A Compensation Algorithm For Zero Drifting Error of MEMS Gyroscope

Du Jin¹, Li Jie²

¹North University of China Science and Technology on Electronic Test & Measurement Laboratory, Taiyuan 030051, China

²Key Laboratory of Instrumentation Science & Dynamic Measurement (North University of China) Ministry of Education, Taiyuan 030051, China

^a454552639@qq.com, ^blijie@nuc.edu.cn

Keywords: MEMS gyroscope; zero drift; error compensate; least square method

Abstract. The undesirable accuracy of MEMS sensor limits the range of its application. The compensating method for MEMS gyroscope random drift error is discussed. According to actual test data of gyroscope, the equation of fitting curve was deduced and compensating effect of different kinds of fitting methods were compared. The car experiments were carried out to prove that this compensating method can restrain drift random error of gyros and improve navigation accuracy effectively.

Introduction

With the development of MEMS technology, MEMS inertial device has been widely used in military and civilian areas for its small size, low power consumption, high reliability, and easy to integrate. MEMS technology belongs to frontier subject, influenced by manufacturing process and other factors, the gyroscope we produced always exist shortcomings such as zero drift, sensitivity error and temperature drift [1]. This gyroscope can only be applied to low precision occasion, which restricting the development of MEMS gyroscope seriously. How to compensate the zero drift error of MEMS gyroscope has become an urgent problem to be solved in the practical engineering.

Firstly, this paper reviews current compensating method of MEMS gyroscope error. Through the analysis of lots of zero output data of MEMS gyroscope, a zero drift random error compensating methods based on polynomial fitting were put forward. After that, comparisons are made between gyro accumulated error output before and after the compensating. Finally, car experiments were carried out to verify the effectiveness of the proposed compensating method.

Comparisons between various compensating methods

The method of zero drift compensation of MEMS gyroscope can be divided into hardware compensation and software compensation according to the implementation conditions. Hardware compensation usually include optimizing device structure, improving production process, adding bridge compensation and so on [2]. Hardware compensation can enhance the accuracy of device but it exist shortcomings such as long research period, high cost, poor generality and hard to debug. It becomes more convenient and effective to compensate zero drift of MEMS gyroscope by software with the wide application of computer technology [3].

The basic idea of software compensation is analysis and modeling of zero output of the gyroscope, and then make prediction and compensation of zero drift curve. There are many curve fitting method, such as BP neural network, interpolation method, best linear fitting, polynomial fitting [4]. BP neural network has the ability to approach any nonlinear function, but it converges very slowly. The basic idea of interpolation is to replacing the interpolation function with a high degree algebraic polynomial, however, when the interpolation points increase or decrease one, interpolation polynomial need to be reconstructed. The least square method is an optimal estimation technique, which is derived from the maximum likelihood method when the random error is normal distribution. It is considered as the most reliable method for calculating the regression equation from a set of measurements

[5].The method is simple in calculation and conducive to computer programming. This paper discuss the application of polynomial fitting method in compensation of zero drift error of MEMS gyroscope in detail, and provide a method of thinking and technical reference for the accuracy improvement of MEMS gyroscope.

Analysis and compensation to zero drift random error of MEMS gyroscope

Data acquisition and preprocessing

Sample continuous signal of the actual output of MEMS gyroscope, obtain the original data and then filter the raw signal, the result is shown in Fig.1.

Theoretically the zero drift of MEMS gyroscope is random, but we find that the trend of zero drift is not without any rules in the process of signal acquisition of the same type gyros. Influenced by unknown external and internal factors, zero drift signal often contains a certain trend [6]. The drift curves of the same type of gyroscope are similar. By fitting the zero drift curve, the implicit relationship is summarized and the regression equation of fitting curve is deduced. The zero drift error of MEMS gyroscope is compensated. Similar to the gyroscope's calibration, sample the zero drift signal before using the gyros and summarize the characteristics of the gyroscope. In practical, firstly, filter the zero drift signal of MEMS gyros, and then use the compensating result to perform a variety of inertial measurement operations [7].

Fig.1 gyro zero drift signal

Selection of compensating method

(1) Best fitting straight-line method

We set fitting straight-line: $Y = A + BX$, y_i is actual output voltage of gyro, $y_i - Y_i$ the deviation between No.i point and the fitting line. If we set

$$j_{A,B} = \sum_{i=1}^n n^2_i = \sum_{i=1}^n (y_i - Y_i)^2 = \sum_{i=1}^n (y_i - A - Bx_i)^2 \quad \text{To minimize } j_{A,B} = \sum_{i=1}^n n^2_i, \text{ take partial derivative respect}$$

to A and B respectively, let it equal to zero, two equations are obtained

$$\frac{\partial j}{\partial A} = \sum_{i=1}^n [-2(y_i - A - Bx_i)] = 0 \quad (1)$$

$$\frac{\partial j}{\partial B} = \sum_{i=1}^n [-2x_i(y_i - A - Bx_i)] = 0 \quad (2)$$

The equations have unique solutions.

$$A = \frac{\sum_{i=1}^n y_i \sum_{i=1}^n x_i^2 - \sum_{i=1}^n x_i y_i \sum_{i=1}^n x_i}{n(\sum_{i=1}^n x_i^2) - (\sum_{i=1}^n x_i)^2} \quad (3)$$

$$B = \frac{n(\sum_{i=1}^n x_i y_i) - \sum_{i=1}^n x_i \sum_{i=1}^n y_i}{n(\sum_{i=1}^n x_i^2) - (\sum_{i=1}^n x_i)^2} \quad (4)$$

According to above formula, we write MATLAB program, and calculate the intercept and slope of the regression equation.

(2) Polynomial fitting curve method

Set fitting line as $Y_n(x) = a_0 + a_1x + a_2x^2 + \dots$ (5)

$$I = \sum_{i=0}^m [Y_n(x) - y_i]^2 = \sum_{i=0}^m (\sum_{k=0}^n a_k x_i^k - y_i)^2$$

the deviation (6)

$Y_n(x)$ represent the regression equation we demand when I reach its minimum.

Let partial derivative equal to zero

$$\frac{\partial I}{\partial a_j} = 2 \sum_{i=0}^m (\sum_{k=0}^n a_k x_i^k - y_i) x_i^j = 0 \quad (7)$$

The linear equations about $a_0, a_1 \dots a_n$ are obtained, solve out $a_k (k = 0, 1, \dots, n)$, obtain corresponding regression equation.

Compensating effect contrast

The expression of best fitting line

$$U = 4.50094 \times 10^{-6} T + 1.65106 \quad (8)$$

Fig. 2 best fitting line

Fig.3 two-order polynomial fitting curve

The expression of two-order polynomial fitting curve

$$U = -2.47795 \times 10^{-9} T^2 + 4.87511 \times 10^{-6} T + 1.65105 \quad (9)$$

The expression of three-order polynomial fitting curve

$$U = 6.18302 \times 10^{-10} T^3 + (-9.9246) \times 10^{-6} T^2 + 9.8666 \times 10^{-6} T + 1.65099 \quad (10)$$

Fig.4 three-order polynomial fitting curve

Fig.5 four-order polynomial fitting curve

The expression of four-order polynomial fitting curve

$$U = 1.26712 \times 10^{-10} T^4 + (-1.6567) \times 10^{-8} T^3 + 8.788 \times 10^{-7} T^2 + (-1.1514) \times 10^{-5} T + 1.6511 \quad (11)$$

It can be seen from the above results that if we set low order number of polynomial fitting curve, it will led to unfavorable effect. In a certain range, increasing the order number of fitting curve can improve the fitting effect, but high order numbers also led to complexity in calculation [8,9]. Comprehensive consideration of the above two factors, we choose 4 three-order polynomial fitting method. Take single axis MEMS gyros as an example, the angle error it accumulate during 300s is larger than 6° when the compensating method is not added into. After the compensation algorithm, cumulative angle error is effectively corrected with low fluctuations. The angle error before and after the compensation is shown in Fig.6.

Fig.6 angle error before and after the compensation

Experiments and results

In order to verify the effectiveness of the compensation method in the actual vehicle environment, we design following car experiment. Select two sets of the same MEMS inertial navigation system, one of them use compensation method and the other do not use compensation method as reference. The whole experiment process has high precision GPS signal receiving which provide a reference for the accuracy verification. Three axis attitude angle of vehicle test before and after compensation are as shown in Fig.7. It can be seen that the attitude of the system is more close to the actual output of GPS after the addition of the compensation method.

Fig.7 Three axis attitude angle of vehicle test before and after the compensation

Conclusion

The zero drift compensation method of MEMS gyroscope is discussed, and the optimal linear and polynomial fitting method based on least square method is presented. The results of polynomial curve fitting of different orders are compared, and the optimal compensation method is applied to the attitude algorithm of inertial navigation system. Through vehicle test, the validity of the method is proved, which provides a new method for reducing random error of the zero drift of MEMS gyroscope.

Acknowledgements

The authors wish to thank Jie Li for helpful discussions. The authors would like to appreciate the assistance of all co-workers in the Science and Technology on Electronic Test & Measurement Laboratory for their contribution on experiments.

References

- [1] Savage P 1998 Strapdown inertial navigation integration algorithm design part 1: attitude algorithms J.Guid.Control Dyn.21 19-28
- [2] Sabatini A 2006 A wavelet-based bootstrap method applied to inertial sensor stochastic error modeling using the Allan variance Meas.Sci.Technol.17 2980-8
- [3] Jie Li, Jun Liu, Zhang Wen-dong. 2006 Mems based micro inertial measurement system[J]. Wseas Transactions on Circuits and Systems. 5 691-696.
- [4] Tan C W, Park S, Mostov K. 2001 Design of gyroscope free navigation systems[C] 2001 IEEE Intelligent Transportation System Proceedings, Oakland, USA, August 25-29.
- [5] Kennedy P J. Direct versus indirect line of sight stabilization[J]. IEEE Trans. on Control Systems Technology, 2003, 11(1): 3-15.
- [6] David H Titterton. Strapdown inertial navigation technology[M]. UK: The Institution of Electrical Engineers, 2004: 59-115.
- [7] Zarlink Semiconductor. GP4020 GPS Receiver Baseband Processor[Z]. 2002-05.
- [8] WANG Li-dong, ZHANG Chun-xi. On-line modeling and filter of high-precise FOG signal[J]. Opto-Electronic Engineering, 2007, 34(1): 1-4.
- [9] YI Kang, LI Ting-zhi, WU Wen-qi. Application of forward linear prediction filter in signal process of FOG[J]. Journal of Chinese Inertial Technology, 2005, 13(5): 58-62.