Analysis of the Inertial MEMS Sensor Parameters for Navigation Applications

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Abstract – **The paper discuss the analysis of the MEMS sensor parameters, which are important in the different control and navigation systems, where the sensor bias offset could significantly degrade the system performance. The axes bias offset and standard deviation are analyzed for ADIS16405 inertial sensor. Also distance and angular error is calculated according to the measured values.**

Keywords – **MEMS sensor, offset, standard deviation**

I. Introduction

Interest in the development of microelectro-mechanical systems (MEMS) has mushroomed during the past decade [1,2]. In the most general sense, MEMS attempts to exploit and extend the fabrication techniques developed for the integrated circuit (IC) industry to add mechanical elements to the electrical circuits to make integrated microsystems for perception and control of the physical world. MEMS devices are already being used in a number of commercial applications [3,4] and the new applications are emerging as the existing technology is applied to the miniaturization and integration of conventional devices. MEMS sensors allow the implementation of a lot of different functions, as free-fall detection, car navigation, map browsing, gaming, menu scrolling, motion control, vibration monitoring, antitheft and many others.

The current paper discusses the sensor offset and standard deviation of the output signal due to their significant role for the inertial system accuracy and different control and measurement devices and systems, which use integration with time to calculate the speed and the movement according to the measured acceleration [5,6]. The integrative nature of this approach has both positive and negative aspects. On the positive side, integration will smoothed out the high-frequency errors (e.g., sensor noise). On the negative side, integration of low frequency errors due to biases, scale factor error, or misalignment will cause increasing error between the true and estimated vehicle state [1]. Bias offset drift exhibited in the acceleration signal is accumulative and the accuracy of the distance measurement could degrade with time due to the integration [7].

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II. Inertial MEMS Sensors Description

The analyzed inertial MEMS sensors are recognized as ADIS16405 - Triaxial Inertial Sensor with Magnetometer, produced by Analog Devices. The ADIS16400/ADIS16405 combine industry-leading *i*MEMS® technology with signal conditioning that optimizes dynamic performance. ADIS16405 sensor is a member of ADIS16400 inertial sensor family, but each sensor has its own dynamic compensation for correction formulas that provide accurate sensor measurements over a temperature range of −40°C to +85°C.

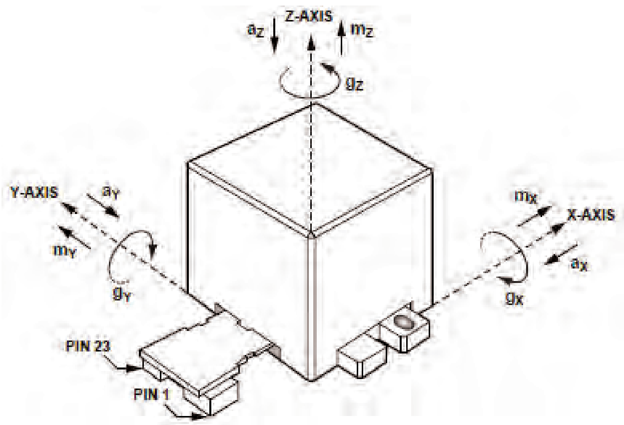


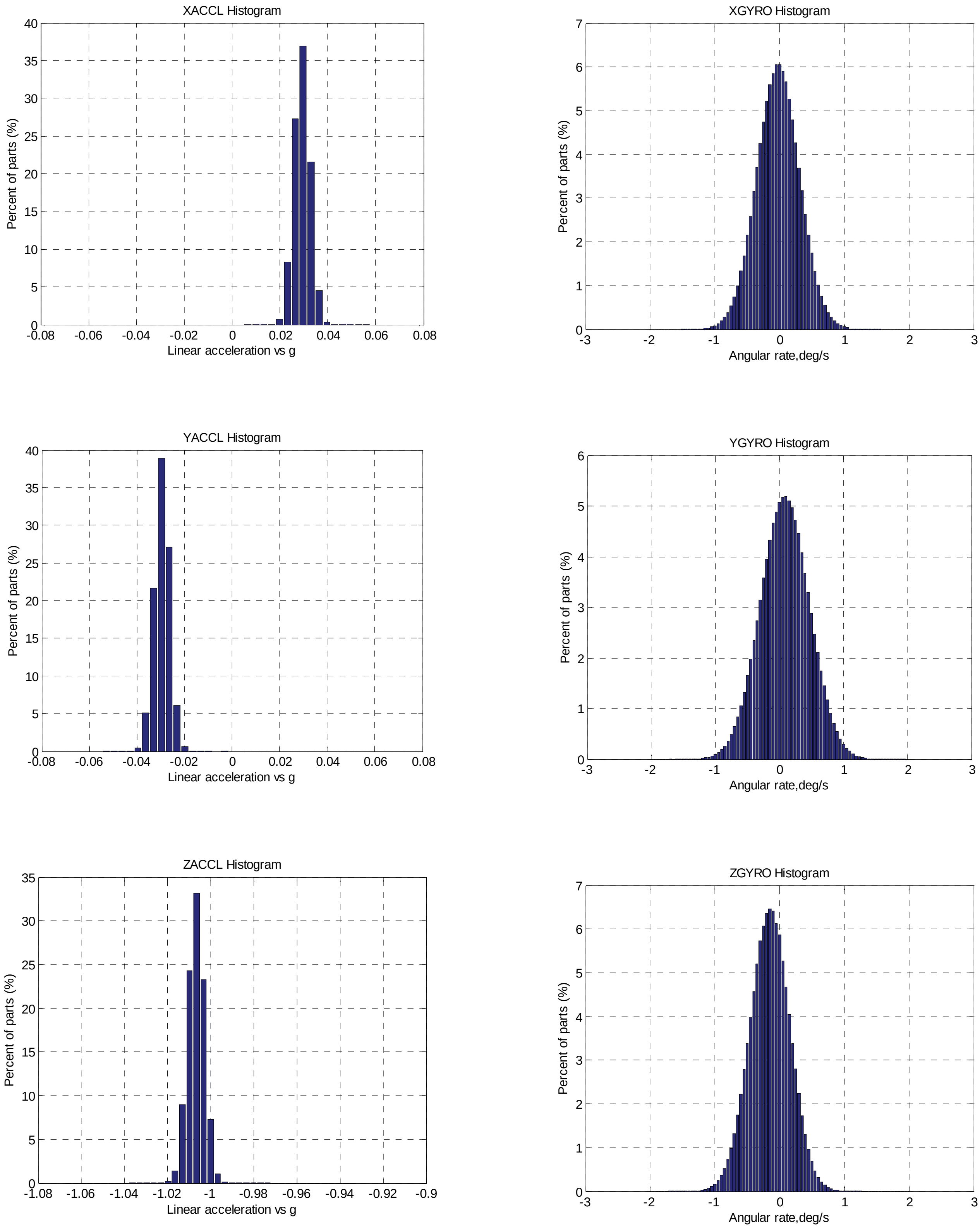
Figure.1. Inertial sensor ADIS16405

The ADIS16405 parameters are defined as follows [8]:

- Triaxial, digital gyroscope with digital range scaling - ±75°/sec, ±150°/sec, ±300°/sec settings
- Triaxial, digital accelerometer, ±18 *g*
- Triaxial, digital magnetometer, ±2.5 gauss
- Autonomous operation and data collection
- Calibrated temperature range: −40°C to +85°C
- Software configuration of the sampling rate, digital filtering and offset
- Autocalibration option available

III. Analysis of the Inertial Sensor Parameters

The analysis of the inertial sensor parameters is accomplished by a measurement of the output signal (linear and angular rate registers for the ADIS1640 sensor) without motion. The sampling rate of the ADIS sensor is set to 819.2Hz and 901056 samples are recorded.



(a) (b)

(a) – linear accelerometers
(b) – angular rate sensors

Figure 4. ADIS16405 histograms

The measurement time duration is calculated as 901056 / 819.2 = 1100s. The measurements are accomplished by ADISUSBZ evaluation system and iSENSOR Evaluation Tool. The obtain data for ADIS16405 sensor are processed by MATLAB routine and the results are shown at Figure 4a and Figure 4b for linear accelerometers and gyroscopes respectively. The calculated mean value and standard deviation are shown at Table 1 and Table 2 for gyroscopes and accelerometers respectively.

Table 1. Analyzed parameters of the gyroscope sensor

Parameter	Mean value, °/sec	Standard deviation, °/sec
gyroX	-0.0236	0.3314
gyroY	+0.0838	0.3833
gyroZ	-0.1515	0.3096

Table 2. Analyzed parameters of the linear accelerometer sensor

Parameter	Mean value, g	Standard deviation, g
acclX	+0.0295	0.0035
acclY	-0.0297	0.0034
acclZ	-1.0059	0.0040

The calculated results show that the ADIS16405 inertial sensor is distinguished with a maximum gyroscope bias offset of 0,15°/s for the Z axis and standard deviation 0.3÷0,4°/s, while the corresponding values for the accelerometers are equal respectively to 0,03g and 3÷4mg. The calculated bias offset of the axes degrades the accuracy of the navigation systems, because the error is accumulated. Therefore it has to be compensated.

The shown figures (Fig.5 – Fig.7) represent the numerical integration of the linear accelerations using the trapezoidal rule according to the X, Y, Z axis after bias compensation. The calculated distance error for each axis does not exceed 3 meters. This error could not significantly degrade the inertial navigation system performance in the integrated GPS/INS navigation systems, but it is unacceptable value for the precise systems such as robotic ones. The calculated distance error with offset compensation is much smaller than the calculated one without offset compensation, which is equal to $S=a_{x,0}.t+1/2.a_{x,0}.t^2=1.6236.10^5$m!

The estimated mean values and standard deviation of the velocity of each axis are given at Table 3.

Table 3. Calculated parameters of the accelerometer sensor after one stage integration

Parameter	Mean value, m/s	Standard deviation, m/s
Vx	$2.154.10^{-4}$	$5.232.10^{-5}$
Vy	$6.196.10^{-5}$	$5.493.10^{-5}$
Vz	$2.170.10^{-4}$	$5.152.10^{-5}$

Theoretically, the integration of the zero offset acceleration data could not produce an offset bias of the velocity data, according to the following expressions:

$$a(t)=\sum_{i=1}^{N} A_i \cos\left(\omega_i t+\varphi_i\right) \qquad (1)$$

$$v(t)=\int a(t)\,dt=\sum_{i=1}^{N} A_i \int \cos\left(\omega_i t+\varphi_i\right)dt= \qquad (2)$$

$$=\sum_{i=1}^{N} \frac{A_i}{\omega_i}\cos\left(\omega_i t+\varphi_i-\pi/2\right)$$

But the numerical integration always produces an error E_n, which value may be calculated according to equation [9]:

$$\frac{(\Delta t)^3}{12}.\min\left(\left|a''(x)\right|\right)\le\left|E_n\right|\le\frac{(\Delta t)^3}{12}.\max\left(\left|a''(x)\right|\right), \qquad (3)$$

where $t_{k-1}\le x\le t_k$.

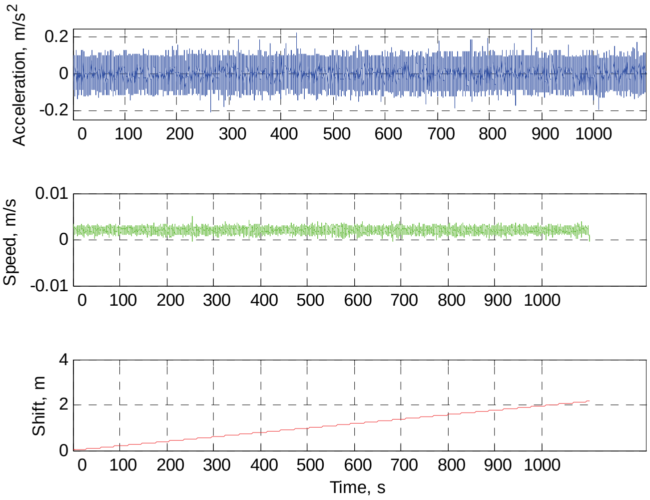


Figure 5. Numerical integration of X acceleration

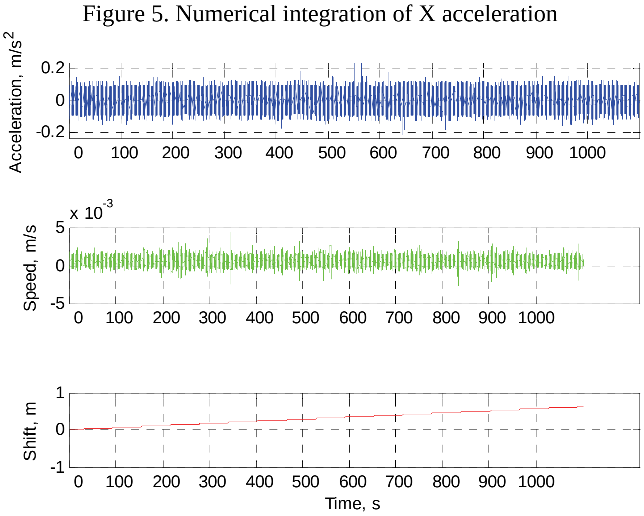


Figure 6. Numerical integration of Y acceleration

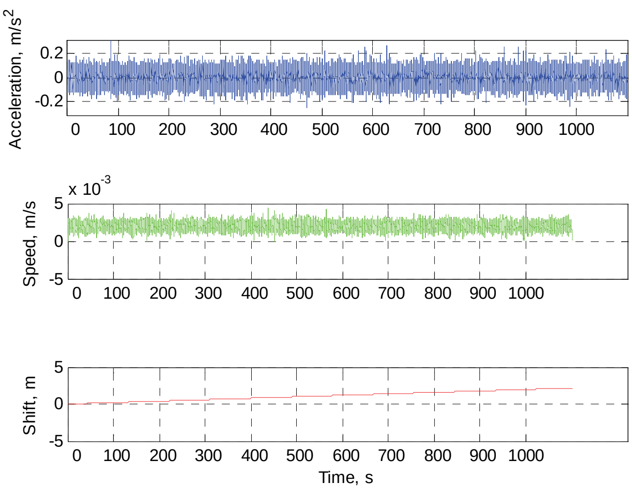


Figure 7. Numerical integration of Z acceleration

It is clearly visible, that the distance error is generated due to the speed offset and the distance error is proportional to the integration time.

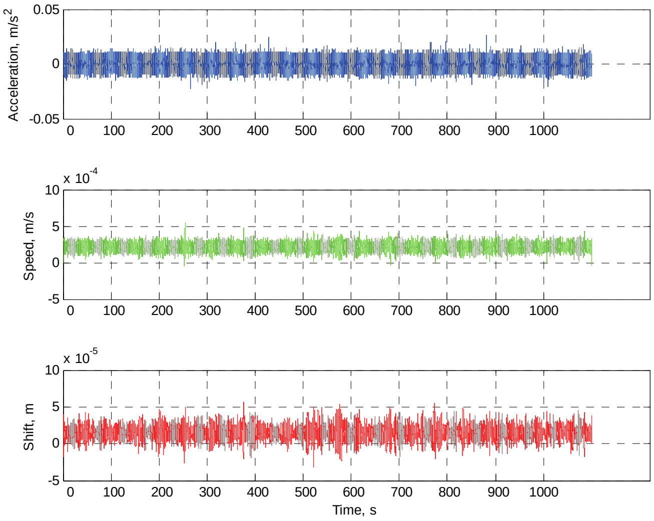


Figure 8. Distance error after velocity offset compensation (X axis)

If the velocity bias offset is also compensated, the distance error is reduced to 5.10^{-5}m, while the mean value of the distance offset is equal to $1.473.10^{-5}$m.

The proposed example and results show that the bias offset compensation is a critical part of the double integration of the acceleration data. The high pass filter could not be used to remove the offset because it will reject the steady acceleration or velocity data. Therefore the mean value of the acceleration and velocity data have to be measured for each sensor and their values have to be compensated for the sensitive applications such as mechanics or robot part moving calculation.

IV. Conclusion

In this paper we discuss the parameters of the ADIS16405 inertial sensor and distance and angular errors are calculated to analyze the sensor performance to be built in the different type of navigation and control systems. It is shown that the analyzed sensor is distinguished with a small bias offset which have to be compensated in the precise systems like robotics, vibration measurement systems, long range inertial navigation systems, etc., but also could be remain uncompensated in the short range GPS/INS navigation systems where the system could lost the GPS signal for several seconds.

The estimated mean and standard deviation value of the output signal also could be used as initial parameters for Kalman filters in the different navigation or control systems.

Acknowledgement

This paper was prepared and supported by the National Fund under contract number No.DTK02/2-2009.

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