ICIC Express Letters ICIC International ©2016 ISSN 1881-803X
Volume **10**, Number **3**, March **2016** pp. 585–591

NEURAL NETWORK COMPENSATION APPLICATION FOR OPTICAL FIBER HYDROGEN SENSOR BASED ON THE VIRTUAL INSTRUMENT

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Received August 2015; accepted October 2015

Abstract. *The present work investigates neural network compensation for optical fiber hydrogen sensor based on virtual instrument. Due to the performances of optical fiber hydrogen sensor changes under the influence of outside vibrations and noises seriously, the virtual instrument and neural network were introduced to the optical fiber hydrogen sensor as compensation method. Experimental results and numerical simulation indicated that the hydrogen sensor with neural network could enhance the nonlinear correction for hydrogen sensor and decrease the interferences effectively. Simultaneously, by way of the contrast test of the traditional linear fitting, experimental results showed that the intrinsic error of hydrogen sensor of full measurement scope could reach 2.6%, and concluded that the proposed neural network compensation based on virtual instrument is an efficient and effective approach to eliminate all sorts of interferences and enhance the linearity and stability of optical fiber hydrogen sensor.*

Keywords: Neural network compensation, Hydrogen sensor, Virtual instrument, Optical fiber sensor

1. **Introduction.** Great interest has concentrated on research and development of clean and renewable energy since the global is getting warmer and warmer. Hydrogen gas is a clean and possibly inexhaustible energy source with the potential to be a panacea for next generation of clean energy [1]. Due to its wide explosion concentration range, low ignition energy and large flame propagation velocity, hydrogen is dangerous; hence development of sensitive, reliable hydrogen sensor is required. The measurement and control of hydrogen concentration have been a challenging technological problem and attracted much research and development efforts in recent years [2]. For hydrogen detection, optical techniques seem to be more attractive in hazardous atmospheres owing to the lack of sparking possibilities [3]; at the same time, with advantages of smaller size, higher speed of response, greater accuracy, better reliability, freedom from electromagnetic interference and non-destructiveness [4], the fiber optical sensors have been used in industry for detecting the concentration of hydrogen by measuring the optical reflectance change of sensing film due to adsorption and desorption of hydrogen in the film [5-11]. However, under the influence of the intrinsic and extrinsic influences in the detecting process, optical fiber hydrogen sensor has the characteristics of non-linearization in whole output process, so it affected the measurement precision of hydrogen sensor. Generally, the optical fiber hydrogen sensor needs to introduce a reference optical path to eliminate the interferences, and the task of the reference optical path was to acquire the independent environment information for hydrogen sensor. Hence, the non-linear two-dimension inverse model which was based on

the two optical path outputs of the hydrogen sensor was established. The model could describe the circumstance effects on the hydrogen sensor final output.

In this paper, the compensation mechanism based on virtual instrument and neural network was proposed. The optimization solution approach could eliminate instability of the optical fiber light, outside interferences and electronic devices drift. The compensation mechanism could enhance the detective precision and stability of optical fiber hydrogen sensor. The paper presents a key technology neural network to process the output signal from the optical fiber hydrogen sensor probe; through virtual instrument the neural network was used to correct static error, and calibrate nonlinearity of the optical fiber hydrogen sensor. The paper focuses on exhibiting the compensation characteristics of commonly used neural network for optical fiber hydrogen sensor simultaneously.

The remainder of this paper is organized as follows. The fabrication of the optical fiber hydrogen sensor was introduced, and the factors which affected the measurements accuracy or stability of optical fiber hydrogen sensor were analyzed in Section 2. Section 3 describes the neural network compensation mechanism for optical fiber hydrogen sensor, and the mathematic model of proposed compensation algorithm of neural network based on the Labview was given. At the same time, how to apply it to optical fiber hydrogen sensor was described. Section 4 shows the neural network parameter optimization processes which are used for the hydrogen sensor. Then serials of experiments were carried out, and the corresponding experiment results with the proposed neural network based on virtual instrument were obtained. The experiment results were compared with conventional linear fitting algorithms in this section. Finally, concluding remarks and further research are given in Section 5.

2. **Optical Fiber Hydrogen Sensor Fabrication.**

Figure 1 illustrates the fabrication of optical path for reflective optical hydrogen sensor. The performances of optical fiber hydrogen sensor were made up of the following several parts: the LED transmitter, the PIN receivers, optical path, and two reflective ultrathin membranes. The properties of the LED transmitter (S) and PIN receivers (D_R and D_S) were subject to the working time and the environment temperature, so the accuracy and power output of light source declined, and the bending loss for optical fiber reduced the accepted light intensity by PIN receivers. In order to eliminate these adverse effects, the adoptive optical fiber bundle as the optical path for hydrogen sensor could eliminate the noise and interferences.

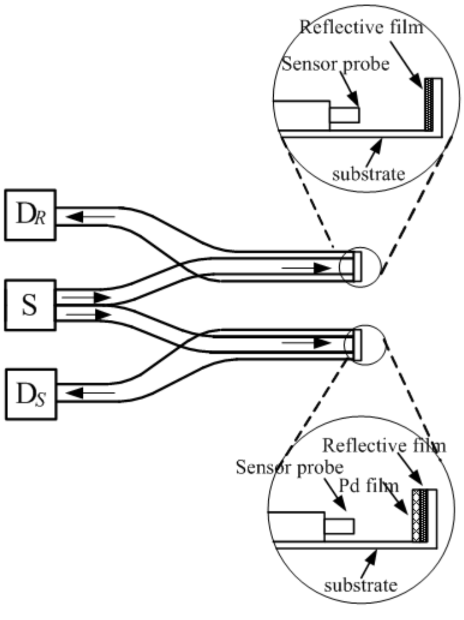


Figure 1. The sketch of optical path for optical fiber hydrogen sensor

In Figure 1, the receiving power of two PIN receivers was expressed by the following equations:

$$D_S = G_S Q_S \delta_S \cdot (k_S I_0) \cdot F_S(r_T, r_R, p, NA, d_S) \tag{1}$$

$$D_R = G_R Q_R \delta_R \cdot (k_R I_0) \cdot F_R(r_T, r_R, p, NA, d_R) \tag{2}$$

The subscript of S and R denoted the sensing optical path and reference optical path respectively in the hydrogen sensor. I_0 was the luminous power of LED transmitter; k was the number of the single optical fibers in optical path, and $k_R/k_S = 1$; δ was the reflectivity of the hydrogen sensor, and δ_S changes along with the hydrogen concentration; G was the voltage gain; Q was the vibration influence coefficient in optical path, and $Q_R \doteq Q_S$; NA was the numerical aperture of the single optical fiber; r was the radius of fiber, and $r_T = r_R$; $F(r_T, r_R, p, NA, d)$ was the optical fiber modulation characteristic function.

The concentration of hydrogen Γ was expressed by

$$\Gamma = \frac{D_S}{D_R} = \frac{G_S}{G_R} \cdot \frac{Q_S}{Q_R} \cdot \frac{\delta_S}{\delta_R} \cdot \frac{k_S I_0}{k_R I_0} \cdot \frac{F_S(r_T, r_R, p, NA, d_S)}{F_R(r_T, r_R, p, NA, d_R)} \tag{3}$$

$$\Gamma = \frac{G_S}{G_R} \cdot \frac{F_S(d_S)}{F_R(d_R)} \cdot \frac{1}{\delta_R} \cdot \delta_S = \left[C \cdot \frac{F_S(d_S)}{F_R(d_R)} \cdot \frac{1}{\delta_R} \right] \cdot \delta_S \tag{4}$$

In Equation (4), the parameter C was a constant, and $C = G_S/G_R$. The implementation system of optical fiber path has the following several advantages for the hydrogen sensor.

The concentration Γ of hydrogen is independent of the LED light power I_0.

The disturbances caused by the fluctuation of light source and the loss of optical fiber transmitting were eliminated by taking a ratio of two PIN receiving signals.

Owing to the same single optical fiber to form the optical fiber bundle, the variations of the modulation function $F(r_T, r_R, p, NA, d)$ was related with the reflecting distance d.

So it is concluded that the enhancement of δ_R in reference optical path could raise the anterior end SNR of sensor, δ_R affects the accuracy and stability of hydrogen sensor, and the high reflectivity plays an important role for the reflective hydrogen sensor.

3. Mathematic Model Based on Neural Network.

3.1. Compensation mechanism of neural network.

The theorem of Hecht-Nielsen has been proved that when given that the sum of square $\varepsilon > 0$, a neural network of three layers can approach any continuous nonlinear function [12,13]. So the neural network could take D_S and D_R as its two inputs, through the compensation processing of neural network algorithm, the output Γ' of the neural network could be considered as the concentration of hydrogen. Generally, it made an assumption that the model of optical fiber hydrogen sensor was expressed as the following functional Equation (5)

$$(D_S, D_R) = f(\Gamma, P) \tag{5}$$

The notation used in Equation (5) were summarized in the following: $f(\cdot)$ was the nonlinear unknown function; P was the integrated disturbances of the optical fiber hydrogen sensor, including the temperature changes, moisture change, outside vibration, etc. Γ was the concentration of hydrogen.

According to Equation (5), the concentration Γ of hydrogen could be calculated

$$\Gamma = f^{-1}(D_S, D_R, P) \tag{6}$$

In Equation (6), $f^{-1}(\cdot)$ was also a non-linear unknown function. Owing to the nonlinear characteristic of the optical fiber sensor, the compensation scheme took the optical fiber hydrogen sensor output D_S, D_R and integrated disturbances P of the optical fiber hydrogen sensor, and the output of the neural network was considered as the concentration of hydrogen.

3.2. **Compensation scheme of hydrogen sensor.** The compensation scheme based on the neural network was presented in Figure 2. Through Equation (6), the neural network could eliminate the integrated disturbance P of hydrogen sensor, and enhance precision of the hydrogen sensor output.

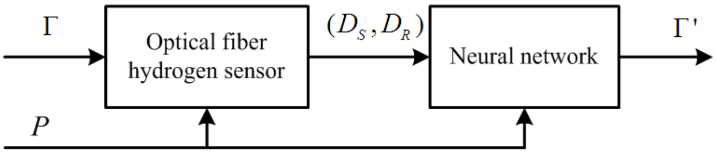


FIGURE 2. Optical fiber hydrogen sensor compensation scheme based on the neural network

The principle of training by neural network is presented as shown in Figure 3. The input layer, hidden layer and output layer mentioned in Figure 3 constitute the feed-forward neural network. According to the transfer functions and learning algorithms in neural network, the feed-forward network was divided into BP network, RBF network, and GRNN network and so on. So the paper took the BP neural network to validate compensation feasibility in optical fiber hydrogen sensor. In the BP neural network, the number of neurons in hidden layer determined the global error and training precision seriously, so choice of the number of neurons in hidden layer was important for the optical fiber hydrogen sensor compensation.

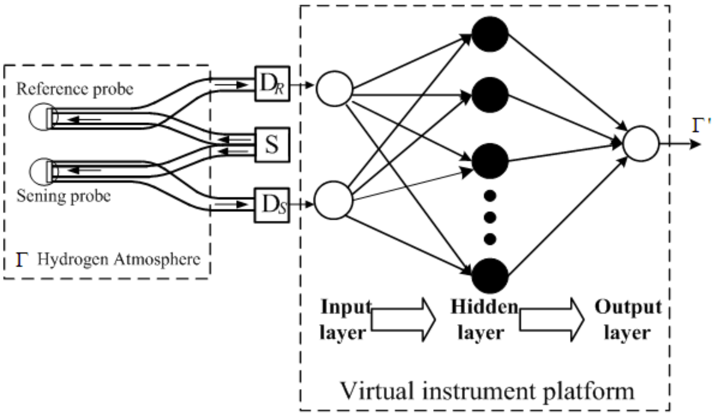


FIGURE 3. Training principle of neural network for optical fiber hydrogen sensor

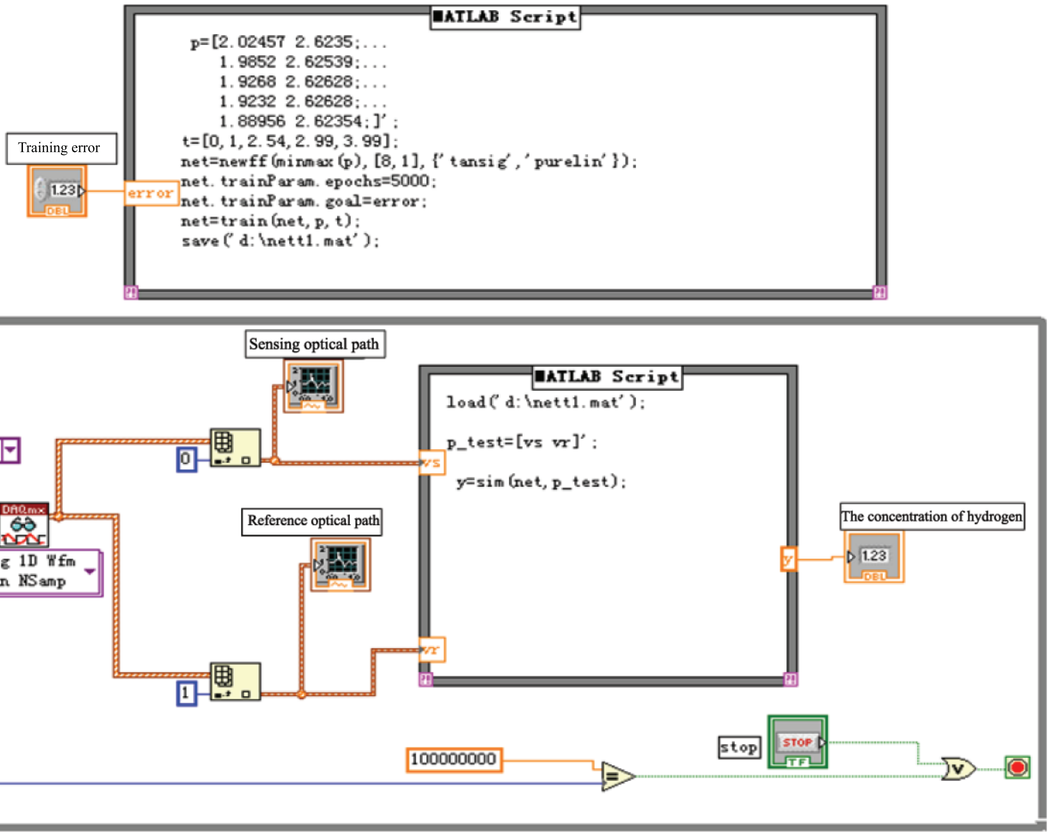
4. Experimental Results.

4.1. **Parameter optimization for neural network.** In the BP neural network, the training function and the neuron in hidden layer determined the global error and training precision seriously, so the choice of the number of neurons and training function in hidden layer was important for the optical fiber hydrogen sensor compensation. So a series of optimization tests was conducted to get the optimal training function and the number of neurons in hidden layer. Table 1 has showed on the training error under the condition of different training functions (including the traingdx, trainlm, traingd, etc.) and the number of neurons in hidden layer. It is concluded that different compensation effect for optical fiber hydrogen sensor was caused by different training functions and the number of neurons in hidden layer; Among the three training functions in BP neural network for hydrogen sensor, the training error changed along with the number of neurons in hidden layer. Meanwhile, according to the training error results in Table 1, it is indicated that the choice of trainlm training algorithm for optical fiber hydrogen sensor could achieve smaller error when the number of neuron is equal to 8 in hidden layer.

Table 1. Training error of the BP neural network for optical fiber hydrogen sensor

The number of neurons in hidden layer		3	4	5	6	7	8
Training function of neural network	traingdx	0.1856	0.1718	0.949	0.0707	0.0704	0.0706
	trainlm	0.0274	0.0704	0.0694	0.0694	0.0665	0.0031
	traingd	0.1967	0.1493	0.3150	0.1368	0.1732	0.3070

4.2. **Testing experiment of hydrogen sensor based on neural network.** To illustrate the effectiveness and performance of neural network proposed in this paper, the neural network training algorithm procedure was implemented in Labview. Serials of experiments for different concentration of hydrogen were carried out through the optical fiber hydrogen sensor. The self-made optical fiber hydrogen sensor probe and Labview signal processing system were shown in Figure 4.



```
  p=[2.02457 2.6235;...
     1.9852 2.62539;...
     1.9268 2.62628;...
     1.9232 2.62628;...
     1.88956 2.62354;]';
t=[0,1,2.54,2.99,3.99];
net=newff(minmax(p),[8,1],{'tansig','purelin'});
net.trainParam.epochs=5000;
net.trainParam.goal=error;
net=train(net,p,t);
save('d:\nett1.mat');
```

```
load('d:\nett1.mat');

p_test=[vs vr]';

 y=sim(net,p_test);
```

Figure 4. Neural network compensation algorithm based on the virtual instrument for optical fiber hydrogen sensor

In the compensation algorithm based on neural network of Figure 4, the sensing optical path output D_S and the reference optical path output D_R were considered as the input of the neural network in virtual instrument signal processing system, and the final output of Labview was viewed as the concentration of hydrogen by BP neural network training; the parts of experiment results were listed in Table 2, the error of the concentration of hydrogen between actual value and measured value was very small, and the intrinsic error of optical fiber hydrogen sensor based on neural network could reach to 2.6%. Through the training algorithm of above-mentioned, the soft Labview could acquire the hydrogen sensor data real-timely. At one time, the output result was the concentration of hydrogen, and the linearity of the hydrogen sensor based on the neural network was superior to the linear fitting algorithm obviously in Figure 5. Through the rapid processing of neural

TABLE 2. Training result of the BP neural network for optical fiber hydrogen sensor

	Sening signal D_S (V)	Reference signal D_R (V)	Hydrogen standard concentration Γ (%)	Output of neural network Γ' (%)
1	2.0246	2.6235	0	−0.0039
2	1.9852	2.6254	1	0.9994
3	1.9268	2.6263	2.54	2.5391
4	1.9232	2.6263	3.05	2.9889
5	1.8896	2.6235	4.1	3.9899

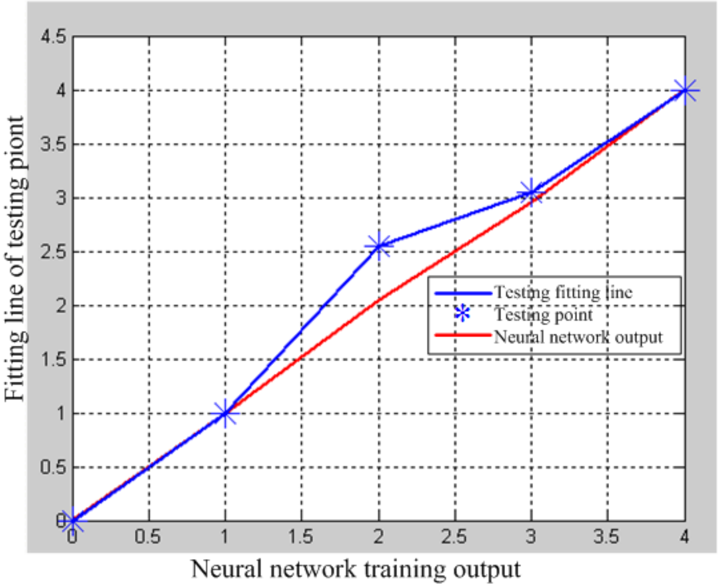


FIGURE 5. Neural network compensation output of optical fiber hydrogen sensor

network training, the neural network could eliminate all kinds of interferences of hydrogen sensor and enhance the better real-time linearity and precision of hydrogen sensor.

5. **Conclusions and Future Research.** In this paper, an effective neural network compensation optimization algorithm based on virtual instrument platform was proposed to solve the optical fiber hydrogen sensor nonlinearity problems. The performance of the presented approach was evaluated in comparison with traditional compensation algorithms. The obtained computational results and time demonstrated the effectiveness of the proposed approach. And a more comprehensive study should be made to apply the efficiency of proposed solution technique.

The further research directions include in the following:

- The combination of neural network and virtual instruments provided a compensation optimization solution for the optical fiber hydrogen sensor. Further, the Labview software efficiency still needs to ameliorate.
- Achieving the reliable training samples was important for neural network, so serials of experiments were carried on in different working environments.
- The neural network training process lies on the CPU, so the developing faster hardware for this neural network compensation optimization technology was still improved to sensor response time.

Acknowledgment. This project is supported by National Natural Science Foundation of China (Grant No.51505506 and No.61203179), Henan Province Education Department Science and Technology Key Project (Grant No.13A460118 and No.14B460011), Science and technology of Zhengzhou for tackling key problems Project (Grant No.131PPTGG416-1).

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