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Machine learning and Silicon Photonic Sensor for Complex Chemical Components Determination

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Abstract: We propose an integrated microring resonator sensing system based on Backward-Propagation Neural Networks (BPNN)-Adaboost algorithm to predict component fraction in binary liquid mixtures. A minimum absolute error of 0.0023 and mean squared error of 0.000345 is achieved by this training model.

OCIS codes: (120.4820) Optical systems; (200.4260) Neural networks; (200.4560) optical data processing

1. Introduction

Refractive index is one of the most important properties of mixed liquids. The study of the relationship between component fraction and mixed refractive index has raised great attention for a long time. Refractive index can be affected by a wide range of parameters such as intermolecular interactions, dielectric permittivity, density and surface tension [1]. During the last few decades, some fundamental and practical formulas in rough quantitative determinations have been built up, such as Gladstone-Dale, Biot-Arago and Lorentz-Lorenz equations [2]. However, they present inherent flaws which have limits not only in the precise data acquisition but also in trying to fill the gap between the theory and experimental uncertainty. With the development of artificial intelligence, Artificial Neural Networks (ANN) has been widely used in many areas and demonstrated to have advantages of high data error tolerance and easy adaptability to online measurements. A Back Propagation Neural Network (BPNN) is a typical ANN [3, 4]. Meanwhile, the algorithm AdaBoost is theoretically used to significantly reduce the error of any learning algorithm [5]. Here, we propose an integrated microring resonator sensing system targeting at the refractive index, which will be sent to a BP-AdaBoost predictor for component determination.

2. Design and Theoretical analysis

Figure 1(a) shows the schematic illustration of the dual-microring resonator sensing system. The light source is a broadband laser. The tracing ring is tuned by an integrated heater using thermo-optic effect. The sensing ring is exposed to the target solution. When the sensing ring has a resonance corresponding to the effective refractive index, we tune the tracing ring by applying an electrical power. Only if the two rings align with each other, the output reaches the peak. Figure 1(b) shows the circuit design for this system. The tracing ring integrated heater is powered by a 12-bit DAC connected with a microcontroller. The output intensity simultaneously comes into a photodetector and is converted to current. The current passes through a low-noise trans-impedance amplifier (TIA) and becomes a voltage signal. Then the analog voltage signal is acquired by a microcontroller with an external 16-bit ADC. This digital signal will be used later as the data sample in the BP-AdaBoost predictor.

Fig.1. (a) Schematic illustration of the dual-microring resonator sensor design. (b) Circuit design of the sensing system.

3. Results and Discussions

To overcome the experimental uncertainty and achieve higher data error tolerance for improving forecast, we employ an algorithm of BP-AdaBoost instead of traditional mathematical modeling method as data analysis. The BP-AdaBoost uses the BPNN as ‘weak’ predictors and Adaboost to combine all of weak predictors to achieve a

final powerful predictor. Figure 2(a) shows the algorithm flowchart and implementation steps. Figure 2(b) indicates the regression result of implementing BP-Adaboost on acquired datasets.

Fig. 2. Diagrams of (a) BP-AdaBoost forecast model and (b) Regression result upon training, validation, test and all.

Figure 3(a) shows the component fraction forecast results using dataset of binary mixtures of Acetone and 15% NaCl solution. This forecast model can achieve a minimum absolute error of 0.0023. Figure 3(b) shows the absolute error when applying BPNN and BPNN-Adaboost respectively. The mean squared error of BPNN-Adaboost is 0.000345, which demonstrates a significant improvement when compared to the mean squared error of BPNN which is 0.0012. Figure 3(c) shows the improvement of performance when applying BPNN-Adaboost with number of Adaboost trees varying. The overall trend is that the improvement of accuracy becomes more significant as the number of trees increases.

Fig. 3. (a) Component fraction forecast result using dataset of binary mixtures of Acetone and 15%NaCl solution. (b) The absolute error when applying BPNN and BPNN-Adaboost respectively. (c) Improvement of accuracy compared to BPNN with number of adaboost trees varying.

4. Summary

A dual-microring resonator sensing system for component fraction forecast in binary mixtures is demonstrated using BP-AdaBoost algorithm. A minimum absolute error of 0.0023 and mean squared error of 0.000345 is achieved, which has a great potential in the mixtures detection using machine learning method.

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6. References

- [1] P. Brocos, A. Peineiro, R. Bravo, et al. "Refractive indices, molar volumes and molar refractions of binary liquid mixtures: concepts and correlations." *Physical Chemistry Chemical Physics* 5.3 (2003): 550-557.
- [2] C. Franchini, A. Marchetti, R. Seiber, et al. "Refractive properties of binary mixtures containing N, N-dimethylformamide+ 2-methoxyethanol or 1, 2-dimethoxyethane." *Physics and Chemistry of Liquids* 39.3 (2001): 277-300.
- [3] H. Ding, X. Jiang, B. Shuai, A. Q. Liu, G. Wang. "Context Contrasted Feature and Gated Multi-scale Aggregation for Scene Segmentation." In *CVPR* 2018.
- [4] W. Jin, et al. "The improvements of BP neural network learning algorithm." *Signal Processing Proceedings* 3 (2000): 1647-1649.
- [5] Y. Freund, & R. E. Schapire, "Experiments with a new boosting algorithm." In *ICML* 96 (1996): 148-156. (2014).