Biaxial Angle Sensor Calibration Method Based on Artificial Neural Network

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With regard to the nonlinearity, installation errors and other uncertainties existing in biaxial inclination sensors of borehole inclinometer, this article contrastively applies traditional curve fitting method and artificial neural network theory in the error correction work of inclinometer. Besides, this article also establishes the coordinate transformation model and gives details about the traditional curve fitting method; meanwhile, this article sets up a BP neural network with 2 inputs and 2 outputs to do the curve fitting. After the test, it is proved that the neural network has superiorities of less work and high correcting precision, which means this neural network can be a new kind method for effective error correction.

1. Introduction

Borehole inclinometer is an instrument which measure the lateral displacement of objective depth of drilling in the rock (soil). In the field of geological disaster monitoring, through the application of the instrument at home and abroad for many years, it has been proved to be an effective method of monitoring landslide deep displacement monitoring. In addition to the field of geological disasters, the instrument can be used for geotechnical, exploration, bridge and tunnel, construction, dam safety and other areas. Because the sensor of borehole inclinometer is easily affected by the installation position and individual differences, it must be calibrated before they go out to be able to make the instrument has good accuracy and interchangeability. The traditional calibration methods mainly include linear regression, polynomial models, etc. According to the actual production experience, traditional calibration methods mainly have the following defects: (1) Nonlinearity of sensor between input and output is difficult to simply fit; (2) There is an angle between the sensor sensitive axis and the axis of rotation of correction units. it is hard to calculate and the accuracy is not high; (3) Because of the biaxial sensor output, the change of one shaft may effect another shaft, and it is difficult to use a mathematical model to describe the error and this effect is uncertain.

2. Measuring Principle

The core device of borehole inclinometer is biaxial angle sensor. The dual axis of biaxial angle sensor is an orthogonal coordinate which is projected in the horizontal plane—X axis and Y axis. As shown in figure 1, suppose OZ as vertical direction, OA direction as the direction of drilling. Early drilling direction and gravity direction coinside, but because of the movement of landslide, the drilling tilted. Borehole inclinometer is working to measure the angle between OA and Z axis. According to the output, the biaxial Angle sensor can get ∠BOD and ∠COD. By trigonometric function relationship, can synthesize ∠AOD. According to the angle and the embedding depth can calculate the horizontal displacement, provided criterion for rock and soil deformation trend.
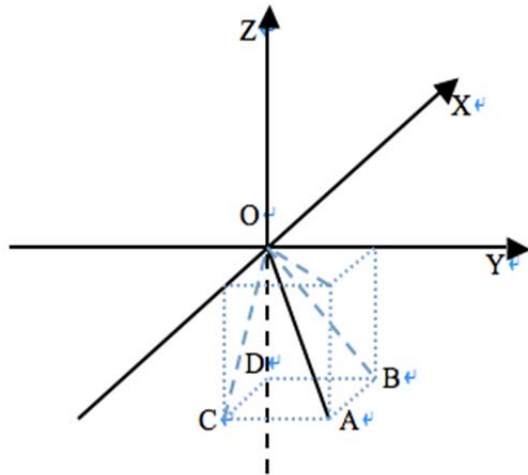
Figure 1: Borehole inclinometer measuring principle diagram

3. Calibration Test

In theory, the sensor is installed in the horizontal plane, as shown in Figure 2 (A). But as a result of sensor manufacturing process, cannot guarantee the sensor in the horizontal plane, as shown in figure 2 (B). The real coordinates O"X"Y"Z " can be regarded as the sensor coordinate system OXYZ after two times of rotation, namely revolve on Y axis at α get coordinate system O'X'Y'Z' at first, and then r revolve on X axis at β, as shown in figure 2 (C) (D). Therefore, the equipment calibration is one of the aims of eliminating the influence of the installation error.

In the meantime, the output curve of dual axis tilt sensor is nonlinear which the same as all sensors be. In order to improve the precision of the instrument, it needs curve fitting of input and output.

The instrument is fixed on the calibration table, revolving on the O point in the plane of XOZ and YOZ, reading the data every 5 degrees. The data has been divided into 7 groups, and the experiment has been repeated 3 times. The instrument uses 16 bit AD conversion chip, and the output of the sensor is voltage signal. The theoretical output is 0 while the sensor in -15° and the theoretical output is 65535 while the sensor in +15°.
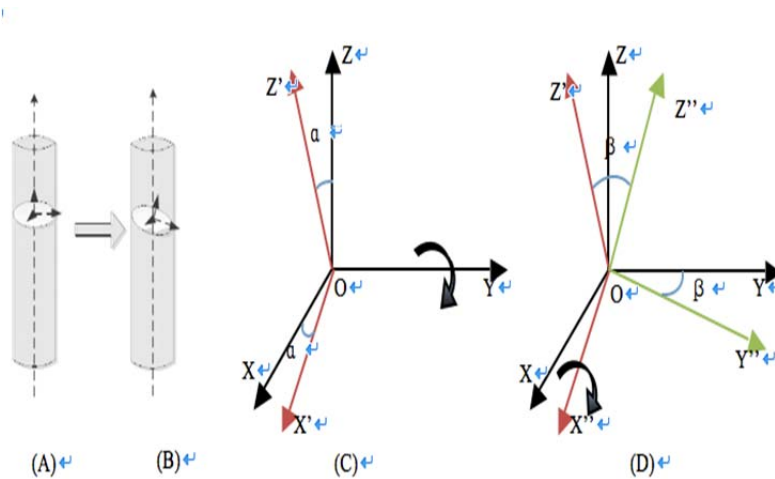

Figure 2: Sensor installation error and coordinate transformation diagram

4. Traditional Method of Correcting

The traditional calibration methods in this paper is using the data of the sensor output, according to the survey principle, and calculating the α, β. According to coordinate transformation theory, the data in the actual coordinate system O"X"Y"Z" is transferred to the horizontal coordinate system OXYZ, then make curve fitting in OXYZ coordinate system, finally find out after the correction of coordinates.
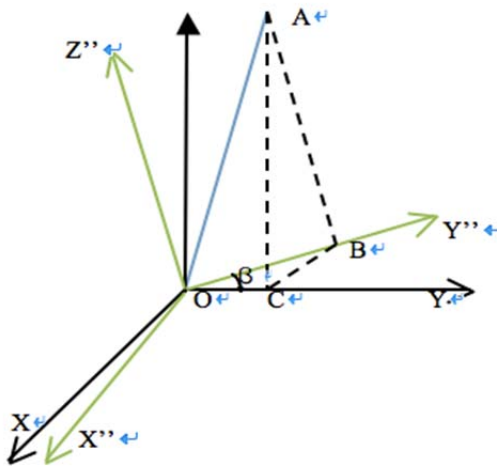
Figure 3: Coordinate transformation diagram

Define the sensor input and output response curve matrix

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} k_x V_{X_i} + b_x \\ k_y V_{Y_i} + b_y \end{bmatrix}$$

(1)

V_{X_i} and V_{Y_i} are output value of the sensor after coordinate transformation, x and y are output value after curve fitting.

According to the theoretical value of sensor, we can calculate the amplification coefficient $k_x = 1.197$, $k_y = 1.195$, and the bias coefficient $b_x = -6562.35$, $b_y = -6979.16$.

5. Neural Network Correction

5.1 Questions
In the context of the traditional calibration method we can find, the angle calculation is very complex and the calculation of curve fitting with the increasing of the sampling points will be greater. Faced with non-linearity of the sensor, installation angle in the instrument, and biaxial correlation, the borehole inclinometer is attached to a model like a black box which input is the angle and output is voltage. Processing method of BP neural network, is a good way to solve the problem of black box.

5.2 Solution
BP neural network is a kind of three or more than three layers neural network, including an input layer, one or more hidden layer (middle layer), one output layer. Below is the typical three layer BP network structure. R is the number of input layer nodes, S1 is the number of hidden layer nodes, S2 is the number of output layer node.
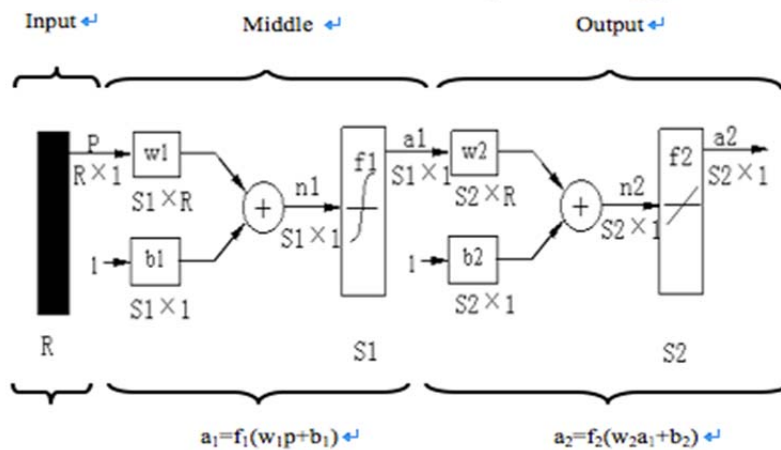
Figure 4: The principle diagram of the BP neural network structure

Define the function between input and output of biaxial angle sensor is

$$(x, y) = f(\alpha, \beta, \varphi, \tau) \tag{2}$$

x, y are the biaxial Angle sensor output voltage value, α, β are the actual tilted angle, φ is the angle between installation of the sensor and correction error state, τ is biaxial uncertainty relation of mutual influence. Obviously, the function F is a nonlinear function.

There is a one-to-one relationship between α, β and x, y, and there must be a function

$$(\alpha, \beta) = g(x, y, \varphi, \tau) \tag{3}$$

This function is nonlinear and also difficult to obtain. But the characteristics of the neural network could be used to simulate any nonlinear function at any accuracy. The correction could be achieve by using the part of a compensation which be trained by neural network, as shown below.
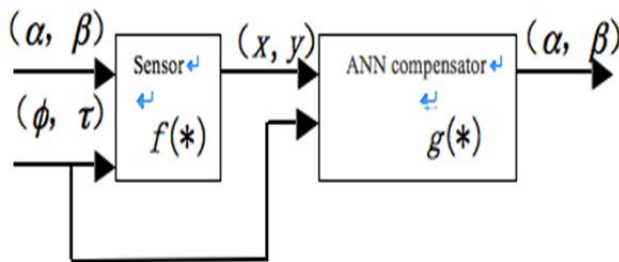

Figure 5: The principle diagram of the neural network error correction

5.3 Simulation and test

Set up a BP neural network with 2 inputs, 2 outputs and 3 middle layer. Two input nodes input X-axis and Y-axis data of the sensor, and two output nodes output the theoretical value of the X-axis and Y-axis. The number of the middle hidden layer nodes is 10 according experience, learning factor, and learning target is 10^{-7}.

Additionally, record 5 groups of test data, as shown in table 1. We can find the predictive value by neural network. Predictive value, measured value and theoretical value are draw as shown figure 6.

We can see clearly from the map, the measured value which be corrected is closer to the theoretical value than measured value. For example, the maximum error of the third groups of data without corrected reaches 8.6%;however, using the traditional method of calibration, error is reduced to 3.2%, while the neural network correction, the error is reduced to 1.6%; The fourth group of data is the most able to reflect the effect of two

correction methods. The error is 25.5% by using traditional calibration method, while adopting the method of neural network correction error is only 6%.
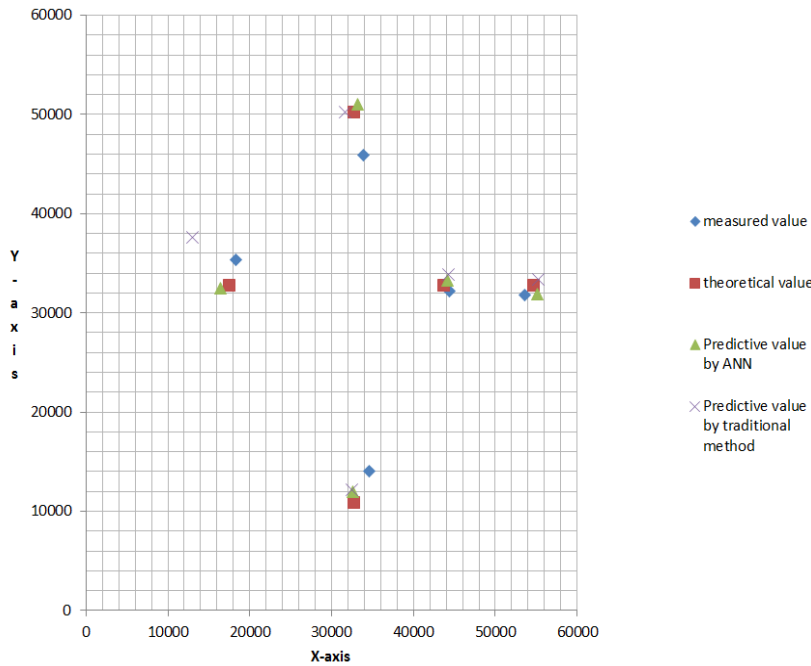

Figure 6: Two methods of correction effect contrast figure

6. Conclusions

By adopting traditional error correction method to calibrate biaxial tilt sensor, the accuracy is not high enough in addition to complex calculation process. The main reason is that, apart from the installation error, simple curve fitting cannot fully meet the nonlinear characteristics of sensor, and does not take into account that the biaxial tilt sensor with two ways of output signal, there may be other unexpected types of action. Neural network method is very suitable for dealing with this kind of black-box problem. This thesis innovatively adopts BP neural network with two ways of input and output to conduct error calibration on biaxial tilt sensor. Different from traditional calibration sensor method by neural network with single output, this thesis is actually carrying out surface fitting to the sensor with biaxial output. The testing result shows that by adopting BP neural network to carry out error correction on biaxial tilt sensor, it not only improves the accuracy of the instrument, improves the interchangeability among instruments, but is superior to curve fitting method in terms of the amount of computation and correction effect, therefore, it is a new method for instrument calibration.

Table 1: Contrast figure of two correction methods

data	measured value		theoretical value		traditional method		Ann method	
	X	Y	X	Y	X	Y	X	Y
1	44395	32159	43693	32767	44234	33830	44118	33258
2	53563	31815	54611	32767	55199	33419	55156	31868
3	33927	45902	32767	50246	31704	50251	33190	51038
4	18300	35298	17478	32767	13021	37580	16422	32444
5	34607	13997	32767	10923	32539	12128	32552	12022

Acknowledgments

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