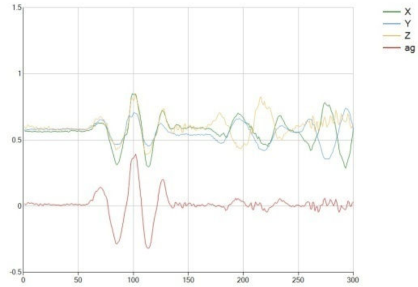

Fig. 9 Data signal of inclined to each of three axes by about 54.7 degree

From Figs. 8 and 9, it can be known that, when in vertical direction movement, the same gravity force component acts on each axis, so there will be the same amplitude change of acceleration; while in horizontal movement, will have changes in different directions, however under the condition of mutually offsetting, a_g will approach to the constant value of *0*, and thereby can determine whether there is a movement vertical ground surface. Fig. 10 demonstrates the circumstance when the experimental device is inclined to negative direction of Y-axis, it can be seen that when vertical movement occurs, the change of sensed values in Y-axis is contrary to the changes in other two axes, but due inclination angle to Y-axis is approximately -42.3 degree, so $Sin(\theta_y)$ is a negative value, and after multiplied with the value change of a_y, the obtained change of a_g is in the same direction with X-axis, Z-axis. Finally, the vertical and horizontal movements also can be distinguished by the changes of a_g.

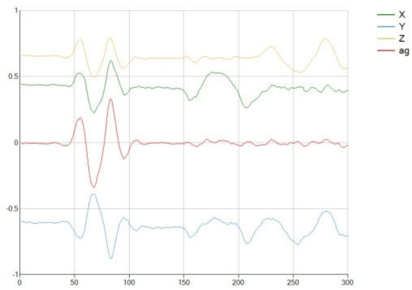

Fig. 10 Data signal of inclining to negative direction of Y-axis

F. Acceleration Changes in the Direction of Gravity when in Walking Exercise

Actual measurements of walking and running exercises were carried out in this stage, and the pedometer wearing styles are shown as in Fig. 11. The pedometer was worn on the waist, and coupled with foam adhesive to fix the placement methods at different angles.

Fig. 11 Pedometer wearing styles

The acceleration a_g in the direction of gravity was calculated according to detection, and walking and jogging 10 steps each, obtained the results of Figs. 12 and 13. From the data diagrams of walking and jogging it can be found that, a positive and a negative *G* values will appear in each step, so thereby the number of walking steps can be determined. However, it can be seen in Fig. 10 that, the amplitude in walking is smaller and is about half of the amplitude in running. Many noisy signals will run out between footsteps, this is caused by the inertial oscillation of the body between footsteps, therefore in the experiment it is necessary to be filtered by using a threshold.

IV. Experimental Results

A. Threshold Settings for Detecting Walking

Due to noisy signals will be caused by the inertial oscillation of the body between footsteps, as shown in Fig. 12, so it is necessary to use a threshold to filter out the noisy signals.

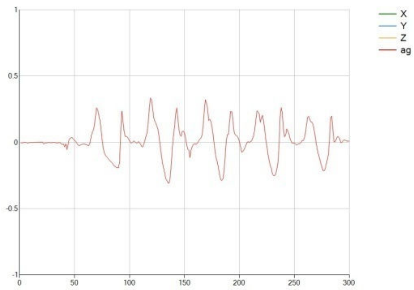

Fig. 12 Data signal of walking 10 steps

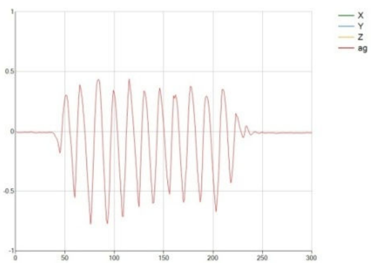

Fig. 13 Data signal of jogging 10 steps

In the experiment, we used a fixed threshold to do the filtering, and carried out human walking test at five different angles of placement state, as shown in Table III, respectively walked 20 steps in each state, total number walking steps is 100, and then judged the number of steps with different thresholds from 0.02G to 0.12G according to the acceleration a_g in the direction of gravity, the results are shown as in Table IV. As measured by accuracy, it can be found that the most accurate judgment is when 0.04G is used as a threshold.

TABLE III
Inclination Angles to Three Axes in Various Placement States

Status item	X-axis (Degree)	Y-axis (Degree)	Z-axis (Degree)
No. 1	90	0	0
No. 2	0	-90	0
No. 3	0	45	45
No. 4	45	0	-45
No. 5	-30	-30	60

TABLE IV
Results of the Number of Steps Filtered by Different Thresholds

Threshold (G)	No.1	No.2	No.3	No.4	No.5	Total (step)	Accuracy (%)
0.02	26	24	23	27	20	120	80%
0.04	22	20	21	21	19	103	97%
0.06	21	19	17	18	18	93	93%
0.08	19	17	12	16	16	80	80%
0.10	16	15	9	13	11	64	64%
0.12	12	10	7	11	8	48	48%

B. Actual Walking Test

From Figs. 12 and 13 it can be seen that, compared to walking, the acceleration amplitude in running is larger and more stable, so in the actual test walking was used to conduct accuracy assessment of the present device. In the subsequent experiment the experimental device was also placed at five different angles (see Table III), carried out walking detection of 20 steps for each state, total of 100 steps, and got different subjects to conduct the experiment, the experiment samples consist of two males and three females, the experimental results are shown as in Table V.

TABLE V
Detected Results of Different Samples at Different Placement States

Sample	No.1	No.2	No.3	No.4	No.5	Total (step)	Accuracy (%)
Male1	23	18	21	20	17	99	99%
Male2	16	22	19	26	24	107	93%
Female1	17	18	19	18	16	88	88%
Female2	22	20	20	20	26	108	92%
Female3	24	26	20	23	21	114	86%

V. Conclusion

This paper implemented a practical pedometer utilized a three-axis acceleration sensor. First, the angles between three axes respectively with horizontal plane were calculated by the gravity force components, and obtained the acceleration changes of the movement direction vertical ground surface. Then the proposed method can directly obtain the changes of acceleration in the direction of gravity without calculating angles. Finally a threshold is used to filter the number of steps of human walking to achieve the step count function for this device. The presented electronic pedometer can be placed at any angle to improve the disadvantage of general mechanical pedometers, which can only be applied in single direction. Moreover, the proposed pedometer can get rid of the need of using a continuous movement mechanism as error estimation criteria in general pedometers. Therefore, this system is good at detection accuracy and achieves a compact pedometer for putting with any angle.

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