Voltage Compensation Based Calibration Measurement of 3D-acceleration Transducer in Fall Detection System for the Elderly

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***Abstract* —The fall detection algorithm, which can recognize the fall of human body by collecting the acceleration signals in different directions of the body, is an important part of fall detection system for the elderly. The system, however, may have errors during analyzing the acceleration signal, due to that the coordinate system of the transducer does not coincide with the one of human motion. Furthermore, voltage variation of the battery also influences the accuracy of the acceleration signal. Therefore, in this paper, a fall detection system based on the 3D-acceleration transducer MMA7260 is designed, which can calibrate the acceleration data through compensation of voltage and transformation of coordinates. Experiments illustrated that the proposed method can accurately transform the collected data from the coordinate system of the transducer to that of the human motion, and can recognize various postural changes in the course of the motion of human body.**

***Keywords*—Calibration; 3D-acceleration transducer; voltage compensation; transformation of coordinates.**

I. INTRODUCTION

Various studies have concluded that fall is a common unexpected event and a cause of traumatic death in daily life [1-3]. It seldom damages young people severely, but is really a crucial problem for elderly people. About 10% to 15% falls could cause serious injuries while more than 1/3 of the people aged over 65 will fall at least once per year [4]. Therefore, there is a particular need to monitor the behavior of the elderly people living on their own, so early detection of fall is an important step to alert and protect the people from serious injuries.

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This paper illustrates a wearable fall detection system based on the 3D-acceleration transducer MMA7260, produced by the Company Freescale. The errors of collected data, which were resulted by a variety of external and internal factors of the system, were found during the analysis of the acceleration data. As the transducer cannot be worn by the users in a completely ideal way and orientation deviation may exist between the angle of the user and the device, the acceleration detected by the acceleration transducer cannot really describe the postural changes during human body motion [6-8]. Meanwhile, as indicated in the experiments, a large margin of error, which is lead by the dropping of the system's battery voltage, exists in the calculation of the orientation deviation [4, 9]. In recent studies, the common method to solve this problem is to detect the battery power automatically and then remind the users to replace the battery [10, 11]. This method, however, is not only a waste of resource but also leads to unavoidable errors when battery voltage drops [12-14]. In this paper, in order to improve the recognition accuracy of human body motion, a method is proposed to calibrate the acceleration data through several steps, such as the voltage compensation, initial deviation angle calculation and data calibration.

II. METHODS

A. Voltage Compensation

The primary task for transducer calibration is to calculate the angle between the orientation of the worn transducer and the *X*, *Y* axes of the horizontal plane. Experimental results, however, show that the degradation of the system's battery voltage can lead to a big error in calculating the angle, even though the degradation magnitude is small. In order to calculate θ_x and θ_y, which are the angles between the transducer's *X'* and *Y'* axes and the horizontal plane, the relationship between the gravitational acceleration component of *X'* and *Y'* axes and the horizontal axis must be found while the acceleration transducer is under the static condition (as shown in Figure 1).

In this paper, the acceleration transducer is calibrated firstly. By setting the angle ranges of X, Y axes to be 1°, 2°, … , 10°, the accelerations of X and Y axes are then collected under 100 specific angles ranging from {1°, 1°} to {10°, 10°}on the X, and Y axes.

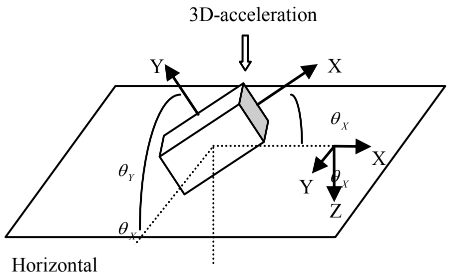
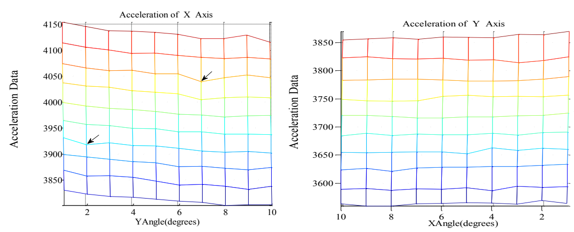


Figure 1. The relationship of spatial position between the 3D-acceleration transducer and the horizontal plane.



(a) (b)

Figure 2. The plane graph of various angles on the X, Y axes and the corresponding acceleration data. (a)The acceleration data along X axis; (b) The acceleration data along Y axis.

As shown in Figure 2(a), when the angle on the X axis is constant, the smaller the angle on the Y axis is, the bigger the measured gravitational acceleration component on the corresponding X axis direction will be. Similarly, Figure 2(b) shows the situation when the angle on the Y axis is constant. It has the trend of contrary direction, and is not as apparent as shown in Figure 2(a). This is because that the experiments illustrate that the gravitational acceleration components on the X, Y axes are mutual independent and are only dependent on the angles in their own axes, and thus a good linear correlation is observed.

If the time to complete the sampling of one point of the acceleration in Figure 2 is regarded as a unit, then the sample interval between two successive points on the X axis curve in the left graph is 10 units and one acceleration curve under a particular X axis angle contains at least 90 units. Since the fall detection system will be successive, the output of AD transformation is reduced gradually as a result of the battery voltage dropping.

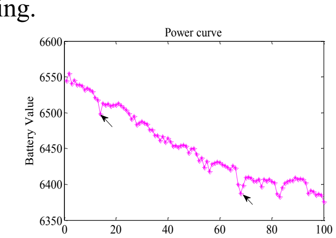


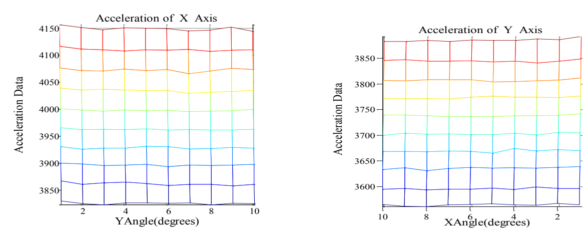
Figure 3. The corresponding battery voltages under different angles during calibration.

Figure 3 shows the battery voltages under the 100 specific angles. The curve has apparent fluctuations in some particular points, such as the 14th and the 68th angles indicated by black arrows, which have rapid degradation in voltage. Accordingly, for the corresponding points {4°, 2°} and {8°, 2°} in the Figure 2(a), as also indicated by black arrows, there exist apparently downward trends. It shows that a sudden drop of the battery voltage can lead to a corresponding drop of the acceleration transducer's output to some extent.

The process of voltage compensation is as follows. Firstly, the reference voltage will be set by measuring the gravitational acceleration components on the X, Y axes. Then in each of the following experiments, the voltage is compensated by comparing the current voltage and the reference voltage. After several experimental analysis and verification, the voltage compensation formula is estimated as equation (1).

$$\begin{bmatrix} A\_D_x \\ A\_D_y \\ A\_D_z \end{bmatrix} = \begin{bmatrix} A\_D_{p\_x} \\ A\_D_{p\_y} \\ A\_D_{p\_z} \end{bmatrix} + (V_p - V_{reference}) \times \frac{1}{3} \times \frac{1}{2} \tag{1}$$

In formula (1), A_Dp_x represents the acceleration data in the X axis after the compensation of voltage; A_Dp_x represents the acceleration data on the X axis before the compensation; Vp is the current battery voltage during the measurement, and Vreference stands for the acceleration's reference battery voltage on the horizontal plane.



(a) (b)

Figure 4. The compensation for the acceleration signal on the X, Y axes. (a)The acceleration data along X axis; (b) The acceleration data along Y axis.

Figure 4 shows the results of acceleration compensation on the X, Y axes with formula (1). In Figure 4(a), it can be found that the acceleration curve's fluctuations, led by the variation of battery voltage, are removed. In the Figure 4(b), a similar compensation is done to the acceleration on the Y axis, and the curve's horizontally fluctuation trend is reduced as well.

B. *Calculation of the Initial Angle*

Angles θ_x and θ_y, which are the angles between the acceleration transducer's X' and Y' axes and the horizontal plane while the detection device is worn, need to be obtained. There exists an angle θ_x between the X' axis in the acceleration transducer's coordinate system and the X axis in the human body motion's coordinate system. Moreover, the gravitational acceleration (g), measured by the acceleration transducer, always has a vertical downward direction. Therefore, the gravitational acceleration generates a gravitational acceleration component $a_{x'}$ on the acceleration transducer's X' axis and a component $a_{z'}$ on the transducer's Z' axis, as well as for the transducer's Y' axis.

The highest acceleration sensitivity of the sensor used by the fall detection system is 800mv/g. During the experiments, the reference voltage of the 14 bit AD conversion is V_f, and the highest bit of the AD conversion result output data in 14 bits is the sign bit. Therefore, when the input signal of the AD conversion is V_f, the conversion result will be 8192. As illustrated in formula (2), when the variation of the acceleration is ***g*** and the reference voltage of the AD conversion circuit is 3.0 V, the conversion result will be V_g =2185.

$$AD_{out} = \frac{V_i}{V_f} \times 8192 \tag{2}$$

In formula (2), V_i is the AD analog voltage input of AD and is also the analog voltage output of the acceleration transducer, V_f is the reference voltage of AD conversion, and AD_{out} is the output of AD conversion.

After the conversion, the vertical gravitational acceleration is resolved along the X' axis of the transducer's coordinate system, which is shown in formula (3).

$$\operatorname{Sin}\theta_x = \frac{a_{x'}}{G} \tag{3}$$

If *G* was set as the unit of the acceleration of the transducer's X', Y', Z' axes during data conversion, $\sin\theta_x = a_{x'}$ and $\sin\theta_y = a_{y'}$ can be obtained according to the formula (3).

With this method, the inclination angle can be measured through putting the detection device on an absolute horizontal plane firstly. The external reference coordinate system and the transducer's coordinate system can be suggested as coincidence and the acceleration on the transducer's X', Y', Z' axes is {0,0,1}, the result of AD conversion is $\{X_0, Y_0, Z_0\}$. When the device is worn correctly, the conversion result of the accelerations on the X', Y', Z' axes under the initial condition is detected. Moreover, the result can be recorded as $\{X_1, Y_1, Z_1\}$ and the value θ_x and θ_y can be derived from formula (4).

$$\{\theta_x, \theta_y\} = \arcsin \frac{\{X_1, Y_1\} - \{X_0, Y_0\}}{V_g} \tag{4}$$

The angles of the detection device on the X, Y axes can be acquired through formula (4), and then formula (5) can be derived from the inverse transformation of formula (4). Furthermore, if the acceleration output of the transducer along the absolute horizontal plane is known, the gravitational acceleration components on the X, Y axes can be calculated while the angles are varying.

$$\{X_1, Y_1\} = \{X_0, Y_0\} + V_g \times \sin\{\theta_x, \theta_y\} \tag{5}$$

After trails and errors, we find that, when the inclination angle is smaller than 7°, the theoretical values and the acceleration data obtained from experiments are in good agreement, and the bigger the angle is, the larger the error is. After the transducer is worn, the angles on the current X, Y axes can be calculated and the angles can be estimated. If one of them is detected to be larger than 7°, the device will alarm to inform the user to adjust the position of the transducer.

C. Calibration Model

After obtaining the θ_x and θ_y angles on the X, Y directions under the initial condition, the method for calibrating the acceleration data collected by the transducer needs to be proposed, and the first of the method is the calibration of θ_x and θ_y. The actual acceleration of the X axis of the human body motion coordinate system is $a_{x'}$ and a_x can be obtained by projecting the acceleration $a_{x'}$ and $a_{z'}$ on the X' and Z' axes of the transducer's coordinate system to the X axis, as shown in formula (6):

$$a_X = a_{x'} \times \cos\theta_x - a_{z'} \times \sin\theta_x \tag{6}$$

As skewing will occur in both the X and Y axes of the transducer's coordinate system if we project the measured acceleration $a_{x'}$ and $a_{z'}$ to the Z axis, the acceleration will not on the Z axis but in the plane composed by the Y and Z axes of the human body motion's coordinate system. As described in Figure 5, the projected acceleration's direction is set as the $a_{z''}$ axis and its value is set as $a_{z'}$. The method for calculating $a_{z'}$ is shown in formula (7).

$$a_{z''} = a_{x'} \times \sin\theta_x + a_{z'} \times \cos\theta_x \tag{7}$$

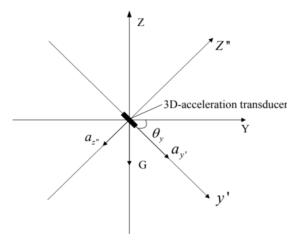


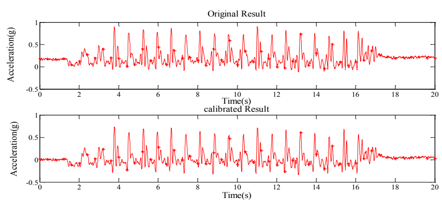
Figure 5. The transducer acceleration component on the plane of Y, Z axes.

Figure 5 shows the skewing condition from the acceleration components on the y' and $a_{z''}$ axes to the human body motion's coordinate system, where y' is the axis in the acceleration transducer's coordinate system and $a_{z''}$ is the assumed axis. As the X axial acceleration is calibrated, the actual acceleration components on the Y, Z axes of the human body motion' coordinate system can be obtained from formula (8).

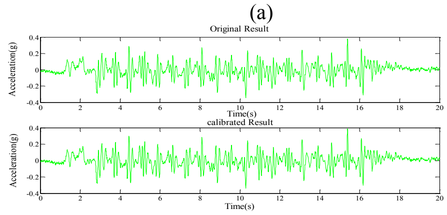
$$\begin{cases} a_Y = a_{y'} \times \cos\theta_y - a_{z''} \times \sin\theta_y \\ a_Z = a_{y'} \times \sin\theta_y + a_{z''} \times \cos\theta_y \end{cases} \tag{8}$$

III. Experiments

The proposed method, which is used for calibrating the static acceleration data, can also be utilized to calibrate the acceleration generated by human motion. In this paper, the acceleration data during human body's normal walking and fall are collected for calibration and validation. The calibration results of walking and fall data are shown in Figure 6 and Figure 7, respectively. Figure 6 describes the analysis of normal walking data. The calibration result in Figure 6(a) shows that the acceleration data on the X axis is totally calibrated to the X axis of the human body motion coordinate system, and Figure 6(b) shows the calibration result of the acceleration on the Z axis of the transducer's coordinate system. Figure 7(a) and Figure 7(b) illustrate that, after the transducer is worn, both the X and Z axes have gravitational acceleration components resulted from the initial angle. After the calibration, the initial acceleration curve on the X axis is more close to 0, and the initial data is adjusted to the X axis of the human body motion's coordinate system. Similarly, on the Z axis, as the calibration eliminates the cumulated influence generated by the acceleration on the X, Y axes during the motion, the acceleration data of Z acceleration is overall reduced.

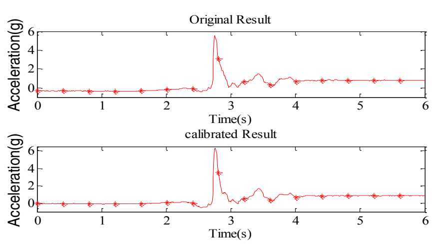


(a)

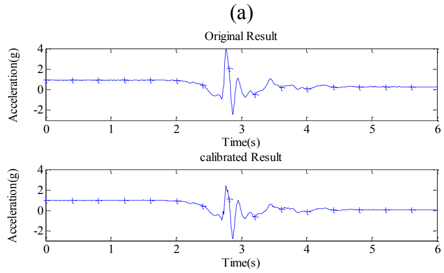


(b)

Figure 6. (a) Calibration for the acceleration on the X axis of the normally walking data. (b) Calibration for the acceleration on the Z axis of the normally walking data.



(a)



(b)

Figure 7. (a) Calibration for the acceleration on the X axis of the fall data.(b) Calibration for the acceleration on the Z axis of the fall data.

IV. DISSCUSSION AND CONCLUSION

In this paper, a method based on 3D-acceleration transducer for calibrating the output data of the fall detection device is proposed, and formula for initial inclination angles θ_x, θ_y on the transducer's X, Y axes are investigated. The error caused by variation in the battery voltage is reduced by using voltage compensation. With the method of three-dimensional coordinate projection, the acceleration on the transducer's coordinate system is transformed to the human body motion's coordinate system in order to make the final acceleration data be able to describe people's postural changes in around directions during motion. Experiments showed that the error of initial inclination angle can be reduced by 90%.

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