Application of BP Neural Network in Cross-Sensitivity Solution of Temperature and Strain of FBG Sensor

Yingshan Ma
College of Physics and Optoelectronic Engineering, Shenzhen University, Shenzhen 518061, Guangdong Province, China

Abstract. Fiber Bragg grating (FBG) sensor has the advantages of long transmission distance and less channel occupied by data acquisition instrument, so it can be used for strain measurement of power engineering and electronic engineering and so on. FBG is sensitive to both strain and temperature, that is, both changes can change the central wavelength of the grating. In structural health monitoring, the load on the tested part is complicated, and the temperature also changes greatly in the long-term monitoring process. If the FBG sensor is fixed on the tested component, it will inevitably be affected by the combined action of temperature and strain at the same time, making the test result produce error or deviation. In this paper, the temperature compensation of FBG strain sensor is analyzed and studied. Based on the calibration data, the FBG strain sensor temperature compensation is realized by BP Neural Network Algorithm. The research results of this paper can be used as a reference for health monitoring of large-scale structures using FBG sensors.

1 Brief Introduction of existing compensation methods

Because FBG is sensitive to both temperature and strain, in order to make the measurement more accurate and reliable, it is necessary to eliminate the influence of temperature on the result of strain measurement by FBG strain sensor. In view of this problem, domestic and foreign scholars have done a lot of research work, and put forward a variety of solutions, in general can be divided into two categories: Structural Compensation and data correction. Among them, the sensor structure compensation is mainly through the special structure or multi-sensor measurement at the same time to achieve the compensation\cite{1,2}. However, this method is expensive and the measurement results are not accurate. The method of measurement data correction of measurement data is to eliminate the temperature effect in data by signal processing and correlation calculation. By setting another FBG sensor in the same temperature field as the FBG strain sensor, the temperature of the test environment is measured and collected synchronously, and the strain data is corrected and processed by mathematical method. Measurement data correction is used in this paper.
2 OS3110 sensor parameter calibration test

When the strain and the temperature act on the fiber grating at the same time, it is not accurate to measure the total offset by simply adding the wavelength offset when the strain and the temperature act alone, cross sensitivity can also be used to describe the degree of interaction, which has been described in the relevant literature and given a more detailed theoretical derivation\[^{3-4}\]. In the later experiments, the bare fiber optic strain gauge will be selected. In this section, only the temperature compensation of this type of sensor will be analyzed and studied. The schematic diagram of the calibration test is shown in Figure 1.

![Figure 1. Schematic diagram of calibration test.](image)

Before the test, the free end of the cantilever beam was preloaded for 3 times, and the initial wavelength of the sensor was determined to be 1560.78nm. At this time, the room temperature was 20°C. The temperature in the test area was adjusted by the heater. The change gradient was 5°C, and the range was 20°C ~ 40°C. The free end of the cantilever beam was gradually loaded at each temperature level, the loading range was 0 ~ 6kg, and each 1kg increase was recorded, and the test was repeated. For length only, some experimental data are given in Table 1, where the calculation of microstrain refers to the use of formula to calculate the specific value after temperature compensation.

| Loading(kg) | The wavelength(nm) | Calculated microstrain | Strain collector Value | error  |
|-------------|--------------------|------------------------|------------------------|--------|
| 0           | 1560.601           | -2.86                  | 1.01                   | --     |
| 1           | 1560.963           | 141.097                | 136.781                | -3.16% |
| 2           | 1561.527           | 293.601                | 316.982                | 7.38%  |
| 3           | 1562.268           | 432.454                | 448.091                | 3.49%  |
| 4           | 1563.183           | 573.287                | 604.456                | 5.16%  |
| 5           | 1564.302           | 740.861                | 779.864                | 5.01%  |
| 6           | 1565.627           | 904.167                | 959.681                | 5.78%  |

It can be seen from the statistical results in Table 1 that the calculated strain value after compensation is close to the strain collector value.
3 Temperature compensation based on neural network

3.1 Temperature compensation principle of BP neural network

Among various neural Network models, BP Network is a kind of multi-layer feedforward neural Network, which has been widely used for its advantages of simple modeling and stable working state[5]. The temperature compensation principle of BP neural network is as follows: the actual output wavelength and environmental temperature parameters of the strain sensor are input into The BP network, and the output result has eliminated the influence of temperature. The compensation network structure is shown in Figure 2.

![Figure 2. Neural network model of temperature compensation.](image)

In the figure, $\mu E_0$ is the actual strain measurement value, $\lambda$ is the actual wavelength response value of the fiber grating strain sensor, $t$ is the measured temperature value of the reference temperature sensor, and $\mu E$ is the neural network simulation value. If the network can meet the working requirements $\mu E_0$, the output value of the network $\mu E$ should be very close to the actual strain measurement value. The $\lambda$ and $t$ is input into the trained neural network for processing, and the output value $\mu E$ is the strain measurement value after temperature compensation.

3.2 Determination of BP neural network structure

According to the relevant research results of previous scholars, the forward network of a single hidden layer can map any continuous function. The functional relationship between input and output in this paper is relatively simple, so this paper uses a single hidden layer BP neural network. The method to determine the best hidden node is called trial and error method. When trial and error method is adopted, some empirical formulas can be referred to as the initial value of trial and error method[6]. The empirical reference formula is:

\[
\begin{align*}
    w &= \sqrt{(a + b) + \alpha} \\
    w &= \log 2^w \\
    w &= \sqrt{ab} \\
    w &= 2a + 1
\end{align*}
\]
In Formula (1)-(4), \( W \) represents the number of hidden layer nodes, \( a \) represents the number of input layer nodes, \( b \) represents the number of output layer nodes, and the \( \alpha \) represents constant between 1 and 10. The number of hidden layer nodes and the network structure of BP neural network are determined by trial and error method as 3 and 2:3:1 respectively.

### 3.3 Training and simulation of BP neural network

This paper use MATLAB software to realize the establishment, training and simulation of BP neural network model\(^7\). The first set of test data in the calibration test was used for the training sample data. The wavelength and temperature were taken as inputs, and the actual measurement value of the resistance strain gauge was used as the target value. The second set of measured data was used to verify the trained BP neural network, and the statistical error was calculated. The network model construction in MATLAB is shown in Figure 3.

![Figure 3. BP Neural network temperature compensation model software construction plans.](image)

Before training, data should be normalized, such as setting the learning rate, maximum of training times, momentum factor and minimum mean square error of the network. The detailed setting is operated in the software as follows:

```matlab
Net.TrainParam.Lr = 0.1;
Net.TrainParam.MC = 0.9;
Net.TrainParam.Epochs = 10000;
Net.TrainParam.Goal = 1e-3;
```

The simulation results of the networks obtained by different training functions are different from each other. After comparing and using multiple training functions, this article selects the trainingdm function as the training function constructed by the neural network in this paper. Due to space limitations, the comparison process is not discussed. The simulation results are shown in Figure 4. After 7071 trainings, the network accuracy reached 0.00999995.
The second group of measured data was used to test the trained network. Due to space limitation, this paper only listed the test results of the single group of data. Specific results are shown in Table 2.

| The simulation value | 1.01 | 137.781 | 316.982 | 448.091 | 604.456 | 779.864 | 959.681 |
|----------------------|------|---------|---------|---------|---------|---------|---------|
| The measured values  | -2.08 | 142.981 | 295.896 | 431.667 | 572.187 | 739.897 | 903.998 |
| error                | 4.53% | -6.65%  | -3.67%  | -5.34%  | -5.13%  | -5.82%  |

### 4 Conclusion

From the above software simulation results can be seen, the actual output wavelength value of the strain sensor is significantly reduced by the artificial compensation of the neural network. The minimum error in the table is only -3.67%, the maximum error in the table is -6.65%, but considering the influence of factors such as neural network parameter settings and training functions on the result, the BP neural network is used for temperature compensation is still a good choice. This method has good guidance for structural health monitoring using FGB sensors.

I would like to express my gratitude to those who helped me in the process of writing this paper. I would like to thank the technical staff of Dalian Zhongzhen Intelligent Technology Development Co., Ltd. for providing relevant data and technical support.

### References

1. Zhang Jintao. Health Monitoring Technology based on fiber Bragg grating sensing networks[D]. Harbin: Heilongjiang University, 2005.
2. Yang Kejian. Structural health monitoring system based on FBG sensor and its application[J]. Journal of Xihua University (9 Natural Science Edition 0, 2019, 38(1): 20-31.
3. Ye Changjin. Characteristics of Fiber Bragg gratings[D]. Chengdu: University of Electronic Science and Technology, 2008.
4. Zhang Panheng. Application of FBG sensor in structural health monitoring[J]. Telecom World, 2018(5):328-329.

5. Xiong Fan et al. Application of Matlab-based BP neural network in predicting TBM tunneling speed[J]. Modern Tunnelling Technology, 2017, 54 (5): 101-107.

6. Shi Jianjun et al. Blasting vibration prediction system based on Matlab and BP neural network[J]. Explosion and Shock, 2017, 37 (6): 1087-1092.

7. Wen Xinyan, Liu Hao. MATLAB R2018a from entry to mastery[M]. Tsinghua University Press, 2019.