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POWER SUPPLY SENSITIVITY OF MEMS GYROSCOPES

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Abstract: Little is known about a sensitivity of MEMS gyroscopes to a power supply fluctuation and how to measure these effects. This information can be helpful to improve a performance of sensors, which is crucial especially for an inertial navigation. The paper is focused on the zero rate drift and the behavior of a build-in temperature sensor. These properties are analyzed for MEMS gyroscopes of various brands with different output configurations. The method of our measurement and underlying problems are described. Finally, results of the experiment are discussed and suitable models are suggested.

Keywords: MEMS, gyroscope, zero rate supply drift, temperature sensor supply drift, power supply voltage, self-heating

1. INTRODUCTION

Gyroscopes based on the MEMS technology are being widely used especially in mobile applications. They are cheap, light-weight, small and they have low power consumption. On the other hand, they suffer by more errors than classical devices. For this reason, it is hard to use them for a strapdown inertial navigation. One of the biggest problems in strapdown systems is caused by an inaccurate estimate of sensor bias. This difference is integrated and it yields in an error of attitude that grows indefinitely in time.

A model of gyroscope errors is usually composed of two parts. The first part contains errors and processes with a random behaviour. They are unpredictable and can not be corrected by a calibration. Angle random walk, bias instability and rate random walk are usually considered here.

The second part comprises errors that can be described and removed like as a constant bias, scale factor error or nonlinearity. The most important component for MEMS gyroscopes is an influence of temperature, which affects almost all parameters, thus the MEMS gyroscopes are usually equipped by an internal temperature sensor. However, MEMS gyroscopes are also sensitive to a power supply voltage. The power supply voltage has an influence especially to the zero rate voltage but the information from the temperature sensor is affected too. It can cause other error trough inadequate temperature compensation. Especially in mobile applications, it is hard to keep power supply steady thus a proper model of power supply sensitivity should be used to suppress an influence of these fluctuations and improve a performance of system in this situation.

Unfortunately there is a lack of information about the power supply sensitivity of MEMS gyroscopes provided by manufacturers. Some sensors have specified only the maximum supply drift of the zero rate, however the precise value is necessary to achieve the best performance. Moreover, there is no information about supply drift for an internal temperature sensor. So we need a methodology how to measure and correct this behaviour.

2. POWER SUPPLY SENSITIVITY

Basically, the power supply sensitivity arises from the imperfections of analog front-end, which is used to drive a sensing element and pick-off its displacement due to a Coriolis force. Unfortunately, an analytical description is impossible without knowledge of an internal structure. A good design is essential to achieve a high power supply rejection.

The balanced structures are often used [1, 2, 3], because they effectively suppress power supply disturbances, but not all circuits are done in this way. A typical example from an end-user view is an output of sensor. Three basic configurations are usually used in MEMS gyroscopes and these configurations are single-ended, reference-ended and ratiometric output. The question is whether the output configuration has some influence on the power supply sensitivity.

LISY300AL is an example of sensor with the single ended output in our experiment. This gyroscope has an internal reference voltage which defines a zero rate level. However, the reference voltage is not brought out, thus a signal has to be sensed between ground and output pins. Stability of the internal reference can significantly affect the overall power supply sensitivity in this case.

The reference-ended output is just a modification of single-ended one. The internal reference is brought out and can be used for a conditioning of an A/D converter. Gyroscopes ADXRS300 and MLX90609N2 are examples of this case.

The ratiometric output is depicted in figure 1. This configuration is used by ADXRS610 and ADXRS613. The signal conditioning is referenced against the external input V_{RATIO}. Thus, a zero rate voltage is determined by a voltage divider to one half of V_{RATIO}. The internal temperature sensor is also is related to the input V_{RATIO} here.

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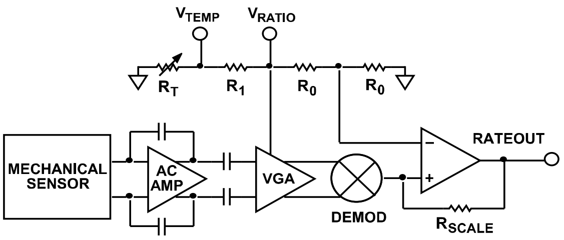

Fig. 1. Ratiometric configuration of ADXRS610 [4]

3. MEASUREMENT CHAIN

The data acquisition stage is the most important to obtain reliable results. Our first measurement chain was assembled from a linear DC power supply, a DC coupled power amplifier, a NI-USB6218 acquisition card and a temperature chamber as it is shown in figure 2a.

An analog output of the NI-USB6218 along with the DC power amplifier is used as a power supply for a device under test (DUT). This combination is chosen to achieve the variable power supply with a fine resolution, a low noise and a small temperature drift. A custom amplifier was built to accomplish these specifications.

The temperature chamber is indispensable, because we have to distinguish between the influence of an ambient temperature, a self-heating of the sensor and the power supply sensitivity. Thus, the temperature was kept at a reference level 25 ± 0.05 °C during the measurement. Also, it is advisable to suppress vibrations, because they can cause an increased level of sensor noise. All tested devices are single axis yaw rate gyroscopes and they were rigidly mounted inside the temperature chamber with their sensitive axis perpendicular to the ground. We are not interested in an absolute value of the zero rate level, therefore earth rotation is not considered.

Responses of the gyroscope and its internal temperature sensor to power supply changes were captured using analog inputs of NI-USB6218. There were no additional antialiasing filters because the breakout boards of our gyroscopes are equipped by low-pass filters. Thus, the data were recorded with high sampling rate to satisfy the sampling theorem and then processed by our software.

Unfortunately, the acquisition card has no simultaneous sampling and it suffers by crosstalk between channels in this configuration. The crosstalk is caused by the capacitance of a sample and hold circuit in a combination with a high impedance of outputs. Both outputs provide voltages very close to zero in a steady state at 25 °C, but the power supply level is many times higher and the high impedance output cannot fully discharge the sample-and-hold circuit.

Therefore, we used three independent multimeters Agilent 34410A to overcome the crosstalk problem. These multimeters are synchronized using an external trigger, which is controlled by one digital output of NI-USB6218. An integration time can be controlled through a multimeter's aperture function. The block diagram of this configuration is depicted in figure 2b.

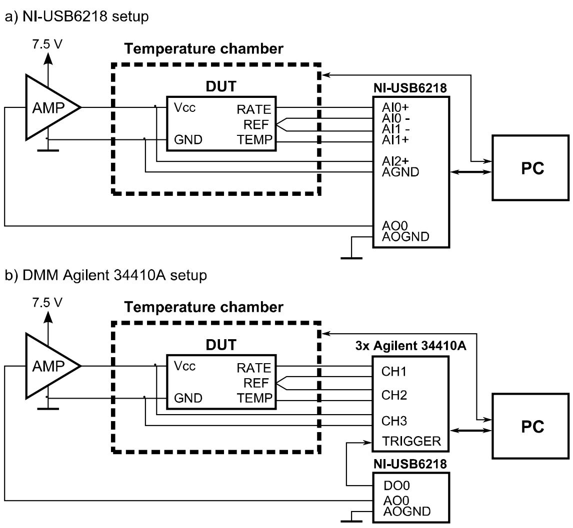

Fig. 2. Measurement chains

4. EXPERIMENT

Figure 3 describes the timing of this measurement. The experiment starts with a delay of 600 sec to heat-up a sensor. This stage is necessary to reach a steady state of the internal temperature. We used the worst case value for our sensors; however the time interval should be different for other sensors because it depends on following factors: power dissipation, thermal conductivity, mounting and ambient temperature.

The following stage is composed from forty periods of the supply pattern to achieve a better uncertainty. Finally, there is a short delay of 500 ms before each sample is taken. This delay is necessary to stabilize power supply voltage in our case.

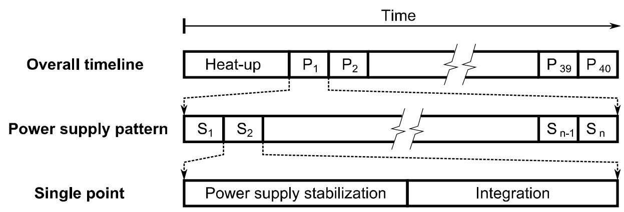

Fig. 3. Timetable of the measurement

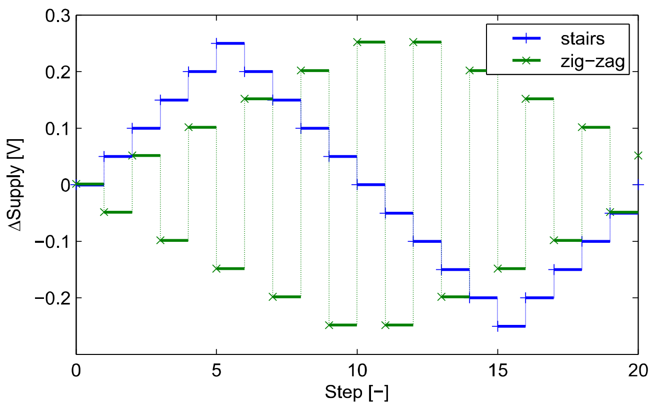

Fig. 4. One period of power supply patterns

The first problem is how to obtain a reliable estimate of mean value of output signals. Especially, the rate output is corrupted by random errors and they are making the situation more complicated.

The optimal averaging time interval for a bias estimation can be determined using the Allan variance (AV) analysis [5, 6]. This method and related problems are described for MEMS gyroscopes in our previous work [7].

Short time averages are compromised by a wideband noise which is usually quantified by the angle random walk error (ARW). The variance has falling character if the averaging time grows. The deepest point of AV curve is determined by the bias instability error. After that, the rate random walk error can be observed and the variance is now growing again. Therefore, the optimal averaging time is related to the deepest point of AV curve. However, these gyroscopes have optimal averaging time about a hundred seconds and there is a problem with the self-heating.

We used the long averaging time (60 seconds) and the stairs-like pattern of power supply voltage (figure 4) in our preliminary experiment. The result from build-in temperature sensor of the MLX90609 gyroscope is shown in figure 5 as the blue line. After that, a shorter averaging time was used and the slope was smaller. This behaviour indicates that there is a systematic error caused by the self-heating. Therefore, we used the short averaging time of 0.2 seconds and the zig-zag pattern of power supply voltage (figure 4). This pattern has a much shorter period, thus the influence of self-heating is also smaller.

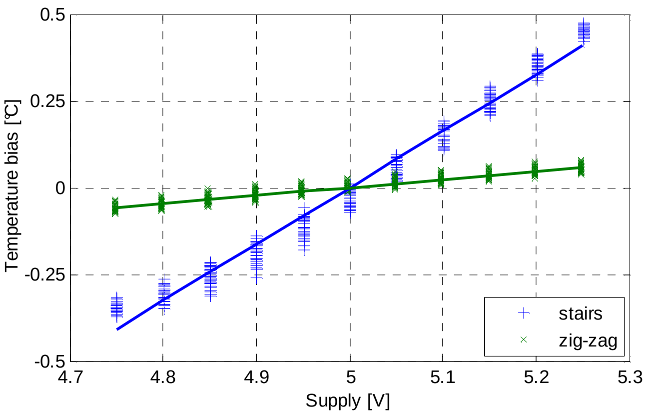

Fig. 5. Self-heating effect and temperature sensor power supply sensitivity of MLX90609N2

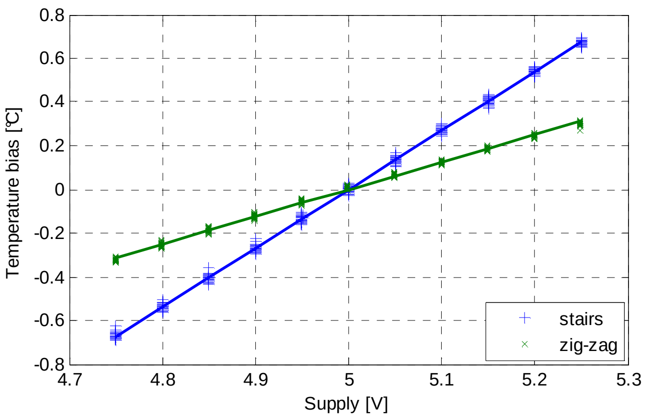

Fig. 6. Self-heating effect and temperature sensor power supply sensitivity of ADXRS300

The result is depicted in figure 5 as the green curve. The difference between these two trials is very dramatic. For this sensor, the difference of 0.5 V in the power supply caused the increase about 0.7 °C in the internal temperature. This is the reason why the self-heating effect cannot be neglected.

If we take a look on the green curve in figure 5, we can see the residual dependency of the build-in temperature sensor on power supply voltage. The relationship can be considered as linear with the slope 0.23 °C/V. A similar behaviour was observed for the rest of sensors. It can be shown in figure 6 for the ADXRS300 gyroscope. Again, there is a difference between supply patterns due to the self-heating but it is a little different in this case. The reason is the almost three times lower power consumption and a much smaller package of the ADXRS300 gyro. The power supply drift of the temperature sensor is also nearly linear and the slope is 1.2 °C/V. An approximation by a polynomial of second order has better fit, but the improvement is not significant, because a repeatability of build-in temperature sensor is just moderate.

The influence of self-heating on the measurement of zero rate supply drift is smaller, because it depends on the temperature sensitivity of a gyroscope. The MLX90609 has build-in temperature compensation, thus there is no significant difference between our supply patterns. Other sensors without internal temperature compensation showed a discrepancy in results, so the self-heating cannot be omitted.

The example of zero rate supply sensitivity is depicted in figure 7. The improvement of the fit using polynomials compared to the linear approximation is illustrated in figure 8 and the maximal value is about 1.5 %. Therefore, the linear fit is also appropriate for the MLX90609 gyroscope including our other sensors if we are looking for a simple model. The actual sensitivity of the MLX90609 is 5.6 °/s/V and the slope is positive unlike the other gyroscopes. Probably, it is caused by a different internal structure.

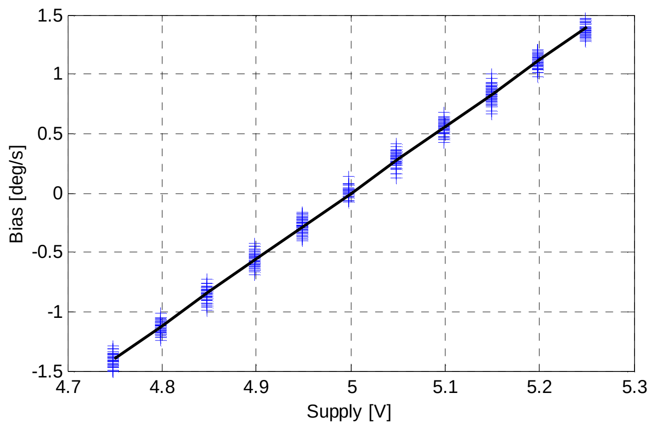

Fig. 7. Zero rate supply drift of MLX90609N2

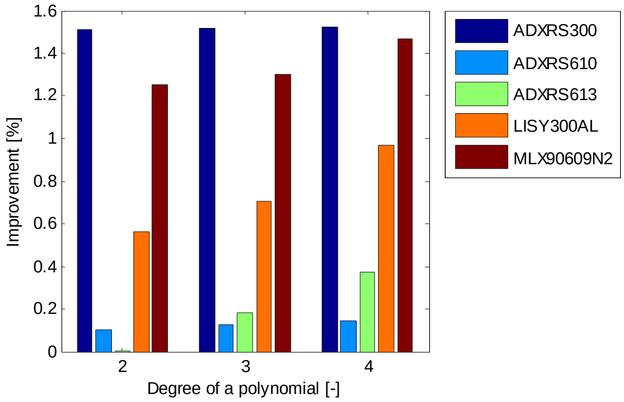

Fig. 8. The improvement of the fit using a polynomial model (zero rate supply drift)

Our results are summarized in Table 1 along with basic parameters. The worst zero rate power supply drift has the MLX90609 even if this gyro is designed for navigational applications and it offers a quite low level of the ARW. For example, after 100 seconds of integration we have the uncertainty of an attitude due to the ARW error:

$$\delta_{ARW} = ARW \cdot \sqrt{t} = 0.02 \cdot \sqrt{100} = 0.2° \qquad (1)$$

If we assume a constant difference in power supply voltage, the error grows linearly in time. For the difference of just 1 mV we have the error:

$$\delta_{pr} = S_R \cdot U_\Delta \cdot t = 5.6 \cdot 10^{-3} \cdot 100 = 0.56° \qquad (2)$$

In this case, the error due to the power supply drift is almost three times higher than the ARW error. This is the reason why the zero rate supply drift has to be carefully considered in the inertial navigation systems.

The worst power supply drift of the internal temperature sensor has the ADXRS300 gyroscope. The propagation of this error into the attitude depends on the temperature sensitivity of the zero rate level. It has been evaluated in a temperature chamber during a different experiment. The actual value of this parameter is 0.179 °/s/°C if we are using a linear model. Therefore, the resulting error is more than ten times smaller compared to the zero rate power supply drift in this case. However, this effect has to be considered if we are using a more complicated model of the temperature sensitivity, because instability of power supply voltage can compromise its benefits.

5. CONCLUSION

We have proved the sensitivity of MEMS gyroscopes to a variation of power supply voltage. The power supply inflicts the zero rate level and bias of build-in temperature sensor. We did not check a scale factor, thus we can only assume, that it is affected too.

A linear approximation is sufficient for the zero rate level in our study and also for the bias of the build-in temperature sensor. It is very useful, because if we have information about actual power supply voltage, then linear

Table 1: Basic parameters and measurement results

Sensor	Range [°/s]	ARW [$°/\sqrt{s}$]	Power [mW]	Supply drift	
				Zero rate [°/s/V]	Temp. [°C/V]
ADXRS300	±300	0.04	30	-3.2	1.2
ADXRS610	±300	0.03	18	-0.29	0.73
ADXRS613	±150	0.03	18	-1.5	-0.28
LISY300AL	±300	0.01	16	-4.6	N/A
MLX90609N2	±75	0.02	80	5.6	0.23

models can be easily incorporated into the system and these errors can be suppressed.

The influence of output configuration is not provable, however a slightly smaller sensitivity showed ratiometric sensors in our case. Also, these sensors have their characteristic much more linear compared to the other gyroscopes.

Moreover, we have shown the influence of self-heating on the measurement, therefore an appropriate method should be used to get reliable results. We have suppressed this problem using the short averaging time and the suitable supply pattern with the short period.

Finally, we cannot generalize a degree of influence because this study is done on just a small set of sensors, but the power supply sensitivity should be considered, if we want to achieve the best performance of MEMS gyroscopes. Therefore, a sufficiently stable power supply or an active compensation should be used.

In a future work, we are going to expand this study to cover more different sensors and also more pieces of one type to check repeatability of these results. Another goal is to investigate behaviour of the scale factor as a function of the power supply voltage.

6. REFERENCES

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