Acta Technica 62 (2017), No. 5A, 589–596

Data processing method for the division-of-amplitude photopolarimeter based on an artificial neural network

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Abstract. The Division-of-Amplitude Photopolarimeter (DOAP) is a kind of widely used sensors. In order to improve the measurement precision of DOAP, aiming at the problems existing in the data processing of DOAP, this paper presents the data processing method of DOAP with neural network. Firstly, the measurement data of polarization polarizer is collected, and then the BP neural network is used to fit the relationship between the input signal and the output signal. Finally, the DOAP is used to process the data. The experimental results show that this method can improve the accuracy of data processing of DOAP and control the data processing error within the actual requirements, has wide application prospect.

Key words. Division-of-amplitude photopolarimeter, data processing, time series, neural network.

1. Introduction

The Division-of-Amplitude Photopolarimeter (DOAP) is a kind of optical wave sensor which can measure the speed of the measurement, and its variation characteristics are analyzed to improve the measurement accuracy. Therefore, it is of great significance to design the data processing method of the DOAP with excellent performance [1-3]. In the process of data processing of the DOAP, the measurement accuracy of the spectrometer is greatly reduced due to the influence of many factors, such as background light [4-6]. In order to improve the measurement accuracy of the DOAP, the traditional method of data processing of the DOAP is analyzed by means of the estimation of the relationship between the input and output signals of the DOAP, the data processing method of the DOAP is established [7]. However, this method is computationally expensive and can only fit the linear variation of the data, so that, it makes DOAP data processing result is not optimal, and leads to low DOAP precision [8,9]. Aiming at regression analysis of the deficiencies, some scholars put forward neural network is adopted to establish the DOAP data processing

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method [9], the nonlinear fitting characteristics of neural networks are used to fit the input and output signal relations of the DOAP, obtained the quite ideal DOAP treatment effect, improving the measuring accuracy of the DOAP. However, the neural network is in the process of data processing of the DOAP, the parameters of the neural network are very important. If the hidden layer kernel function selection is not reasonable, the structure of the neural network is not optimal. Therefore, a reasonable hidden layer kernel function is set up to get the premise of the measurement result of the ideal DOAP.

In order to improve the measurement accuracy of the DOAP, aiming at the selection of hidden layer kernel function of neural network, a wavelet function is put forward as a hidden layer kernel function, and a neural network based data processing method for the DOAP is proposed. First, we collect the input and output signals of the DOAP. Then we use neural network to establish the data processing method of the DOAP. Finally, we analyze the measurement effect of the DOAP through simulation experiments. The results show that this method solves the problem of hidden layer kernel function selection in neural network, improves the measurement accuracy of the DOAP, and has superiority over other methods.

2. The working principle of DOAP

The DOAP is a common measuring sensor. The working principle is shown in Figure 1.

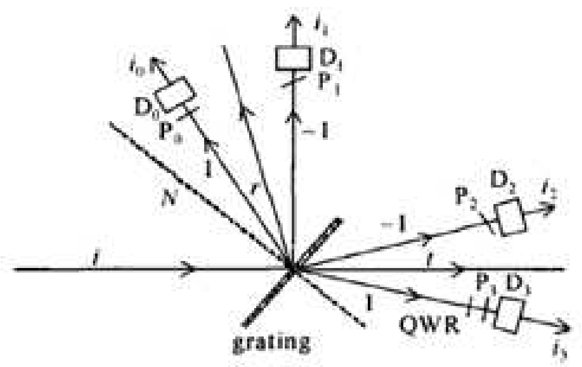

Fig. 1. The working principle of the DOAP

The grating can produce diffraction of reflected light and transmitted light. According to the measurement of four beams of light such as reflected light and transmitted light, we will convert four photoelectric detectors and circuit system signals into electrical signals, and we will use the formula (1) to describe them.

$$I = [i_0 \; i_1 \; i_2 \; i_3]^T \tag{1}$$

In this form, T is transposed.

The working process of the DOAP does not take into account the influence of background light and other nonlinear factors, the relationship between the electrical signal and the incident light

$$S_i = [s_0\ s_1\ s_2\ s_3]^T\, is : I = A\,[s_0\ s_1\ s_2\ s_3]^T \tag{2}$$

In the form, A represents the instrument matrix.

According to the inverse matrix A^{-1}, the table mode of $S_i = [s_0\ s_1\ s_2\ s_3]^T$is obtained:

$$S_i = A^{-1} I \tag{3}$$

The I is obtained from the output of the electric system, and the parameters of the light polarization state are estimated according to the formula (3).

3. Neural Network

3.1. Wavelet Function

Wavelet analysis is a signal analysis method, which not only has the frequency domain processing function of Fourier transform, but also has insensitivity to translation and expansion transformation. Set $\psi(x)$ is the mother wavelet, so the wavelet function $\{\psi_{a,b}(x)\}$ is defined as follows:

$$\left(\begin{array}{c} X \\ P(X) \end{array}\right) = \left\{\begin{array}{cccc} a_1, & a_2, & \cdots, & a_m \\ p(a_1), & p(a_2), & \cdots, & p(a_m) \end{array}\right\} \tag{4}$$

In the formula, Variables a and b are scaling and translation factors.

The function f (x) L^2 is introduced, and the wavelet transform is obtained.

$$\begin{aligned} W_f\,(a,b) &= \langle f, \psi_{a,b}\rangle \\ &= \int_{-\infty}^{+\infty} f\,(x)\, \tfrac{1}{\sqrt{a}} \psi\left(\tfrac{x-b}{a}\right) dx \end{aligned} \tag{5}$$

And satisfy the following conditions:

$$\sum_{i=1}^{m} p(a_i \tag{6}$$

3.2. Neural Network

In all neural networks, because of the error feedback function, the BP neural network has the strongest nonlinear mapping ability and the wide range of applications. In this paper, the wavelet analysis is introduced into the BP neural network to speed up the learning speed of the neural network and improve its fitting ability. The Sigmoid function of the wavelet function agent neural network is used to make the neural network more flexible by using the parameters of scale and translation as weights and threshold parameters. The results of the 3 layer structure of the neural network are shown in Figure 2. The Morlet function is used in the hidden layer, which is as follows:

$$\psi(x) = cos(1.75x)\, exp\left(-x^2/2\right) \tag{7}$$

The Sigmoid function is used in the output layer, which is as follows:

$$f(x) = 1/1 + exp(\lambda x) \tag{8}$$

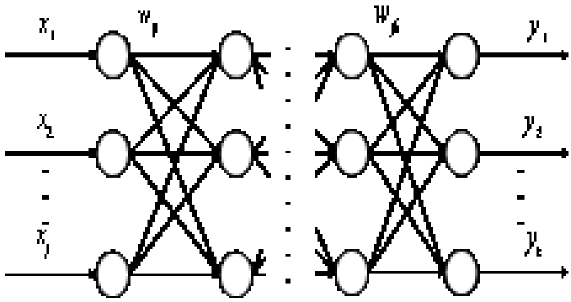

Fig. 2. Structure of neural network

The number of nodes in the input layer, the hidden layer and the output layer of the neural network is I, H, and O, and then the node j is defined as follows:

$$net_j = \sum_{i=1}^{I} \frac{(w_{ij}x_i - b_j)}{a_j} \tag{9}$$

The output of the node K is:

$$O_k = w_{jk} f(\sum_{j=1}^{H} w_{ij}(\psi_{a,b}(net_j) + \delta_j)) + \delta_k \tag{10}$$

Among them, the parameters J and K represent the threshold.

In the learning process of neural network, we calculate the error between expected value and prediction value. If the prediction error cannot meet the presetting requirement, we must constantly adjust the weights and thresholds. That is

$$\frac{\partial E}{\partial w_{jk}} = \sum_{p=1}^{P} (d_k - O_k)\, O_k\, (1 - O_k)\, y_j \tag{11}$$

$$\frac{\partial E}{\partial w_{ij}} = \sum_{p=1}^{P} (\sum_{k=1}^{O} (d_k - O_k)\, O_k\, (1 - O_k)\, w_{jk}) \frac{\psi'_{a,b}(net_j)}{a_j} x_i \tag{12}$$

$$\frac{\partial E}{\partial \delta_k} = \sum_{p=1}^{P} (d_k - O_k)\, O_k\, (1 - O_k) \tag{13}$$

$$\frac{\partial E}{\partial \delta_j} = \sum_{p=1}^{P}(\sum_{k=1}^{O}(d_k - O_k)\, O_k\,(1 - O_k)\, w_{jk})\frac{\psi'_{a,b}\,(net_j)}{a_j} \tag{14}$$

$$\frac{\partial E}{\partial b_j} = -\sum_{p=1}^{P}(\sum_{k=1}^{O}(d_k - O_k)\, O_k\,(1 - O_k)\, w_{jk})\frac{\psi'_{a,b}\,(net_j)}{a_j} \tag{15}$$

$$\frac{\partial E}{\partial a_j} = -\sum_{p=1}^{P}(\sum_{k=1}^{O}(d_k - O_k)\, O_k\,(1 - O_k)\, w_{jk})\frac{\psi'_{a,b}\,(net_j)}{a_j}net_j \tag{16}$$

The weights, thresholds and wavelet parameters are corrected, and the corrected quantities are as follows:

$$\Delta w_{jk}(t+1) = (1 - mc)\,\eta\frac{\partial E}{\partial w_{jk}} + mc\Delta w_{jk}\,(t) \tag{17}$$

$$\Delta w_{ij}(t+1) = (1 - mc)\,\eta\frac{\partial E}{\partial w_{ij}} + mc\Delta w_{ij}\,(t) \tag{18}$$

$$\Delta \delta_k(t+1) = (1 - mc)\,\eta\frac{\partial E}{\partial \delta_k} + mc\Delta \delta_k\,(t) \tag{19}$$

$$\Delta \delta_j(t+1) = (1 - mc)\,\eta\frac{\partial E}{\partial \delta_j} + mc\Delta \delta_j\,(t) \tag{20}$$

$$\Delta b_j(t+1) = (1 - mc)\,\eta\frac{\partial E}{\partial b_j} + mc\Delta b_j\,(t) \tag{21}$$

$$\Delta a_j(t+1) = (1 - mc)\,\eta\frac{\partial E}{\partial a_j} + mc\Delta a_j\,(t) \tag{22}$$

4. Data processing of DOAP in a neural network

During the data processing of the DOAP, the relationship between the input signal and the output signal cannot be described by the formula (3). The BP neural network has good nonlinear regression. The input signal of the polarization amplitude polarizer is used as the input vector of the BP neural network, and the polarization parameter of the incident light is used as the output vector of the BP neural network. The wavelet function is used as the core function of the hidden layer to establish a DOAP based neural network. The weights and thresholds of the neural network are constantly adjusted so that the mapping relationship between the input signal and the output signal of the polarization polarizer is infinitely approached. When the estimated error between the actual output and the expected output of the neural network satisfies the actual requirements of the data processing of the polarization amplitude polarizer, the optimal data processing method of DOAP is established. The specific steps are as follows:

(1) The learning data of the neural network is generated by the polarizer of the DOAP and the normalization of the emitted light parameters is normalized. That is:

$$S = \begin{bmatrix} 1 \\ \cos 2Q \cos(2Q - 2\theta) \\ \sin 2Q \cos(2Q - 2\theta) \\ \sin(2Q - 2\theta) \end{bmatrix} \tag{23}$$

In the formula, $\theta$and Q are the azimuth angles of the bias and the wave plates respectively.

(2) According to the input signal, the stokes parameters of the DOAP are calculated, and they are used as the output layer data of the neural network.

(3) The maximum error of training times and accuracy of measurement is set up. The neural network is used to fit the learning samples, and the data processing method of the DOAP is established.

5. Experimental results and analysis

In order to analyze the effectiveness of the data processing of the DOAP of the neural network, some samples are collected as the experimental objects, and the data are shown in Table 1.

Table 1 Experimental data

Sample number	i_1	i_2	i_3	i_4	s
1	0.150	0.013	0.342	0.800	1.118
2	0.172	0.002	0.738	0.221	0.763
3	0.233	0.007	0.356	0.784	0.488
4	0.285	0.034	0.505	0.216	0.174
5	0.163	0.007	0.414	0.784	0.449
6	0.425	0.189	0.232	0.909	0.616
7	0.217	0.173	0.163	0.250	0.514
8	0.251	0.159	0.049	0.513	0.319
9	0.394	0.308	0.008	0.555	0.529
10	0.125	0.345	0.005	0.478	0.402
...	...	...	...	...	...

The data of table 1 are studied by this method, and 50 samples are selected for analysis, and the results are shown in figure 4. It can be seen from figure 3, that is, the method can obtain the data processing effect of the ideal DOAP, and the experimental results show that the method is effective.

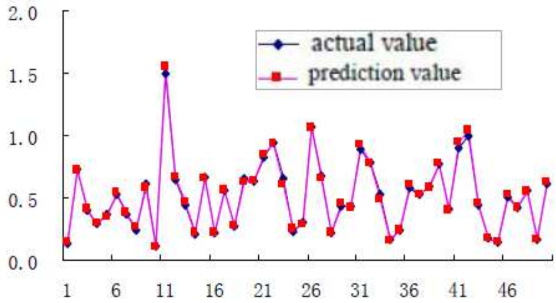

Fig. 3. The processing results of the DOAP in this method

In order to test the superiority of this method on DOAP data processing, choice of comparison matrix operation and data processing method of neural network based on the literature [10], the neural network literature [10]by using the Sigmoid function as the kernel function of the hidden layer, their processing precision are shown in table 2. The table shows that, the method presented in this paper DOAP data processing result has obvious advantages, is a kind of high precision for the DOAP data processing method.

Table 2 Comparison of processing precision with other methods

The name of the method	The processing precision /%
Matrix operation method	86.35
literature	93.29
This paper method	96.47

6. Concluding remarks

In order to improve the measurement precision of DOAP, aiming at the problems existing in the data processing of DOAP, this paper presents the data processing method of DOAP with neural network. Firstly, the measurement data of polarization polarizer is collected, and then the BP neural network is used to fit the relationship between the input signal and the output signal. Finally, the DOAP is used to process the data. The experimental results show that this method can improve the accuracy of data processing of DOAP and control the data processing error within the actual requirements, has wide application prospect.

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Received November 16, 2017