Intelligent error compensation

Yiping Song [*1], Ning Liu[*2]

[*1] Beijing Information Technology University, 18813161493@163.com
[*2] Beijing Key Laboratory of High Dynamic Navigation Technology, ning.liu@bistu.edu.cn

Abstract. A temperature error compensation method based on RBF neural network is proposed to solve the problem that the navigation accuracy of MEMS gyroscope is reduced due to the influence of temperature. The temperature related output data of MEMS gyroscope are collected through the designed experimental scheme. The conventional temperature compensation model is a polynomial model, and the polynomial model as the temperature compensation model of MEMS gyroscope has shortcomings, that is, it cannot show the deviation in a small temperature interval. Therefore, the temperature error compensation method of RBF neural network is suggested as an improvement of polynomial fitting.

Keywords: MEMS gyroscope, temperature error compensation, polynomial model, RBF neural network

1. INTRODUCTION

MEMS (micro electro mechanical system) is a micro electromechanical system which integrates micro sensors, actuators, signal processing and control circuit, interface circuit, communication and power supply. The goal of MEMS method is to integrate the acquisition, processing and execution of information to form a multifunctional micro system, so as to improve the automation and intelligence of the system. With the rapid development of MEMS inertial device technology, MEMS has been widely used in society, military and other fields. However, due to the material characteristics of the micromachined gyroscope, its data output is significantly affected by temperature and has nonlinear characteristics. As the temperature changes, the zero drift of the gyro increases and the error becomes larger. Therefore, relevant researches on the temperature characteristics of MEMS gyroscopes are carried out, and a mathematical model between gyroscope drift and temperature is established to improve the zero drift of the gyroscope and reduce errors.

The traditional method is to establish the approximate temperature model of gyro by means of statistical method and fuzzy algorithm, such as AR model and polynomial model. In reference [3], a digital temperature compensation method is used to reduce the influence of temperature on the gyro output and improve the performance indexes such as gyro drift. In reference [1], gray model is used to preprocess the output data of MEMS gyroscope, which can effectively reduce the noise of data and make the data have certain rules. The temperature drift of the gyroscope is compensated by the temperature compensation method of RBF neural network. However, due to the large amount of calculation needed in the process of temperature compensation using RBF neural network method, it is still necessary to optimize the selection of basis function and the number of neurons.

In this paper, the temperature error compensation method of MEMS gyroscope is studied. The polynomial model and RBF neural network are used to compensate the temperature error. The experiment shows that the compensation effect of RBF neural network is better than the traditional polynomial compensation method.

2. TEMPERATURE ERROR ANALYSIS OF MEMS GYROSCOPE

Bias thermal drift is one of the key error components in MEMS gyroscope, which is defined as the change of bias estimation value at startup caused by thermal change. Temperature affects the performance of gyroscope through the change of resonant frequency and driving amplitude. Because the MEMS inertial sensor architecture is made of silicon, which is a kind of thermal sensitive material, the elastic modulus changes with temperature. Under the action of elastic modulus and thermal stress, the relationship between gyroscope stiffness and temperature can be expressed as follows：

$$K = K_0 - C_E K_0 \left(T - T_0\right) \tag{1}$$

Where K and K_0 are the stiffness of the gyroscope at temperature T and T_0 respectively. Therefore, the relationship between the resonance frequency and temperature of the gyroscope is as follows:

$$\begin{aligned} f\left(T\right) &= \sqrt{K/m} \\ &= \sqrt{\left[K_0 - C_E K_0\left(T - T_0\right)\right]/m} \\ &= f_0\sqrt{1 - C_E\left(T - T_0\right)} \end{aligned} \tag{2}$$

In formula (2), $f\left(T\right)$ and f_0 are the resonant frequencies of the harmonic oscillator at the temperature of T and T_0 respectively. In a word, the resonant frequency of the gyroscope is related to the temperature change, so the MEMS gyroscope will be affected by the temperature and the output accuracy will be reduced.

3. POLYNOMIAL MODEL

According to the literature [4], the commonly used MEMS gyroscope temperature compensation model is a polynomial model. Polynomial model is a linear regression model based on least square method. When the order of the polynomial is determined, the least mean square curve fitting can be used to estimate its coefficient. The polynomial model of gyro bias temperature can be expressed as:

$$B_0 = a_0 + a_1 T + a_2 T^2 + \cdots + a_n T^n \tag{3}$$

Among them, B_0 is gyro bias, T is temperature and $a_0, a_{1,} \cdots a_n$ is fitting coefficient. $a_0, a_{1,} \cdots a_n$ can be determined by least square fitting.

4. RBF NEURAL NETWORK MODEL

Artificial neural network (ANN) is a research hotspot in the field of artificial intelligence since 1980s. It is an operational model, which is composed of a large number of nodes connected with each other, and each node represents a specific output function. Artificial neural network can fully approximate any complex nonlinear relationship. Among them, radial basis function neural network is a kind of forward network based on function approximation theory. Among them, radial basis function is a real value function, its value only depends on the distance from the origin, the formula is as follows:

$$\Phi(x) = \Phi(\|x\|) \tag{4}$$

Any function satisfying $\Phi(x) = \Phi(\|x\|)$ can be called radial basis function. RBF neural network is a three-layer neural network, including input layer, hidden layer and output layer. The input layer of the first layer is composed of signal source nodes, the number of hidden layer nodes in the second layer depends on the needs of the problem described, and the output layer of the third layer is the response to the input mode. The transformation from output space to hidden layer space is nonlinear, and from hidden layer space to output layer space is linear. The structure of RBF neural network is shown in Figure 1.

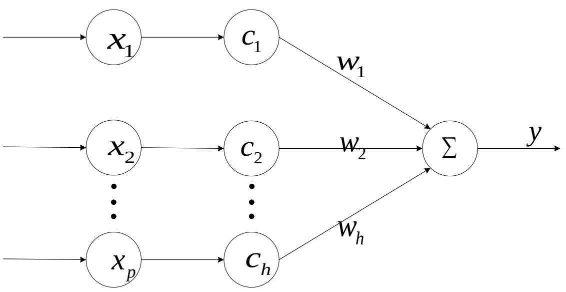

Fig. 2 Structure of RBF neural network.

In the structure of RBF neural network, any node in input layer is represented by a, any node in hidden layer is represented by B, and any node in output layer is represented by C. The mathematical model of each layer is obtained. The activation function of input vector of input layer and any point of hidden layer is as follows:

$$x = (x_1, x_2, \cdots, x_P)^T \tag{5}$$

$$c_j(x), (j = 1, 2, 3 \cdots h) \tag{6}$$

The activation function at any point in the hidden layer is also known as Gauss function. Generally, it is represented by Gaussian function. Among them, the output weight matrix and the output vector formula of the output layer are as follows:

$$W = [w_1, w_2, \cdots, w_h] \tag{7}$$

$$y = WC = w_1 c_1 + w_2 c_2 + \cdots + w_h c_h \tag{8}$$

5. EXPERIMENT al ANALYSIS

Put the MEMS gyroscope in the incubator, adjust the temperature of the incubator, and set the temperature to - 40 ℃ to 60 ℃. Set the temperature box to - 40 ℃, and record the data after the temperature is stable. After 1 hour, adjust the temperature rate of the incubator to 0.5 ℃ / min and increase to 60 ℃. Close the incubator after the temperature reaches 60 ℃ for 1 hour. Data sampling is carried out in the temperature range to obtain the relationship between gyro bias and temperature, as shown in Fig. 2.

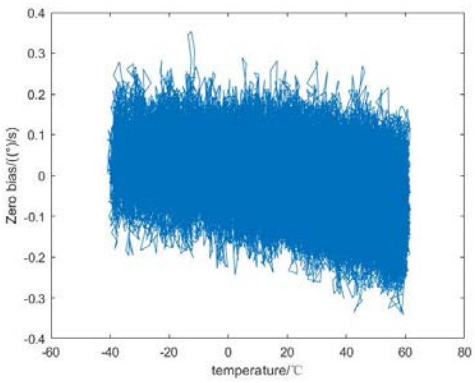

Fig. 2 Gyro bias temperature relationship.

As can be seen from Fig. 2, there are too many data about the relationship between the bias and temperature of the original gyro, which makes the image inaccurate. In order to obtain more accurate gyro bias temperature relationship curve, it is necessary to take the average value of 100 samples on the original gyro bias temperature relationship curve every 0.1 ℃ as the sample point of the new gyro bias temperature relationship curve, as shown in Fig. 3.

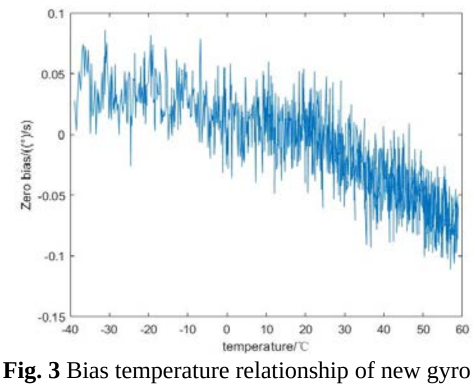

Fig. 3 Bias temperature relationship of new gyro samples

The polynomial model and RBF neural network model are used to compensate the original data of gyro bias. The compensation effect is shown in Fig. 4 ~ Fig. 5. Then the polynomial model and RBF neural network model are compared with the original bias data of MEMS gyroscope after compensation, and table 1 is obtained. It can be seen that after the temperature error of gyro is compensated based on polynomial model and RBF neural network model, the bias caused by temperature change is restrained, and the temperature drift in the range of - 40 ℃ ~ 60 ℃ is greatly reduced, which has significant compensation effect.

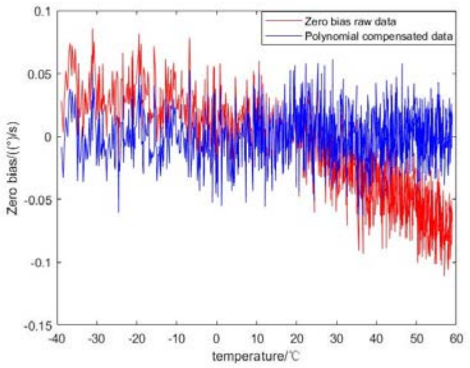

Fig. 4 Compensation effect of polynomial model.

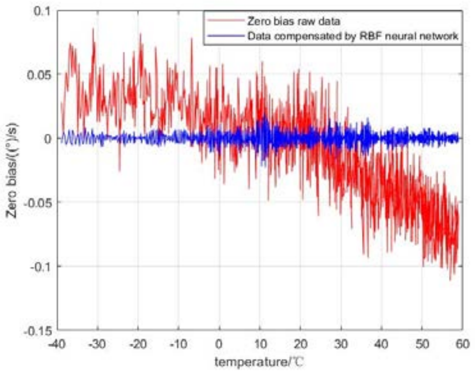

Fig. 5 Compensation effect of RBF neural network model

Table. 1 Comparison for results of gyro 's different compensation models.

Mathematical Model	**Drift Maximum**	**Standard Deviation**	**Percent Reduction Of Standard Deviation**
No compensation	-0.1112	0.0390	
Polynomial model	0.0621	0.0201	48.46%
RBF neural network model	-0.0229	0.0053	86.41%

6. CONCLUSION

In this paper, the temperature data related to MEMS gyroscope is obtained through temperature experiment, combined with the temperature error principle of MEMS gyroscope, the traditional polynomial model and RBF neural network model are used to analyze and compare the zero bias of the gyroscope. It can be seen from the simulation result graph that the error compensation effect of the RBF neural network model is better than that of the polynomial model, and it is closer to a horizontal straight line. It can also be seen from the data in Table 1 that the maximum drift value and standard deviation of the RBF neural network model are smaller than those of the polynomial model. From the perspective of reducing the standard deviation, the RBF neural network model is better than the traditional polynomial model. The output accuracy of the gyro after compensation based on the RBF neural network model is significantly improved, the compensation effect is obvious, and it has certain engineering application value.

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