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Temperature compensating model of MEMS gyro based on BP neural network

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Abstract. A temperature compensation model of MEMS gyro based on BP neural network is proposed in this paper. According to recent researches, the temperature error accounts for about 80% of the total MEMS gyro error. So, it is an effective way to improve the precision of MEMS gyro by compensating the temperature error. However, the temperature error is a nonlinear characteristic, therefore, it can only be estimated by experiment. Traditional modelling methods always use piecewise linear function to fit the temperature error model, they can get accurate fitting results at segmentation points. But for other temperature points, the compensation cannot produce effective results. Based on the BP neural network, which has powerful ability on fitting nonlinear functions, a better model for temperature error of MEMS gyro is built in this paper by analysing amounts of data from repeated experiments. The results show that the method can fit the curve of temperature error well, and has better accuracy comparing to traditional methods. Meanwhile, the method is extensible and valuable in engineering practice fields.

1. Introduction

MEMS(Micro-electromechanical Systems) gyroscope is a new type of gyroscope that has the advantages of small size, light weight, low power dissipation and is widely used in many fields such as inertial navigation, guidance, control and others. Among the MEMS gyros, the micro-mechanical vibratory one is most widely used. With the improvement of precision, micro-mechanical gyro has become one of the key components of MEMS-SINS (Strapdown Inertial Navigation System) and promote the development of micro navigation system, which will gradually replace traditional SINS. But the output of MEMS gyroscope is sensitive to temperature. It mainly manifested in the deviation of gyroscope varies with temperature and has great temperature drift, which affects the accuracy of measurement seriously. The error produced by temperature drift will account for about 80% of the total error of the system. Therefore, the temperature error of MEMS gyroscope is an important factor that affects the precision of MEMS gyro and inertial system and will finally restrict the application range of MEMS gyroscope.

As for the temperature characteristic of MEMS gyroscope, a large number of studies have been conducted by many researchers: in reference[1], researchers study the bias of gyroscope under different temperatures, verifying the main cause of MEMS gyro bias output characteristics is the change of temperature; in reference [2] simple linear fitting method is used to fit the relationship between temperature and bias of MEMS gyro; in reference [3], using mixed linear regression method, the average bias error can reduce by 1~2 magnitude after the compensation; the author of reference [4] proposed a method of standardization, which uses cross correlation analysis to save time and ensure the accuracy of the model; in [5], a piecewise polynomial method is used to effectively fit the model.

On the basis of previous work, a model of temperature compensation method is put forward in this paper, which is based on the BP neural network. This model can fit the temperature drift of gyroscopes better. The compensated gyro can achieve higher precision than using traditional compensating method, realizing the temperature compensation of the gyro and enhancing the performance of the gyroscope.

2. Analysis of temperature error mechanism of MEMS gyro

The main material of MEMS gyro is silicon, which is sensitive to temperature characteristics, the mechanical and physical parameters such as Young's Modulus and stress are influenced by temperature, and will affect the system stiffness and gyro resonance frequency, causes drift of the output temperature of gyro. The relationship between the natural resonant frequency of gyro and the temperature is

$$\omega(T) = \omega(T_0)[1 - 0.5k_{ET}(T - T_0)] \tag{1}$$

$\omega(T)$ is the gyro's resonant frequency when the temperature is at T ; $\omega(T_0)$ is the gyro's resonant frequency when the temperature is at T_0 ; k_{ET} is the temperature varying coefficient of silicon elastic modulus.

In reference [8], the inherent frequency and its change law of temperature of MEMS gyro is studied, and the result is verified by experiments. Denote the sensitivity of gyro is S

$$S = \frac{2mF_0\omega_d Q_x}{k_x k_y \sqrt{(1 - \frac{\omega_d^2}{\omega_y^2}) + \frac{\omega_d^2}{Q_y^2 \omega_y^2}}} \tag{2}$$

In the formula: m is mass of the gyro, F_0 is the amplitude of electrostatic force; ω_d is the frequency of electrostatic force; Q_x and Q_y is the quality factor of driving and test axis; k_x and k_y is the stiffness coefficient of driving and test axis; ω_y is the resonant frequency of test axis.

With the change of temperature, the sensitivity of gyroscope also changes, causing the temperature drift of scale factor. At the same time, the characteristics of other circuit components will also affect the bias of MEMS gyroscope with the change of temperature. In inertial navigation system, the amount of error caused by the change of temperature will accumulate with the prolonging of time.

3. Analysis of MEMS gyro's temperature test

After the aging test, under the condition of temperature range of -40 $^\circ C$ ~60 $^\circ C$, the whole temperature region and temperature coefficient experiment of MEMS gyro are carried out at every 20 $^\circ C$. The experimental devices is shown in Figure 1.

Fig. 1. Devices of temperature test

As shown above, the MEMS gyroscope is fixed in the thermostat. Test the gyro in the whole temperature zone, the temperature of the thermostat varies from -40$^\circ C$ to 60$^\circ C$ and set the interval of 20$^\circ C$. The ambient temperature points are -40$^\circ C$, -20$^\circ C$, 0$^\circ C$, 20$^\circ C$, 40$^\circ C$, and 60$^\circ C$ respectively. The test starts from -40$^\circ C$, keep half an hour at each temperature point and the gyros is in shutdown state. After the insulation, start the gyro. After about 10 seconds, start recording for 2 minute output data of the gyroscope. Then turn off the gyroscope and heat it for 10 minutes. Then we start the gyroscope to repeat the above steps. At the same temperature, we have measured three sets of gyroscopes output data. After data processing, we can get the zero bias of gyros at every temperature point.

By analogy, the zero deviation results of three tests at each temperature point are obtained, as shown in the following figure.

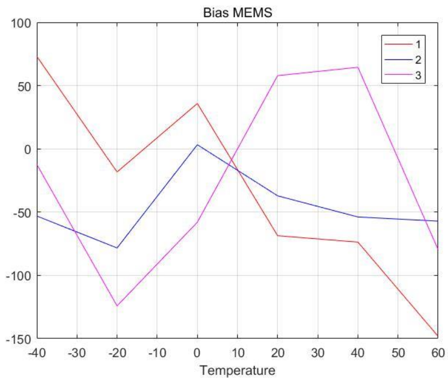


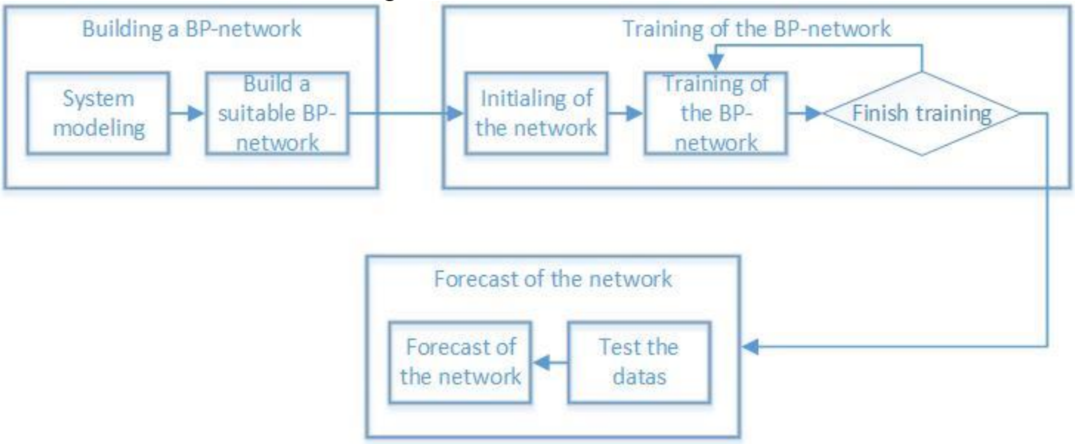
Fig.2. Bias of gyro at different temperature point.

According to Figure 2, although the zero bias fluctuate with temperature. But it still can be seen that the bias gradually reduce to 0 with the increases of temperature, and then increase inversely. In the first test, the difference between bias at -40$^\circ C$ and 60$^\circ C$ is about 220° per hour. These errors due to the change of environmental temperature is very deadly in the navigation calculation. Therefore, it is necessary to establish an error model for the output of gyroscopes, to compensate the output of the gyroscope, so as to improve the precision of the inertial navigation.

4. Compensation model on temperature of MEMS gyro based on BP neural network

In recent years, the application of BP neural network in nonlinear field has increasingly aroused people's attention, because the BP network can represent any nonlinear function, and has parallel distributed processing ability and adaptive learning ability, strong robustness and fault tolerance, so it is suitable for fitting the complex nonlinear function.

The process of nonlinear function fitting algorithm based on BP neural network can be divided into three steps: BP neural network construction, BP neural network training and BP neural network prediction, as is shown in the following:



Fif.3. Process of BP neural network

In the construction of BP neural network, the structure of network is based on the characteristics of nonlinear function, in this problem, among the parameters that the MEMS gyro bias related to, temperature is the only considered one, so there is only one input and one output. According to the empirical formula, selects 3 nodes in the hidden layer, and form a 1-3-1 structure, that is, the input layer has 1 nodes, 3 nodes in hidden layer, and the output layer has 1 nodes. The BP neural network trains the neural network by using the input and output data of nonlinear function, so that the trained network can predict the output of nonlinear function.

Because the temperature drift function of MEMS gyroscope is an unknown nonlinear function, it is difficult to find the function extremum accurately by data of temperature and gyro drift, so it can be solved by neural network. In addition, the accuracy of MEMS gyroscope is low, the drift curve of temperature has poor repeatability, so in order to obtain more accurate data to consider at the same temperature, so do the same test three times at each temperature point, and will obtain more accurate data according to the principle of BP neural network.

The neural network model has only one input node. In order to make the best use of all three sets of data, the data need to be processed.

Suppose that the three sets of data are recorded as:

$$Bias_1(T), Bias_2(T), Bias_3(T) \tag{3}$$

$Bias_i(T)$ is the bias data of MEMS gyro from each group, T is the temperature data.

In order to merge the data into an array, the temperature points of the two sets of data are moved to the left in a smaller unit $\vartriangle T$, denote $\vartriangle T = 0.1$.

Thus

$$Bias(T) = [Bias_i(T - \vartriangle T), Bias_2(T), Bias_3(T + \vartriangle T)] \tag{4}$$

Next, use MATLAB to train the neural network and get results of BP neural network training.
Take the test data into the network and draw it in the same graph with the original data:

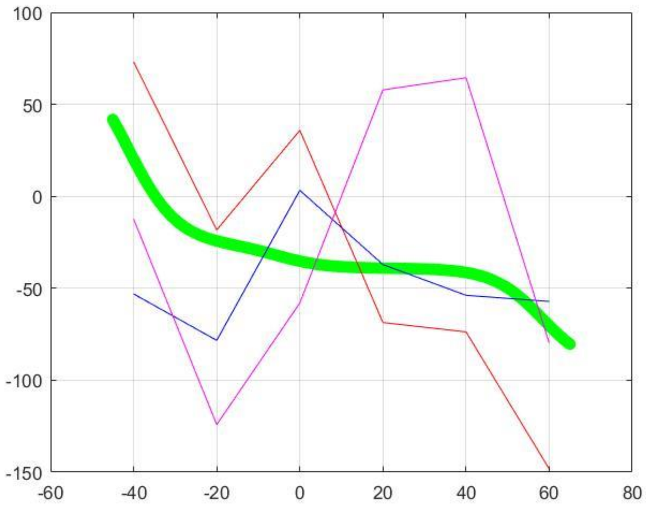


Fig.4. The test result of BP neural network

5. Result analysis

According to figure 4 it can be seen that although the amount of data is small, the network training model can fit the bias changes with the temperature well. According to the previous theoretical analysis in [9], gyro bias is monotonically with increasing temperature change, it can be seen that the BP neural network model has been better fitting the temperature drift model of MEMS gyro, and also abandon some abnormal points in the process of training, and achieved good results.

6. Conclusion

In this paper, through theoretical analysis, the temperature is a main factor that affects the drift of gyroscope, and then a series of experiments are designed for measuring the temperature drift. Due to the low precision of MEMS gyroscope and the weak repeatability of temperature drift, more accurate data have been obtained in laboratory environment by amounts of experiments. Meanwhile, according to the experimental data and the gyroscopic temperature model, a suitable BP neural network is selected, and a group of experimental data is fused into the neural network for training. The results show that the temperature characteristic of MEMS gyroscope is well displayed. In addition, this method has strong expansibility. When the number of experiments increases, it can better approach the real model of gyroscope. This method has strong engineering application value.

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