"HENRI COANDA"
AIR FORCE ACADEMY
ROMANIA

"GENERAL M.R. STEFANIK"
ARMED FORCES ACADEMY
SLOVAK REPUBLIC

INTERNATIONAL CONFERENCE of SCIENTIFIC PAPER
AFASES 2014
Brasov, 22-24 May 2014

AN APPROACH FOR STATIC CALIBRATION OF ACCELEROMETER MMA8451Q

Marin MARINOV*, Zhivo PETROV*

*Aviation Faculty, NVU "V. Levski", Dolna Mitropolia, Bulgaria

Abstract: *In this paper an approach for low-cost MEMS accelerometer static calibration is proposed. The approach is applied to estimate the MEMS accelerometer mathematical model, including scale factors and bias. The method does not require a three-axis rotary platform to perform perfect alignment to the Earth gravity. The measurement is easy to perform, the calculation is simple, and the proposed approach provides a different choice for accelerometer calibration. Experimental data is analyzed to prove that the bias and scale factors are eliminated.*

Keywords: *accelerometer, bias, calibration, scale factors.*

1. INTRODUCTION

By analyzing MEMS accelerometer measurement principle and environment, it could be proved that the main errors include three gain factors and three biases [4, 5].

The manufacturers of the MEMS accelerometers usually apply a calibration. The original factory accelerometer calibration becomes less accurate once the accelerometer is soldered, by the end users, onto its circuit board as a result of thermal stresses during the soldering process.

Different approaches for recalibration are used. Some of them require measurements in only one or two positions of the accelerometer [3] but only bias can be estimated. Other approaches estimate more than 10 parameters [1, 6]. The approaches computing six calibration parameters are most widely used [1, 3]. Most of these approaches require precise orientation of the accelerometer.

In this paper an approach for low-cost MEMS accelerometer static calibration without precise orientation is proposed.

2. ACCELEROMETER CALIBRATION METHOD

According to the characteristics of the measurement error, the MEMS accelerometer error model is defined as:

$$\begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix} = \begin{bmatrix} S_x & -k_4 S_y & -k_5 S_z \\ k_1 S_x & S_y & -k_6 S_z \\ -k_2 S_x & k_3 S_y & S_z \end{bmatrix} \begin{bmatrix} g_x \\ g_y \\ g_z \end{bmatrix} + \begin{bmatrix} b_x \\ b_y \\ b_z \end{bmatrix} + \begin{bmatrix} n_x \\ n_y \\ n_z \end{bmatrix}, \quad (1)$$

where: b_x, b_y, b_z are accelerometer bias; S_x, S_y, S_z are scale factors for the accelerometer; n_x, n_y, n_z are random measurement noises; $k_1, k_2, k_3, k_4, k_5, k_6$ are installation error coefficients.

For an application demanding lower accuracy it could be assumed that the scale factors are equal to one and the equation (1) becomes:

$$\begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix} = \begin{bmatrix} S_x & 0 & 0 \\ 0 & S_y & 0 \\ 0 & 0 & S_z \end{bmatrix} \begin{bmatrix} g_x \\ g_y \\ g_z \end{bmatrix} + \begin{bmatrix} b_x \\ b_y \\ b_z \end{bmatrix} + \begin{bmatrix} n_x \\ n_y \\ n_z \end{bmatrix}. \quad (2)$$

To determine the accelerometer bias and scale factors six different static positions are used. In each position one of the axes is directed along or opposite Earth gravity.

The instantaneous outputs of the accelerometer in one of the positions a_{px}, a_{py}, a_{pz} are given by:

$$\begin{aligned} a_{px} &= S_x g_{px} + b_x + n_{1x} \\ a_{py} &= S_y g_{py} + b_y + n_y \,, \\ a_{pz} &= S_z g_{pz} + b_z + n_z \end{aligned} \quad (3)$$

where $p = 1 \div 6$ is the position number.

Multiple measurements in each position are done and output data is averaged to decrease the impact of noise. The averaged accelerations are described by:

$$\begin{aligned} A_{px} &= S_x g_{px} + b_x \\ A_{py} &= S_y g_{py} + b_y \Rightarrow \\ A_{pz} &= S_z g_{pz} + b_z \end{aligned}$$

$$\begin{aligned} & \frac{1}{S_x}\left(A_{px} - b_x\right) = g_{px} \\ \Rightarrow & \frac{1}{S_y}\left(A_{py} - b_y\right) = g_{py} \,. \\ & \frac{1}{S_z}\left(A_{pz} - b_z\right) = g_{pz} \end{aligned} \quad (4)$$

Both sides of each equation in (4) are raised to the second power and then the equations are summed to obtain:

$$\begin{aligned} & A_p^2 + 2A_{px}C_x - 2A_{py}C_y - 2A_{pz}C_z + b^2 + \\ & + A_{px}\Delta_x + A_{py}\Delta_y + A_{pz}\Delta_z + \\ & + \Delta_x a_x^2 + \Delta_y a_y^2 + \Delta_z a_z^2 = 1 \end{aligned} \,, (5)$$

where: $A_p^2 = A_{px}^2 + A_{py}^2 + A_{pz}^2$;

$b^2 = b_x^2 + b_y^2 + b_z^2$; $C_x = \left(1 + \Delta_x\right)b_x$;

$Cy = \left(1 + \Delta_y\right)b_y$; $C_z = \left(1 + \Delta_z\right)b_z$;

$\Delta_x = \frac{1}{S_x^2} - 1$; $\Delta_y = \frac{1}{S_y^2} - 1$; $\Delta_z = \frac{1}{S_z^2} - 1$.

In this way six equations are formed. Each equation is combined with other five and the result is fifteen couples of equations. Equations in every couple are subtracted and system of linear equations is created. The matrix form of the system is:

$$\mathbf{H\lambda} = \mathbf{A}, \quad (6)$$

where:

$$\mathbf{H_j} = [A_{px} - A_{qx}, A_{py} - A_{qy}, A_{pz} - A_{qz}, \\ , A_{qx}^2 - A_{px}^2, A_{qy}^2 - A_{py}^2, A_{qz}^2 - A_{pz}^2];$$

$\boldsymbol{\lambda} = \left[C_x, C_y, C_z, \Delta_x, \Delta_y, \Delta_z\right]^T$; $p \neq q$;

$p = 1 \div 6$; $A_i = \left(A_p^2 - A_q^2\right)0.5$; $i = 1 \div 15$;

$q = 1 \div 6$; $j = 1 \div 15$.

An iterative algorithm is used to find the least squares solution of system (6):

$$\hat{\boldsymbol{\lambda}} = \left[\hat{C}_x, \hat{C}_y, \hat{C}_z, \hat{\Delta}_x, \hat{\Delta}_y, \hat{\Delta}_z,\right]. \quad (7)$$

Using (7) the bias and scale factors are obtained:

$$\hat{b}_x = \frac{\hat{C}_x}{1 + \hat{\Delta}_x}, \hat{b}_y = \frac{\hat{C}_y}{1 + \hat{\Delta}_y}, \hat{b}_z = \frac{\hat{C}_z}{1 + \hat{\Delta}_z}. \quad (8)$$

$$\hat{S}_x = \sqrt{\frac{1}{1 + \hat{\Delta}_x}}, \hat{S}_y = \sqrt{\frac{1}{1 + \hat{\Delta}_y}}, \hat{S}_z = \sqrt{\frac{1}{1 + \hat{\Delta}_z}}. \quad (9)$$

The proposed method allows obtaining the bias and scale factors without requiring a perfect orientation of accelerometers along the Earth gravity.

3. TEST RESULTS

The data from MMA8451Q is read using a device described in [2]. The accelerometer is set up to: 14 bits of resolution; ± 2 g full scale; 100 Hz output data rate. The accelerometer was placed in six different positions and in each position the data was collected for 50 seconds. Collected accelerations are shown in figures from 1 to 6.

The proposed method is applied to estimate bias and scale factors of measurement. The obtained values of six parameters are:

$\hat{b}_x = -16.1\,mg$; $\hat{b}_y = 4.7\,mg$; $\hat{b}_z = 4.6\,mg$;

$\hat{S}_x = 0.9961$; $\hat{S}_y = 1.0023$; $\hat{S}_z = 1.0019$

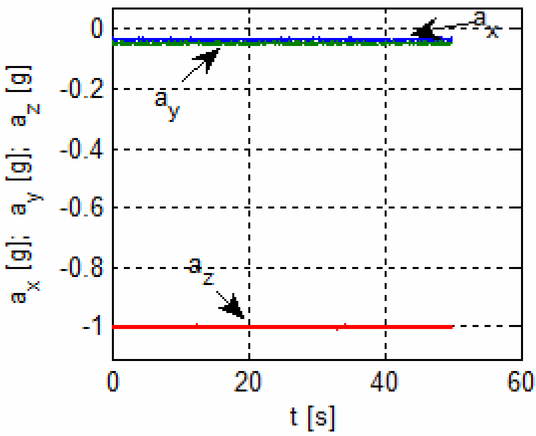

Figure 1. Accelerometer output data in position 1.

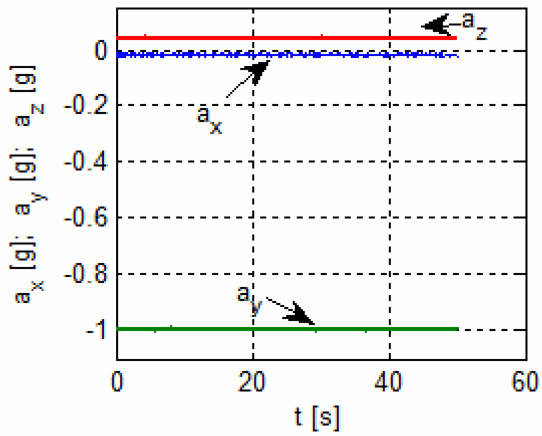

Figure 4. Accelerometer output data in position 4.

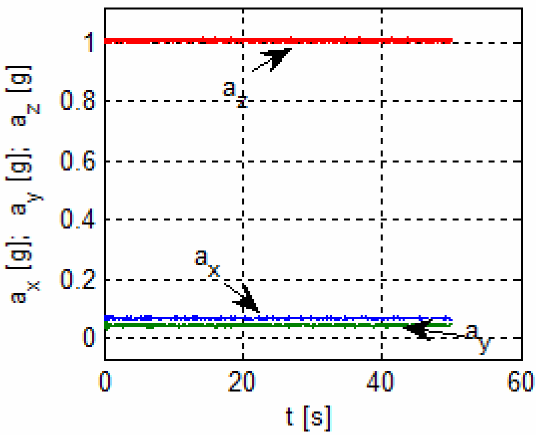

Figure 2. Accelerometer output data in position 2.

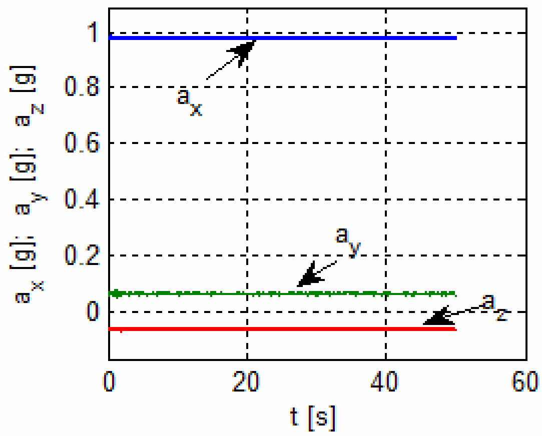

Figure 5. Accelerometer output data in position 5.

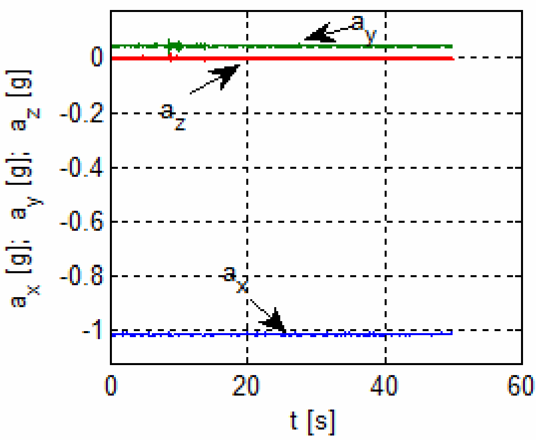

Figure 3. Accelerometer output data in position 3.

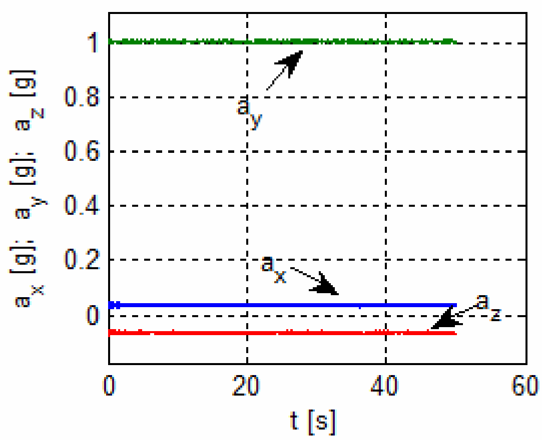

Figure 6. Accelerometer output data in position 6.

To verify proposed approach some data is collected when accelerometer is arbitrary orientated. Using measurements from each axis the relative Earth acceleration is calculated (“a” on fig.7). The relative Earth acceleration is also calculated after calibration of measurements (“a_{cal}” on fig.7).

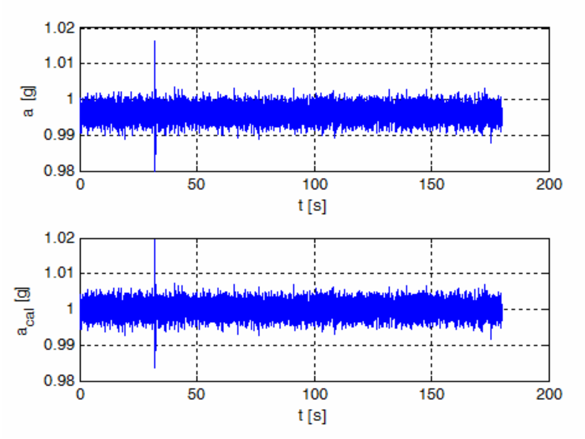

Figure 7. Accelerometer output calibration.

Figure 7 shows that calculated relative Earth acceleration is closer to 1g, when calibration is used. This proves that the proposed approach could be used to eliminate bias from measurement.

4. CONCLUSIONS

This paper proposes the Accelerometer static calibration method using six parameters. The method is accurate, easy to implement and doesn’t require additional equipment.

The bias and scale factors of MEMS accelerometer MMA8451Q are estimated. The results show that the x-axis bias is the biggest whereas y-axis and z- axis bias are almost the same.

The obtained experimental results prove the validity of the method.

REFERENCES

1. Pedley M. *High Precision Calibration of aThree-Axis Accelerometer*, AN4399, Rev. 1, Freescale Semiconductor, (01/2013)
2. *Petrov Zh., Marinov M., Dimitrov D.,3-axis digital accelerometer data transfer controller, Scientific conference , Aviation Faculty, D. Mitropolia, Bulgaria (2013).*
3. Tuck K., *Offset Calibration of the MMA8451, 2, 3Q*, AN4069, Rev. 1, Freescale Semiconductor, (03/2012)
4. Umeda A., Onoe M., Sakata K., Fukushia T., Kanari K., Iioka H., Kobayashi T., *Calibration of three-axis accelerometers using a three-dimensional vibration generator and three laser interferometers*, Sensors and Actuators A: Physical, Volume 114, Issue 1, (2004)
5. Won P., Golnaraghi F., *A trail Accelerometer Calibration Method Using a Mathematical Model*, IEEE Transactions on Instrumentation and Measurement, Vol. 59, NO.8, (2010)
6. Zhang L., Li W., Liu H., *Accelerometer Static Calibration based on the PSO algorithm*, 2nd International Conference on Electronic & Mechanical Engineering and Information Technology (2012)