CALIBRATION OF TRIAXIAL ACCELEROMETER BY DETERMINING SENSITIVITY MATRIX AND OFFSETS SIMULTANEOUSLY

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Summary/conclusions
In this paper, we present a novel approach for calibration of triaxial accelerometer (TA). Acceleration is considered as a vector quantity of three components. Both sensitivity matrix and offsets are estimated simultaneously in least squares (LS) sense from a set of measurements with known accelerations. An easy calibration procedure is presented for situations where no calibration devices are accessible.

Introduction

Accelerometers have been widely used for capturing human movements during last years. Applications of accelerometry cover monitoring and classifying of different types of movements including gait, postural sway and falls [1]. Traditionally, calibration of TA has been carried out as a calibration of three independent, orthogonal uniaxial accelerometers [2]. This approach does not, however, take into account the transverse sensitivities, or cross-axis sensitivities, which can introduce significant amount of error [3]. In this paper, the sensitivity matrix and offsets of a TA are formulated in such a way that they can be estimated simultaneously.

Statement of clinical significance

Sensor calibration is an important part of measuring. Accuracy of calibration affects directly to the clinically interesting parameters.

Methods

Assuming a known acceleration $a = [a_x,a_y,a_z]^T$ (superscript T denotes transpose), the observed acceleration values $z = [z_x,z_y,z_z]^T$ after analog to digital conversion can be written in the matrix form

$$z = Ka + O + v, \qquad (1)$$

where K is a 3x3 sensitivity matrix, $O = [o_x,o_y,o_z]^T$ is offset and v is measurement noise. The diagonal elements of the sensitivity matrix K contain information about calibration gains and off-diagonal elements describe transverse sensitivity due to misalignment of input axis. For an ideal TA, the off-diagonal terms of K should be zero. In the general case, orientation and skewness of sensing axes of a TA are unknown with respect to geometry of TA capsule. Calibration of a TA can be defined as the derivation of all components of K and the offset O simultaneously. The twelve parameters to be estimated can be expressed as a parameter vector, $\theta = [k_{11},k_{21},...,k_{33},o_x,o_y,o_z]^T$. Equation (1) for i'th measurement can be written in the form

$$z^{(i)} = H^{(i)}\theta + v, \qquad (2)$$

where the observation matrix $H^{(i)}$ for i'th measurement is given by

$$H^{(i)} = \begin{bmatrix} a_x^{(i)} & 0 & 0 & a_y^{(i)} & 0 & 0 & a_z^{(i)} & 0 & 0 & 1 & 0 & 0 \\ 0 & a_x^{(i)} & 0 & 0 & a_y^{(i)} & 0 & 0 & a_z^{(i)} & 0 & 0 & 1 & 0 \\ 0 & 0 & a_x^{(i)} & 0 & 0 & a_y^{(i)} & 0 & 0 & a_z^{(i)} & 0 & 0 & 1 \end{bmatrix}. \quad (3)$$

Equation (2) can be solved in LS sense, if at least four linearly independent measurements are made, and the observation matrix H is constructed by stacking $H^{(i)}$'s one upon the other and by expressing the observations as a stacked vector z. The LS solution for θ is

$$\hat{\theta} = (H^T H)^{-1} H^T z \,. \quad (4)$$

The sensitivity matrix $\hat{K}$ and offset $\hat{O}$ can be separated from $\hat{\theta}$, and calibrated values $\hat{a}$ can now be estimated in LS sense from equation (1)

$$\hat{a} = \left(\hat{K}^T \hat{K}\right)^{-1} \hat{K}^T \left(z - \hat{O}\right). \quad (5)$$

This method allows an easy procedure to calibrate a TA when no special calibration devices are present. Complete calibration can be done in six measurements by making use of gravitational acceleration, i.e. one measurement for each sensing directions (+x,-x,+y,-y,+z,-z). If unit of acceleration is expressed as g (9.81 m/s^2), the matrix H consists of zeros, ones and minus ones.

Results

The method presented in this paper can improve the results of acceleration measurements, especially in the case when the sensing axes of a TA are not perpendicular to each other and/or when the orientations of input axes differ from the orientations of sensing axes.

Discussion

By applying the method presented in this paper, the sensitivity matrix and offsets of a TA can be determined simultaneously. Many commercially available TA's have been constructed from uniaxial or biaxial acceleration sensors. Misalignment of those sensors inside the TA capsule can cause transverse sensitivity with relative magnitude of several percents and, thus, the transverse sensitivities should be included in the model.

An advanced calibration method can enable the use of cost-effective TA's by compensating the imprecision of manufacturing process, i.e. the skewness of sensing axes. It should be however be noted that this method does not take into account the nonlinearities in TA sensitivities. The calibration can be accomplished without any special calibration devices by taking advantage of gravitational acceleration. However, better calibration precision could be achieved if such a calibration device is utilized which covers the whole dynamics of a TA.

References

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