Three Axis MEMS Gyroscope Drift Error Filtering and Temperature Compensation Technology

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Abstract

The zero drift of the MEMS gyroscope is the main factor that affects the gyroscope's measurement accuracy. First, the drift error of the three-axis MEMS gyroscope is filtered and denoised, and the temperature compensated model is established for the three-axis MEMS gyroscope after denoising. A piecewise linear approximation method is used to establish a temperature compensation model for the MEMS gyroscope X axis, and a polynomial curve fitting method is used to establish a temperature compensation model for the MEMS gyroscope Y axis and Z axis. After the temperature compensation, the three-axis output value of the MEMS gyroscope fluctuates near zero, which indicates that this solution can effectively perform temperature compensation for the MEMS gyroscope.

Keywords

MEMS gyroscope; Piecewise linear approximation method; Polynomial curve fitting method.

1. Introduction

The zero offset and scale factor are the main performance parameters of the MEMS gyroscope[1]. The zero offset is the output of the MEMS gyroscope when it is stationary, and it is often expressed by the average value of the output over a longer period of time.

MEMS gyroscopes are often sensitive to angular rate changes based on the principle of capacitance detection[2]. According to the analysis of the structure of the MEMS gyroscope, it can be known that silicon-based MEMS gyroscopes have become the mainstream choice, and silicon is a heat-sensitive material, so temperature changes will inevitably cause changes in the internal geometric dimensions of the MEMS gyroscopes, causing MEMS The error in the capacitance value detected by the gyroscope affects the output of the MEMS gyroscope[3]. This error changes the zero offset and scale factor of the MEMS gyroscope, which is called the temperature drift error. The compensation of temperature drift error of MEMS gyroscope in this subject is based on its original output value, which can avoid the error caused by scale factor drift[4]. Therefore, the subject mainly studies the change of zero offset of MEMS gyroscope with temperature.

2. Experimental Design Scheme

2.1 Experimental Facilities

The high and low temperature test chamber produced by Shanghai Espek Environmental Equipment Co., Ltd. was used as the equipment for the temperature experiment in this paper. The temperature range of the temperature control system is -70°C ~ 100°C, and the constant temperature fluctuation rate is less than 0.1°C. Its use conditions are fully satisfied. Requirements for this temperature experiment. The high and low temperature test box is shown in Figure 1.

Fig. 1 High-low temperature test chamber

2.2 Temperature Sensor Calibration

For the temperature experiment of the MEMS gyroscope, the internal temperature of the MEMS gyroscope should be used as a reference, so the temperature inside the MEMS gyroscope needs to be detected. Because the temperature sensor integrated in the MEMS gyroscope selected in this paper, compared with the external temperature sensor, on the one hand, the cost of the experiment is reduced, and on the other hand, the temperature inside the MEMS gyroscope can be accurately reflected. Also before use, the built-in temperature sensor needs to be calibrated. The calibration model of the temperature sensor is shown in equation (1):

$$T = u_0 + ku_T \tag{1}$$

Among them, u_T is a measurement value of a built-in temperature sensor, T is an external temperature, and u0 and k are coefficients to be solved.

In order to determine the coefficients in the calibration model of the temperature sensor, the attitude and attitude reference system is placed in the high and low temperature test box, and the temperature range of the high and low temperature box is set to -35ºC ~ 60ºC, and the step is 5ºC. After the temperature is stable, collect some built-in temperature sensors The average value of the output values of. The output value of the corresponding built-in temperature sensor at each temperature value is shown in the following table (1).

Table 1 Output value of the built-in temperature sensor at each temperature

Temperature/ºC	Output value/LSB	Temperature/ºC	Output value/LSB
-35	-1368.5372	15	-716.1818
-30	-1320.6680	20	-645.6012
-25	-1260.1404	25	-579.6028
-20	-1195.6861	30	-494.4020
-15	-1134.0360	35	-437.0975
-10	-1067.8242	40	-373.6239
-5	-995.9575	45	-307.6414
0	-923.7933	50	-220.2609
5	-855.1844	55	-155.1214
10	-785.8196	60	-83.4496

The above data was fitted based on the least squares method. The fitted curve is shown in Figure 2. The fitted result is $u_0 = 66.7772$， $k = 0.0728$.

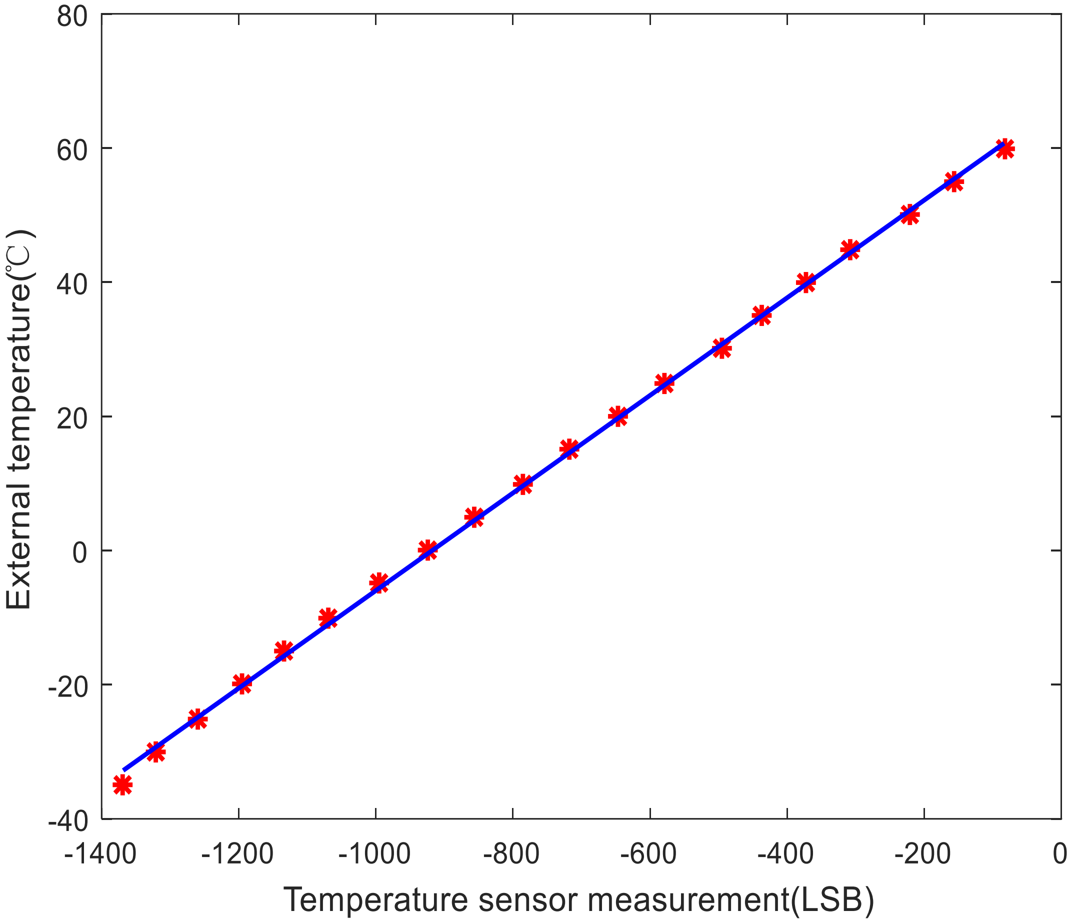


Fig. 2 Calibration results of MEMS gyroscope built-in temperature sensor

2.3 Experimental Data Acquisition

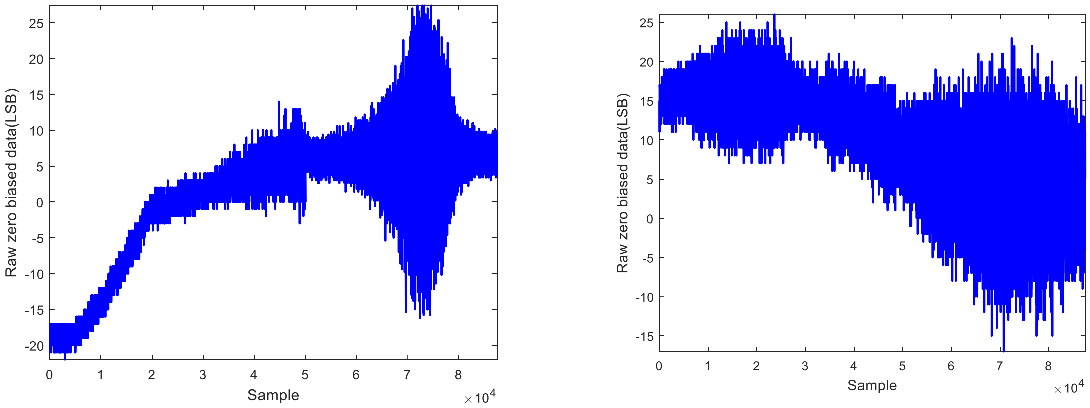
In order to study the change of the zero offset of the MEMS gyroscope with temperature, and then establish a temperature drift model, we need to make a graph analysis of the original output value of the collected MEMS gyroscope. In this experiment, the temperature change range of the MEMS gyroscope is set to -40ºC ~ 60ºC, and the temperature increase experiment is performed at a temperature change rate of 1ºC / min. The specific experimental steps are as follows:

1. Fix the attitude and attitude reference system on the turntable surface in the high and low temperature box to avoid shaking the attitude and attitude reference system due to improper fixing.

2. Set the temperature change of the high and low temperature box manually. Constant temperature for one hour at the lowest temperature (-40ºC) and the highest temperature (60ºC), and then set the temperature change rate to 1ºC / min.

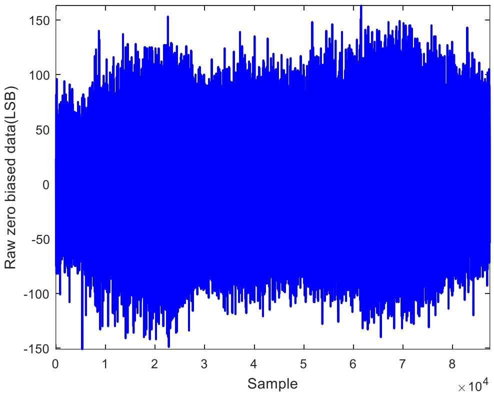
3. The temperature experiment is a single-cycle temperature increase experiment, that is, the temperature in the high and low temperature box is increased from -40ºC to 60ºC at a temperature change rate of 1ºC / min, and the temperature is maintained at two extreme temperatures for 1 hour.

It can be obtained through experiments that the three-axis zero offset value of the MEMS gyroscope changes with temperature as shown in Figure 3 below.



(a) X axis zero offset value changes with temperature

(b) Y axis zero offset value changes with temperature



(c) Z axis zero offset value changes with temperature

Fig. 3 The zero offset of MEMS gyroscope triaxial value varies with temperature

From Figure 3 above, it can be observed that in the temperature range of -40℃ ~ 60℃, the zero offset of the X-axis of the MEMS gyroscope exhibits different temperature characteristics in this temperature range, so the piecewise linear approximation method is used for temperature compensation. For the MEMS gyroscope Y-axis and Z-axis zero offset, a polynomial curve fitting method is used for temperature compensation.

3. Modeling and Compensation of MEMS Gyroscope Temperature Error

3.1 Wavelet Transform to Filter MEMS Gyroscope Data

If the function $f(t) \in L^2(R)$, the wavelet transform of the function can be defined as:

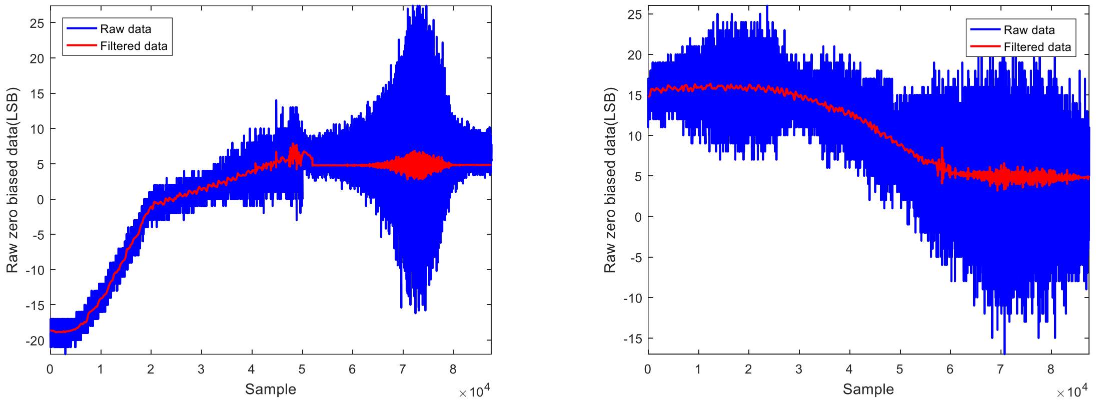
$$WT_f(a,b) = \int_{-\infty}^{+\infty} f(t)\psi_{a,b}(t)dt = (1/\sqrt{a})\int_{-\infty}^{+\infty} f(t)\psi((t-b)/a)dt \quad (a,b \in R, a>0) \tag{2}$$

Among them, *WT* is a wavelet transform of function *f(t)*; $\psi_{a,b}(t) = \left(a^{-1/2}\right)\psi((t-b)/a)$ is called an analysis function, where a is a scale factor and b is a translation factor. The mathematical model of the output signal of the MEMS gyroscope is assumed to be a first-order mathematical model containing noise signals, and its model expression is as follows:

$$s(k) = X(k) + \delta W(k), k = 0,1,\cdots,n-1 \tag{3}$$

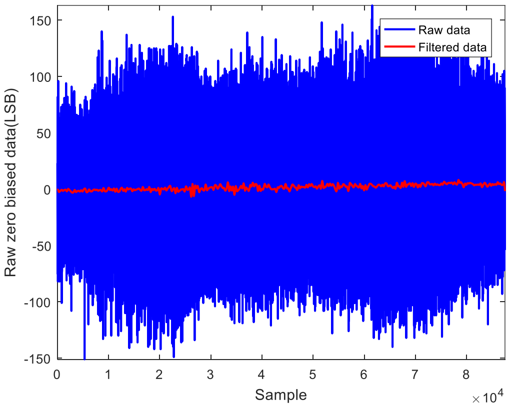
Among them, *s(k)* is the original output value of the MEMS gyroscope, *X(k)* is the input value of the MEMS gyroscope, and *W(k)* is the noise suffered by the MEMS gyroscope. Generally, noise is concentrated in high-frequency signals, while MEMS gyroscope input signals usually appear as low-frequency signals. Therefore, the purpose of wavelet transform is to reduce the influence of noise *W(k)* on the output value *s(k)* of MEMS gyroscope.

Based on the above analysis, wavelet transform is used to filter the three-axis zero-bias data of the MEMS gyroscope. The comparison of the data before and after filtering is shown in Figure 4. Affected by noise, the three-axis zero-bias data of the MEMS gyroscope has a large fluctuation range before filtering, but the data becomes smooth after filtering, and the filtering effect is relatively obvious.



(a) Comparison of X-axis zero offset data before and after filtering

(b) Comparison of Y-axis zero offset data before and after filtering



(c) Comparison of Z-axis zero offset data before and after filtering

Fig. 4 Comparision of MEMS gyroscope triaxial zero offset data before and after filtering

3.2 Compensation Model Establishment

By analyzing the variation of the MEMS gyroscope's zero offset with temperature, it can be obtained that the temperature offset is -40ºC ~ 60ºC, and the piecewise linear approximation method is used to compensate the X-axis zero offset of the MEMS gyroscope. Equation (4) is the X-axis zero offset temperature compensation model corresponding to each temperature interval:

$$\begin{cases} \omega_{x0}(T)=10.4365+0.8629T & -40^{\circ}C\le T<-35.18^{\circ}C \\ \omega_{x0}(T)=43.2025+1.8335T & -35.18^{\circ}C\le T<-23.18^{\circ}C \\ \omega_{x0}(T)=4.0608+0.2078T & -23.18^{\circ}C\le T<13.91^{\circ}C \\ \omega_{x0}(T)=4.8371+0.0475T & 13.91^{\circ}C\le T<25.10^{\circ}C \\ \omega_{x0}(T)=4.7733+(3.36e-05)T & 25.10^{\circ}C\le T<60^{\circ}C \end{cases} \tag{4}$$

Where is the sensitive temperature of the MEMS gyroscope X axis, the unit is ºC; and $\omega_{x0}(T)$ is the zero offset of the X axis at the temperature, the unit is LSB.

Figure 5 shows the X-axis zero offset of the MEMS gyroscope before and after compensation.

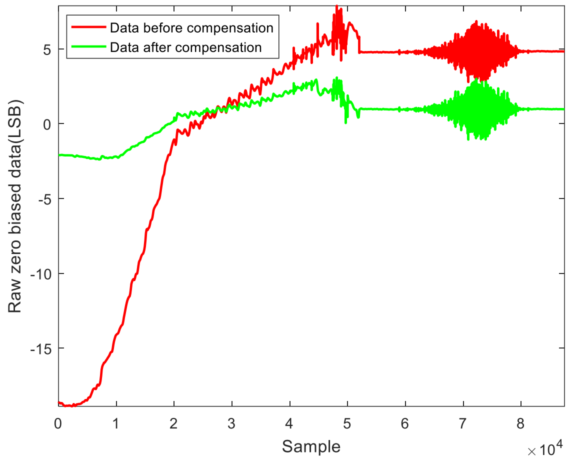


Fig. 5 Compensation of the X-axis zero offset of the MEMS gyroscope before and after

It can be calculated after compensation that the absolute value of the X-axis error output of the MEMS gyroscope changes from $5.9598(LSB)$ before compensation to $1.3059(LSB)$ after compensation. According to Figure 4.8, it can be known that the zero offset value of the X-axis of the MEMS gyroscope is better stabilized at zero after compensation. If the value is near, the compensation model is valid.

For the MEMS gyroscope Y axis, polynomial curve fitting is used to compensate the zero offset temperature. Equation (5) is the Y-axis zero offset temperature compensation model.

$$\omega_{y0}(T)=(5.12e-07)T^4+(1.56e-05)T^3-0.0034T^2-0.1403T+15.4299 \tag{5}$$

Where is the Y-axis sensitive temperature of the MEMS gyroscope in °C; and $\omega_{y0}(T)$ is the zero offset of the Y-axis at temperature in LSB.

Figure 6 shows the Y-axis zero offset of the MEMS gyroscope before and after compensation. After compensation, it can be calculated that the absolute value of the Y-axis error output of the MEMS gyroscope changes from $10.5562(LSB)$ before compensation to $0.6255(LSB)$ after compensation. Observing Figure 6 shows that the Y-axis zero offset value of the MEMS gyroscope after compensation is stable near zero., Then the compensation model is valid.

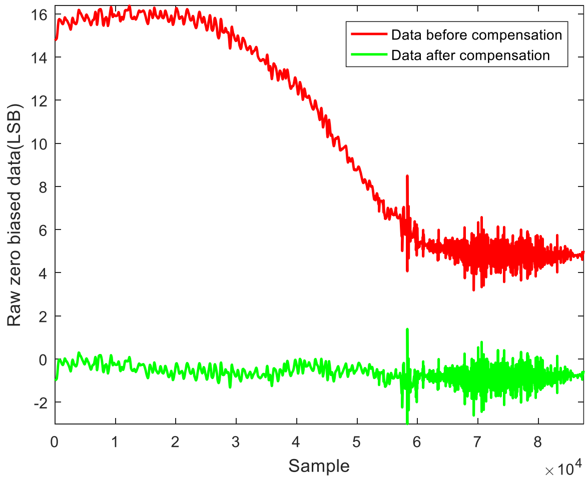


Fig. 6 Compensation of the Y-axis zero offset of the MEMS gyroscope before and after

Polynomial curve fitting is also used for temperature compensation of the MEMS gyroscope Z-axis zero offset, and its processing method is similar to that of the MEMS gyroscope Y-axis, which is not repeated here. Equation (6) is the Z-axis zero offset temperature compensation model.

$$\omega_{z0}(T) = 0.1217T + 2.0353 \tag{6}$$

Where is the Z-axis sensitive temperature of the MEMS gyroscope in °C; and $\omega_{z0}(T)$ is the zero offset of the Z-axis at temperature in LSB.

Figure 7 shows the Z-axis zero offset of the MEMS gyroscope before and after compensation. After compensation, it can be calculated that the absolute value of the Z-axis error output of the MEMS gyroscope changes from $2.4132(LSB)$ before compensation to $1.1565(LSB)$ after compensation. Observing Figure 7 shows that the Y-axis zero offset value of the MEMS gyroscope after compensation is stable near zero., Then the compensation model is valid.

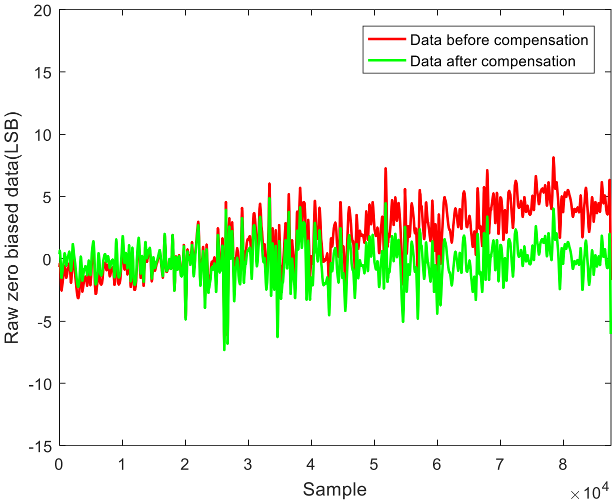


Fig. 7 Compensation of the Z-axis zero offset of the MEMS gyroscope before and after

4. Summary

The compensation of MEMS gyroscope temperature drift error in this paper is based on its original output value. Can avoid errors caused by scale factor drift, first use wavelet filtering to denoise the three-axis MEMS gyroscope, and then use piecewise linear approximation to temperature compensation the zero offset of the MEMS gyroscope, and use polynomial curve fitting The MEMS gyroscope's Y-axis and Z-axis zero offsets are temperature-compensated to improve the output accuracy of the MEMS gyroscope.

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