Analysis of the noise parameters of quad structure of MEMS linear accelerometers

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Abstract – **The current paper discusses the analysis of the noise parameters of quad sensor structure of linear accelerometers in comparison to the same parameters of the single sensors. It is shown that the digital signal processing allows decreasing the main noise parameters (random walk, quantization noise and bias instability) of the quad sensor structure in comparison to the same parameters of the single sensors. This allows increasing the accuracy of the inertial navigation systems which are integrated to obtain the vehicle's position, velocity and attitude.**

Keywords – **Quad sensor structure, MEMS, Allan variance**

INTRODUCTION

Velocity random walk is the additive white noise component on the MEMS sensor output. The sensor noises, bias variations, drifts and scale factor instabilities are the main error sources which cause the accuracy degradation of the modern navigation systems especially based on low cost MEMS inertial sensors. The power spectrum density (PSD) is one of the commonly used for the investigation of sensors' stochastic process. PSD is a frequency-domain approach for modeling noise. The Allan variance (AV) method also may be used to determine the characteristics of the underlying random processes that give rise to the data noise. The Allan variance is a method of representing the root mean square (RMS) random-drift errors as a function of averaging times. Because of the close analogies to inertial sensors, this method has been adapted to random-drift characterization of a variety of devices. The AV method is straightforward and simple for calculation in comparison with other stochastic modeling methods, such as the autocorrelation method, which needs very long term static data. In this paper, this technique is used to characterize various types of noise terms in different inertial-sensor data.

The Allan variance is a time-domain-analysis technique originally developed in the mid-1960s to study the frequency stability of precision oscillators [1]. Due of the close analogies to inertial sensors, this method has been adapted to random-drift characterization of a variety of devices [2]–[5]. The most attractive feature of AV is its ability to sort out various noise components by the slopes on the root AV (Allan deviation) plot provided the different noise mechanisms are reasonably separated in the frequency and time domain [6]-[7].

The current paper discusses the noise parameters of the quad sensor structure, build by four identical digital output inertial sensors with synchronization inputs and microcontroller to compare the error values according to the single sensor.

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SYSTEM DESCRIPTION

The inertial measurement systems consists of four identical MEMS inertial sensors MPU-6000 [8], which are placed in such way that each two sensors have one common axis and two opposite axes (Figure 1) [9]. One of the most important special feature of the selected MEMS sensors is the FSYNC (Frame synchronization) input, which may be used to start the measurement process. The system synchronization is carried out by the multiple output clock generator. It is based on the Ultra-low Jitter LVCMOS Fanout Buffer/Level Translator LMK00105 [10]. The low noise VCMOS fanout buffer may distribute 5 ultra low jitter clocks from a differential, single ended or crystal input. The four of these 5 clocks are used in the quad sensor structure and the fifth one is connected to the microcontroller clock input. The four sensors are divided to two sections which are connected to two independent I^2C interface of the microcontroller. This allows reading the inertial data from two sensors simultaneously and reducing the measurement time. The inertial data are transferred to PC via RS232 interface and may be analyzed later.

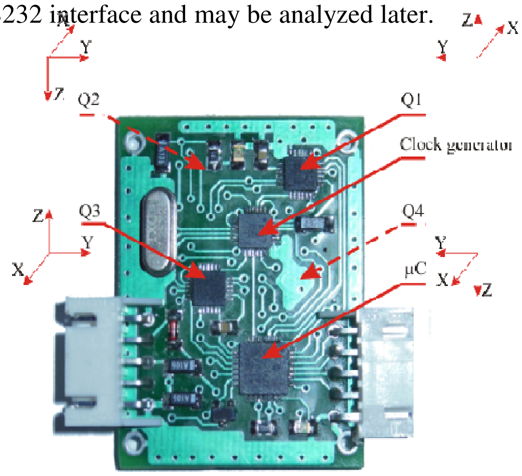

Figure 1. Measurement system design

EXPERIMENTAL RESULTS

The inertial data are sampled in the synchronous mode, which is based on the simultaneous sampling of the inertial data of all four sensors. This mode is realized by a simultaneous activation of the FSYNC inputs of the sensors due to the circumstance that all FSYNC inputs are connected to one port of the microcontroller. The experimental data are obtained and processed in the MATLAB environment. The sensor update time is set to 1 kHz (accelerometers and gyroscopes) while the sampling frequency is set to 100Hz due to the limited time to transfer the inertial data to PC via RS232 interface. The system reads the XYZ linear and angular accelerations (12 bytes) and temperature (2 bytes) from each sensor and sends the data to PC. The data from the sensor couples (sensor #1 and #3) and (sensor #2 and #4) are read simultaneously because the couples are connected to the different hardware implemented I^2C interfaces. The total amount of transferred data is equal to 57 bytes per one time sample (4 sensors multiplied by 14 bytes per sensor plus 1 SYNC byte). The measurement time is set to 2 hours.

The resulting accelerations of the quad sensor structure are calculated according to the equations:

$$A_x = \frac{a_1 + a_2 - a_3 - a_4}{4} + g_x + a_x$$
$$A_y = \frac{a_1 - a_2 - a_3 + a_4}{4} + g_y + a_y \quad , \qquad (1)$$
$$A_z = \frac{a_1 - a_2 + a_3 - a_4}{4} + g_z + a_z$$

where a_x, a_y, a_z – acceleration of the structure
g_x, g_y, g_z – earth acceleration
a_i – bias of the i-th sensor

TABLE 1. Allan variance for X axis for single sensors and quad sensor structure

Error type	X acceleration		Curve slope	Units
	Sensor #1 Sensor #2 Sensor #3 Sensor #4	Quad sensor structure		
Bias instability $B = \frac{\sigma(f_0)}{0.664}$	$1{,}18.10^{-3}$ $1{,}09.10^{-3}$ $1{,}58.10^{-3}$ $1{,}43.10^{-3}$	$2{,}1.10^{-4}$	0	m/s^2
Acceleration random walk $K = \sigma(3)$	1.10^{-4} - $1{,}2.10^{-4}$ -	-	+1/2	$\frac{m/s^2}{\sqrt{s}}$
Velocity random walk $N = \sigma(1)$	$7{,}0.10^{-3}$ $7{,}0.10^{-3}$ $7{,}5.10^{-3}$ $7{,}1.10^{-3}$	$3{,}8.10^{-3}$	-1/2	$\frac{m/s}{\sqrt{s}}$

TABLE 2. Allan variance for Y axis for single sensors and quad sensor structure

Error type	Y acceleration		Curve slope	Units
	Sensor #1 Sensor #2 Sensor #3 Sensor #4	Quad sensor structure		
Bias instability $B = \frac{\sigma(f_0)}{0.664}$	$9{,}03.10^{-4}$ $6{,}17.10^{-4}$ $9{,}03.10^{-4}$ $1{,}05.10^{-3}$	$2{,}93.10^{-4}$	0	m/s^2
Acceleration random walk $K = \sigma(3)$	6.10^{-5} - 8.10^{-5} -	-	+1/2	$\frac{m/s^2}{\sqrt{s}}$
Velocity random walk $N = \sigma(1)$	$7{,}5.10^{-3}$ $7{,}0.10^{-3}$ $6{,}9.10^{-3}$ $7{,}0.10^{-3}$	$3{,}8.10^{-3}$	-1/2	$\frac{m/s}{\sqrt{s}}$

TABLE 3. Allan variance for Z axis for single sensors and quad sensor structure

Error type	Z acceleration		Curve slope	Units
	Sensor #1 Sensor #2 Sensor #3 Sensor #4	Quad sensor structure		
Bias instability $B = \frac{\sigma(f_0)}{0.664}$	$3{,}01.10^{-3}$ $2{,}25.10^{-3}$ $3{,}76.10^{-3}$ $3.16.10^{-3}$	$1{,}28.10^{-3}$	0	m/s^2
Acceleration random walk $K = \sigma(3)$	$8{,}5.10^{-4}$ - $9{,}0.10^{-4}$ $6{,}0.10^{-4}$	$2{,}2.10^{-4}$	+1/2	$\frac{m/s^2}{\sqrt{s}}$
Velocity random walk $N = \sigma(1)$	$9{,}5.10^{-3}$ $9{,}5.10^{-3}$ $1{,}0.10^{-2}$ $9{,}5.10^{-3}$	$5{,}1.10^{-3}$	-1/2	$\frac{m/s}{\sqrt{s}}$

The AV parameters are calculated for each axis acceleration of the single sensor and the resulting acceleration for the quad sensor structure according to the equation (1) and the results are shown at Table 1, Table 2 and Table 3 for the X, Y and Z linear acceleration respectively. It is clearly visible that all values of the quad sensor structure are lower than the corresponding noise parameter of the single sensor. The bias value theoretically may be reduced to zero according to the equation (1) because the bias values are summed with the opposite sign of the different values.

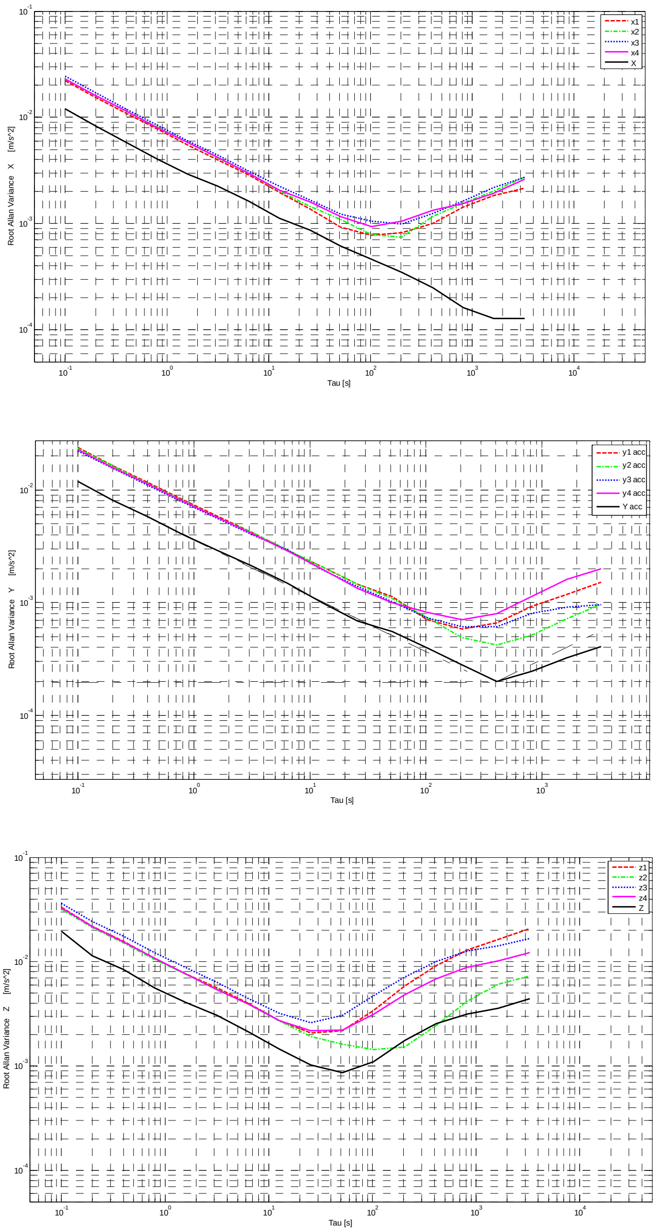

Figure 2. Allan deviation plot for all axes

The Figure 2 represents the AV plots for all axes of the single sensors and the quad sensor structure. The graphics shows that the noise components are lower for all values of the time cluster.

Conclusion

The Allan Variance is a simple and efficient method for identifying and characterizing different stochastic processes and their coefficients. It is shown by this method that the quad sensor structure is distinguished with better noise parameters (acceleration random walk, velocity random walk and bias instability) in comparison with the single MEMS accelerometer. If the structure is manufactured as a single chip it may be used in many different applications like free-fall detection, precise tracking, kinetic measurements, tilt measurements, vehicle vibration monitoring, etc.

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