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Artificial neural network for the hydrogen detection using LPFBG

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Abstract: The hydrogen detection using long period fiber Bragg grating has been investigated using artificial neural network. A number of simulations have been performed to investigate the characteristics of the proposed approach. The trained and the predicted transmission are compared with the experimental data. The Levenberg-Marquardt algorithm has been chosen as the main algorithm because of the lowest mean square error (1.4×10^{-7}). The model of 20 neurons in two hidden layers shows a better fitting with the experimental data. A new predicted data at 10% H_2 concentration has been introduced using proposed ANN model.

Key words:

INTRODUCTION

The long period Fiber Bragg grating couples light from a guided mode into forward propagating cladding modes, where it is lost due to absorption and scattering. The coupling from the guided mode to cladding modes is wavelength dependent so we can obtain a spectrally selective loss (James S and Tatam R, 2003). The addition of the Pd nanoparticle to the host material can yield significant improvement and modification in their mechanical, thermal, transport and optical properties (Kaczmarek M. and Tomita Y., 2009).

In fact, the fiber grating has also been proposed and realized in all-optical switching, because of its low insertion loss and unique property (Zhigang Zang and Wen xuan, 2011). The nonlinear response of EDF FBG/F–P cavity configuration with two identical FBGs separated by an erbium-doped fiber (Zhigang Zang , 2012). Hydrogen participate to a wide range of chemical processes and also appears during energy production and transport. It is becoming an attractive fuel source for use in clean-burning engines and power plants (Caucheteur C., 2008). The sensing mechanism is based on the swelling of the Pd coating, results in a stress on the grating. The optical performances of the all-optical switching based on Yb3+-doped fiber Bragg grating (FBG) are investigated under the case of self-phase modulation (SPM) and cross-phase modulation (XPM).

ANNs provide an attractive alternative to conventional approaches for solving a range of problems. They have been applied to a wide Varity of problems including pattern recognition, clustering, function approximation, forecasting, optimization, adaptive control, medical diagnosis, detection making, as well as information and signal processing (Fornarelli G. et al, 2009).

In this paper, a ANNs approach to reduce the computational time in the hydrogen detection using Nano-Pd LPFBG. The general equation of the wavelength selection in the LPFBG according to the hydrogen concentrations are substituted by ANNs model. The ANNs model requires training by a limited set of input-output data obtained from an experimental treatment.

The Neural Model:

ANNs are parallel computing systems inspired by biological neural networks. They can be defined as asset of elementary processing units that communicate with each other by weighted connections. Each unit receive input signals from near units or external sources and gives an output signal. Which propagates to other units or constitutes a part of the network output. In order to design an ANNs, three characteristic must be identified: 1- the neural model, which the signal; processing unit. 2- the network architecture, which defines the connections of the processing units. 3- the learning algorithm, which evaluates the weights of the connections.

The neutron can be connected in different ways depending on the target, thus giving different network architectures. These networks may give rise to parallel processing with particular properties such as the ability to adapt or learn, to cluster or organize data, or to approximate nonlinear functions.

The neuron transfer function, f, is typically step or sigmoid function that produces a scalar output (n) as in Eq. (1):

$$n = f\left(\sum_i w_i I_i + b\right) \quad (1)$$

where I_i, w_i and b are the i^{th} input , the i^{th} weight and a the bias respectively.

Also, there are many types of learning algorithms (Christodouluo C. and Georgiopoulos M., 2001). However, it is very difficult to know which training algorithm will be more efficient for a given problem. The

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algorithms used to train ANNs in this study are Levenberg-Marquardt (LM), Scaled Conjugate Gradient (SCG), Broyden Flectcher Goldfarb Shanno Quasi-Newton Back Propagation (BFGS), Bayesian Regularization Back propagation (BR) and Conjugate Gradient Back propagation with Polak-Ribiere updates (CGP).

The LM algorithm is an iterative technique locating a local minimum of a multivariate function that is expressed as the sum of squares of several non-linear, real-valued functions and updates weight and bias values according to Levenberg-Marquardt optimization. The SCG which is a member of the class of conjugate gradient methods is a supervised learning algorithm for feed forward neural networks. The BFGS is one of the most powerful and sophisticated quasi-Newton methods and has the advantage over Newton's method that the second partial derivatives are not needed. The BR algorithm updates the weight and bias values according to LM optimization and minimizes a combination of squared errors and weights, and then determines the correct combination so as to produce a network Hidden Layer(s) that generalizes well. The CGP algorithm is a network training function that updates weight and bias values according to the conjugate gradient back propagation with Polak-Ribiere updates. More details about the ANNs and learning algorithms can be found in the literature. The ANN model is simply shown as a block diagram in Fig. 1.

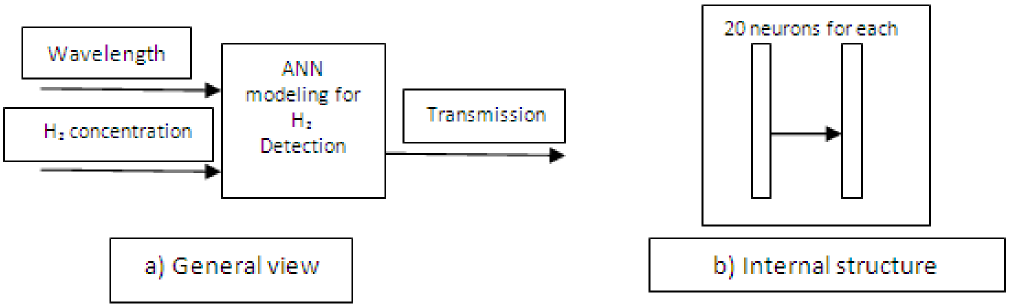

Fig. 1: block diagram of the H_2 detection using LPFBG.

Principle Of Operation:

Uniform FBGs were inscribed into hydrogen-loaded standard single-mode fiber by means of a frequency-double argon-ion laser through a 1060-nm period phase shift. All the grating were characterized by refractive index modulation yielding to a reflectivity approaching 100% at Bragg wavelength .

In the presence of hydrogen in air, the oxidation of H_2 molecules by O_2 is an exothermic reaction that elevates the temperature around the LPFBG, there, based on monitoring of the Bragg wavelength shift induced by a temperature change.

The coupled effectively following the phase match conditions:

$$\beta_1 - \beta_2 = \frac{2\pi}{\lambda_R}\left(n_{e_1} - n_{e_2}\right) = \frac{2\pi}{\Lambda}$$

Where β_1 and β_2 are the propagation constants of the core and cladding, respectively. n_{e_1} and n_{e_2} are the core and cladding mode effective refractive indices, respectively, and Λ is the period of the grating. When a sensing layer is coated outside the cladding area, changes in the refractive index of the sensing layer could results in the change in the effective index of the cladding which leads to the shift of resonance wavelength.

A Pd thin layer was deposited on the cladding area of the fiber grating (6 cm long) by DC magnetron sputtering (Wei X. et al 2008). The distance between the target and fiber was kept at 10 cm. the chamber was evacuated to a pressure in the range 10^{-6} Torr, the deposition rate was about 7 nm/min at room temperature. The fiber was rotated periodically in order to acquire the thin layer with relatively uniform thickness. The spectra of the LPFG before and after coating were record prior to the sensor test.

RESULTS AND DISCUSSION

The ANN model for hydrogen detection using LPFBG is consists of two inputs, two hidden layers, 40 neurons and one output. The training performance of the ANN model are contribute by the algorithm used. The comparisons of the sensor response and the network output are given in table 1. It can be seen from the table that the ANN model with the LM algorithm has the smallest Mean Square Error MSE value. The best LM and the worst BFG with respect to MSEs (Galip O., 2008). the mean squared error of the network starting at a large value and decreasing to a smaller value. It shows that the network is learning. The plot has three lines, because the inputs (wavelength and H_2 concentration) and target is Transmission vectors.

Table 1: Comparisons between different algorithms with (MSE).

Algorithm	Input Layer	Output layer	MSE
LM	2	1	1.4×10^{-7}
BFG	2	1	8×10^{-7}
BR	2	1	6.1×10^{-7}
CGP	2	1	4.5×10^{-7}
SCG	2	1	3×10^{-7}

In the present work, best performance was obtained by a network with two hidden layers having 20 neurons. The algorithm used is LM by considering 1000 epochs. Fig 2 report the transmission variation in LPFBG with the wavelength. As seen from fig. 1558 nm is the Bragg wavelength selected at the H_2 concentration of 8 %. The experimental data is coincide with the proposed ANN model (Line is the ANN model and Solid is experimental data). The pd coating of LPFBG results in the changes of the boundary conditions of the cladding modes and Bragg diffraction. So the resonance quality is reduced because the coupling condition is not as critical as the one without any coating.

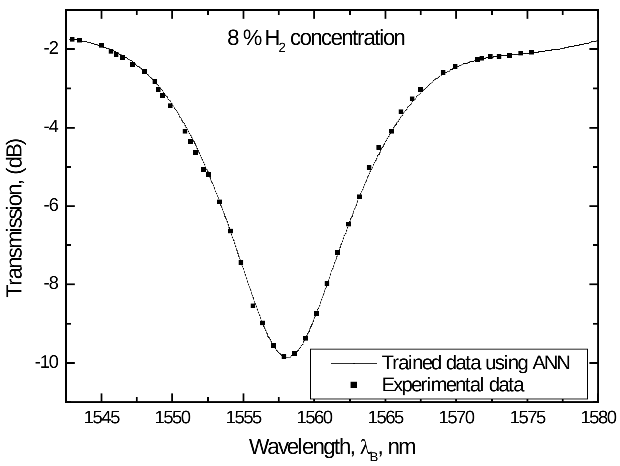

Fig. 2: The trained data using ANN for the transmission variation with the wavelength at 8% hydrogen Concentration (Line is the ANN model and Symbols are experimental data).

Fig. 3 shows the variation of the transmission of signals calculated via the ANN model versus the wavelength (line) for 6% and 4% H_2 concentrations. While the symbols are the experimental data obtained by (3) for the same concentration. A shift of the Bragg wavelength to right appears due to exothermic reaction that occurs with H_2 molecules in the presence of Pd particles. So it is clear from the exposure of the sensor to the hydrogen leads the attenuation band of the transmission spectrum of LPFBG. The equation of the model used for the designed network are provided in the Appendix. The result of ANN model showed a good agreement with the experimental data.

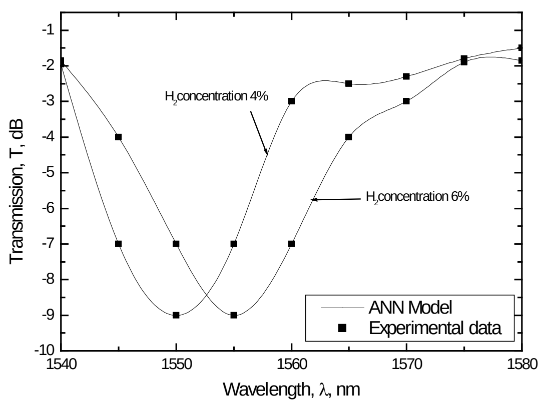

Fig. 3: The tested data using ANN for the transmission variation with the wavelength at 6% and 4 %hydrogen concentration (Line is the ANN model and symbols are experimental data).

The ANN model not only simulated the data but also predicted the data using the above examined model. Fig. 4 shows the transmission of the signals predicted by ANN model with wavelength at H_2 concentration of

10 %. The Bragg wavelength at this concentration is 1562.5 nm. So the ANN model estimated can produce proper outs for given inputs without any necessity to the Mathematical formulations between input and output data. The trained method which used to train the ANN model is Levenberg-Marquardt optimization technique, with number of epochs=22 and 40 neurons. It could be used as a predicted method for the hydrogen detection without any mathematical equation.

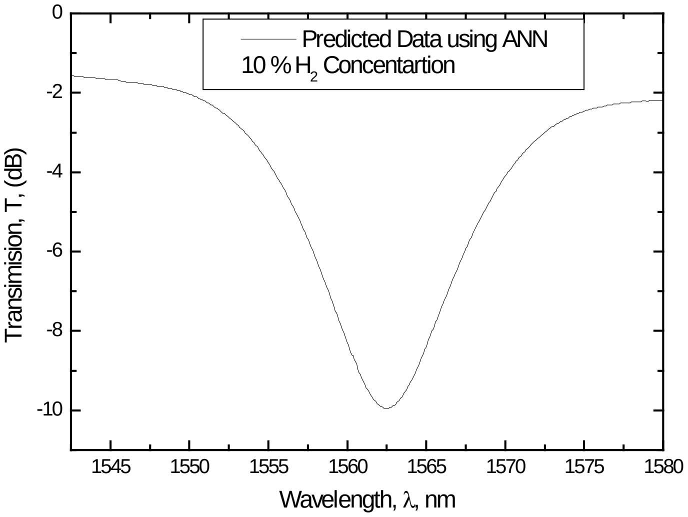

Fig. 4: The predicted values of the transmission variation with the wavelength at 10% hydrogen concentration.

Conclusion:

In this paper a neural network model of LPFBG using Pd coating for hydrogen detection has been introduced. The neutral networks model input was Bragg wavelength, hydrogen concentrations, while the output was the transmitted power. The proposed approach shows attractive advantages. The neural network model generates quickly the transmittance power as a function of the hydrogen concentration for different wavelengths. The model not only simulated the trained data but also predicted other new concentration for the hydrogen. The numerical results show a good agreement among the values also the drastic reduction of the computational time of the ANN with respect to the conventional method. The proposed approach exhibits attractive performance in terms of flexibility, accuracy and computational time.

Appendix:

The network is 2-20-20-1 and the equation representing the model

$$T = pureline[\{net.LW(3,2).tansigmoid.\{net.LW(2,1)\}.tansigmoid\{net.IW(1,1).P + net.b(1)\} + net.b(2) + net.b(3)\}]$$

Where

T is the transmittance of the propagated signal.

net.LW (3,2) is the linked weights between the second hidden layer and the output.

net.LW (2,,1) is the linked weights between the fist hidden layer and the second hidden layer.

net.IW (1,1) is the linked weights between the input and the first hidden layer..

net.b(1) is the bias of the first hidden layer.

net.b(2) is the bias of the second hidden layer.

Net.b(3) is the bias of the output.

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