Temperature Error Modeling Study for Laser Gyro

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Abstract. This paper points out that the laser gyro scale factor is relevant to temperature, temperature increment and temperature rate. Temperature error models of the laser gyro scale factor are set up by the two ways of BP network identification and of Least-Square approximation. BP network identification can approach the nonlinearity of laser gyro scale factor temperature model arbitrarily, and can earn higher precision. Mean squared deviation of the model using BP network identification is smaller than $6.1 \times 10^{-7}$ (/pulse). The Least-Square approximation is simpler, and it is propitious to insure the real-time performance of the system.

1. Introduction
By error of the scale factor in laser gyro we mean the deviation between the actual scale factor and the nominal scale factor. The output beat frequency changes with the changing of the scale factor when the input rate is the same, which affects precision of gyro directly. Temperature affects laser gyro constitutionally and it affects scale factor directly. Measures usually are adopted using hardware for inducing the effect of the temperature [1]. This kind of methods is expensive and the precision is limited. Compensation methods using software are economic and practical [2,3]. Based on lots of experiment data of the laser gyro, temperature error models of the laser gyro scale factor are studied by the two ways of BP network identification and of Least-Square approximation, and results of two ways are compared in this paper.

2. Experiment data analysis
Ten groups of scale factor data with the temperature increasing are shown in figure 1. Testing begins when gyro is switched on. Mean value of all the scale factors is 0.97592 (/pulse), mean squared deviation of all the scale factors is $38.578 \times 10^{-6}$ (/pulse). In figure 1, point shown using $\bullet$ is the starting point of every group. Trend of the points shown using $+$ shows that scale factor diminishes with temperature increasing. The derivate of every group is almost the same. The value of the scale factor is different When starting temperature is different. The value of the scale factor changes more than $140 \times 10^{-6}$ (/pulse) when temperature changes 5°C.

3. Modeling method using BP network
3.1. BP network
The BP neural network is the most representative artificial neural network. It is used extensively because of its advantages. It can provide a model-free input–output nonlinear mapping that does not require a prior statistical model for the input data. It gradually adapts the effect of all the factors
depending on the changeability of the frame and the formidable ability of self-learning then modifies it’s frame for the final goal. BP network is composed of one input layer, some hidden layers and one output layer. There may be one hidden layer or more than two, which lies on special problem. Every layer includes some neurons. All nodes are connected each other between layers. Nodes are not connected each other in the same layer. The study course of the BP network is the back-Propagation course of the error. It adjusts all synaptic weight in the net in order that the net’s output tallies with the desired output. Every synaptic weight in the net will be decided after the study is finished. If there is a group of inputs, the BP network can calculate the output immediately after the study.

![Figure 1. Factual sampling data.](image)

3.2. Temperature error model designing for scale factor using BP network

Temperature, temperature increment and temperature rate have influence on the laser gyro scale factor. Suppose that the temperature of the cabinet where the gyro is put is constant. Gyro temperature is the only observation so three methods are adopted to set up model of the neural network in this paper. In the first method gyro temperature is the only input of the model, so the neural network model is a single-input model. In the second method gyro temperature and temperature increment are the inputs of the model, so the neural network model is a double-inputs model. In the third method gyro temperature, temperature increment and temperature rate are the inputs of the model, so the neural network model is a triple-inputs model. Double-inputs neural network model whose inputs are gyro temperature and temperature rate is set up to experiment. The simulation result shows that there is much saltation in the curve. The experiment manifests that error of the sensor is a litter big, so the temperature rate should not get by difference between the current temperature and the last time temperature. In this paper temperature data is fitted using quadratic polynomial, then temperature rate is got from the differential of the polynomial.

3.3. Simulation testing and analysis

Three neural network models are trained separately using the first method, the second method and the third method based on experiment data. The result of the experiment shows that the fitted lines are not ideal in the first method, the fitted lines are ideal in the second method and the third method. Four groups of simulation results in the third method are shown in figure 2(original data is shown with +, simulation results are shown with curve, initial value of every group data has been set to zero for showing clearly), compensation effects are shown in table 1(there are only simulation result figure and compensation effect table of the third method).
Figure 2. Simulation results using BP network.

Table 1. Compensation effects of model using BP network. (the third method)

| number of group | mean squared deviation of every group/$10^{-5}$ (°/p) | maximal absolute error of every group/$10^{-6}$ (°/p) |
|-----------------|--------------------------------------------------------|------------------------------------------------------|
| 1               | 6.9406                                                 | 1.5863                                               |
| 2               | 6.1014                                                 | 1.5667                                               |
| 3               | 5.7504                                                 | 1.4577                                               |
| 4               | 9.0158                                                 | 2.2588                                               |
| 5               | 5.8906                                                 | 1.2450                                               |
| 6               | 4.6441                                                 | 1.5954                                               |
| 7               | 6.5412                                                 | 1.3997                                               |
| 8               | 4.8442                                                 | 1.2482                                               |
| 9               | 5.5065                                                 | 1.2791                                               |
| 10              | 5.1554                                                 | 1.0699                                               |

Mean squared deviation is $1.168 \times 10^{-5}$ (°/pulse) and the maximal absolute error is $3.591 \times 10^{-6}$ (°/pulse) in the first method. Mean squared deviation is $1.323 \times 10^{-6}$ (°/pulse) and the maximal absolute error is $4.712 \times 10^{-6}$ (°/pulse) in the second method. Mean squared deviation is $6.040 \times 10^{-7}$ (°/pulse) and the maximal absolute error is $2.259 \times 10^{-6}$ (°/pulse) in the third method. These simulation results manifest that fitted precision of the second method is higher, one order of magnitude higher than the first method, the fitted precision of the third method is the highest, one time higher than the second method. Simulation testing validates that temperature, temperature increment and temperature rate affect laser gyro scale factor together, the effect of the temperature rate is less than the other two factors.

Table 2. Least-Square model parameters.

| Model            | $a_0/ \times 10^{-4}$ | $a_1/ \times 10^{-5}$ | $a_2/ \times 10^{-6}$ | $a_3/ \times 10^{-4}$ | $b_1/ \times 10^{-5}$ | $b_2/ \times 10^{-6}$ | $b_3/ \times 10^{-6}$ | $b_4/ \times 10^{-6}$ | $c_1/ \times 10^{4}$ | $c_2/ \times 10^{4}$ |
|------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| The first model  | 9.767                 | 3.788                 | -                     | -                     | 3.775                 | -                     | -                     | -                     | 453.2                 | -                     |
| The second model | 9.773                 | 10.61                 | 1.865                 | -                     | 3.451                 | 8.885                 | -                     | -                     | 183.1                 | 2.233                 |
| The third model  | 6.475                 | 7026                  | -5615                 | 1.987                 | 2.630                 | 3.127                 | 47.55                 | 7.233                 | 1.675                 | 5.311                 | 4.164                 |
4. Modeling method using Least-Square approximation

4.1. Temperature error model designing for scale factor using Least-Square approximation

This paper has validated that temperature, temperature increment and temperature rate affect laser gyro scale factor together. The effect degree of every factor has been pointed out. Three models of the laser gyro scale factor are set up in this paper.

The first method is

\[ P_k = a_0 + a_1 T_0 + b_1 \Delta T + c_1 \dot{T} \]  \hspace{1cm} (1)

The second method is

\[ P_k = a_0 + a_1 T_0 + a_2 T_0^2 + b_1 \Delta T + b_2 \Delta T^2 + c_1 \dot{T} + c_2 \ddot{T} \] \hspace{1cm} (2)

The third method is

\[ P_k = a_0 + a_1 T_0 + a_2 T_0^2 + a_3 T_0^3 + b_1 \Delta T + b_2 \Delta T^2 + b_3 \Delta T^3 + b_4 \Delta T^4 + c_1 \dot{T} + c_2 \ddot{T} + c_3 \dddot{T} \] \hspace{1cm} (3)

Where \( P_k \) is laser gyro current scale factor, \( T_0 \) is initial temperature of laser gyro, viz. environment temperature, \( \Delta T \) is the temperature increment, \( \dot{T} \) is the temperature rate. Above models are gained after that parameters are identified by way of Least-Square approximation. Parameters identified are shown in table 2.

![Simulation results using Least-Square approximation.](image)

**Table 3.** Compensation effects of model using Least-Square approximation. (the third model)

| number of group | mean squared deviation of every group / \( 10^6 \) (\(^{\circ}/\text{p} \)) | maximal absolute error of every group / \( 10^6 \) (\(^{\circ}/\text{p} \)) |
|----------------|-------------------------------------------------|-------------------------------------------------|
| 1              | 6.8635                                          | 17.846                                          |
| 2              | 5.8893                                          | 12.034                                          |
| 3              | 6.8661                                          | 10.056                                          |
| 4              | 9.5239                                          | 14.604                                          |
| 5              | 2.1942                                          | 4.4073                                          |
| 6              | 5.5053                                          | 7.5087                                          |
| 7              | 2.0108                                          | 3.4176                                          |
| 8              | 3.0632                                          | 6.9612                                          |
| 9              | 2.5486                                          | 4.9837                                          |
| 10             | 8.5542                                          | 19.833                                          |
4.2. Analysis of simulation results

Four groups of simulation results in the third model are shown in figure 3 (only simulation results and compensation effect table of the third model are given there), compensation effects are shown in table 3. Mean squared deviation of the first model is $8.880 \times 10^{-6}$ ("/pulse) and the maximal absolute error is $2.301 \times 10^{-5}$ ("/pulse). Mean squared deviation of the second model is $8.531 \times 10^{-6}$ ("/pulse) and the maximal absolute error is $2.048 \times 10^{-5}$ ("/pulse). Mean squared deviation of the third model is $5.637 \times 10^{-6}$ ("/pulse) and the maximal absolute error is $1.983 \times 10^{-5}$ ("/pulse). The analysis of results show that the higher of the model’s order is, the higher of the model’s precision is. Improvement of the model precision is limited and over fitting is likely to occur with the going up of the model order. The higher of the model’s order is, the bigger of the amount of operation is. The big amount of operation makes that the system whose core sensor is laser gyro is difficult on real-time performance. So order of the model should be selected according to the special situation to balance the need of the precision and the need of the real-time performance in the engineering application.

5. Comparison of simulation results between BP network model and Least-Square model

Comparison between figure 2 and figure 3 manifests that the BP network’s fitting effect is better than the Least-Square approximation’s. Comparison between table 1 and table 3 manifests that the BP network’s fitting precision is higher than the Least-Square approximation’s. Comparison of the mean squared deviation between BP network model and Least-Square model manifests that fitted precision of the BP network model is higher, one order of magnitude higher than the Least-Square model’s. In a word, fitting precision of the BP network model is higher. The more outstanding nonlinearity of the laser gyro scale factor is, the more outstanding advantages using BP network is. Least-Square approximation is simple, and can be easily applied into engineering, besides these, the real-time performance of the system is insured easily when the Least-Square approximation is used.

6. Conclusion

The intrinsic characteristic on temperature doesn’t need to be known (it is also needed when experiment is designed and test is executed) and the precision of the simulation model is higher when BP neural network identification is used. Although the disadvantage of using BP network identification is that the model is complex, real-time performance of the compensation will not be affected because of the flying development of the computer technology and the egregious improvement of the computer’s velocity. BP network identification becomes universal modeling tool because of its uniform approximation to nonlinear function. BP network identification has very good application value in improving precision of the temperature modeling for gyro laser scale factor. The advantage of using Least-Square approximation is that the arithmetic is simple. Least-Square approximation has been used into the practical temperature compensation and is useful for engineering application.

References

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