Compensation of the Impact of Temperature and Humidity on Gas Sensors

Zvezditza Nenova[1] and Georgi Dimchev[2]

Abstract – **The methods for gas control have been extensively developed for many applications such as monitoring the quality of air environment, in control systems of indoor gas leakages, or development and implementation of systems such as "electronic nose". In particular, metal oxide based gas sensors have been widely used. However, changes in their parameters depend, apart from changes in the controlled gas, also on temperature and humidity. That is why, compensating for these disturbances is an important problem aiming to increase the accuracy of concentration measurements of the controlled gases and the reliability of control. The present paper proposes a method for compensation of the impact of temperature and humidity on gas sensors using artificial neural network (ANN). This compensation method is applied on the control of methane pollution by gas sensor TGS813 and results are presented.**

Keywords – **Gas sensors, ANN, compensation of disturbing factors.**

I. INTRODUCTION

The methods for gas control of the air environment have been undergoing continuous improvement and development because of the importance of monitoring atmospheric pollution, which can quickly spread over large areas. A wide range of gas sensors [1-5] is offered, metal oxide semiconductor gas sensors being one of them. Different kinds of metal oxides like SnO_2, ZnO, Fe_2O_3, WO_3, Co_3O_4 , etc. [1, 6-8] are used as sensing materials. Their principle of operation is based on increasing the conductivity of the sensitive element in the surface area when the test gas is adsorbed. Depending on the composition of the sensitive material layer, the sensor responds to different gases such as carbon monoxide, carbon dioxide, ethanol, methane, propane, ammonia, hydrogen sulfide, hydrogen, etc. [1-5]. Metal oxide semiconductor gas sensors have high sensitivity, low cost and less reaction time. They are used in gas leakage control systems, monitoring the quality of indoor air environment, development and implementation of systems such as "electronic nose", etc. [9-11]. However, a typical feature of such gas sensors is the impact of temperature and humidity on their readings [2-5], which act as disturbances in the control of gas emissions into the air. To increase the accuracy of measurements and reliability of control it is very important to compensate the impact of these disturbances.

This paper proposes a method for compensating the impact of temperature and humidity on the readings of gas sensors using artificial neural network. It also shows the results of the implementation of the method for control of methane pollution by using gas sensor TGS813 [2].

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II. ANN-BASED METHOD FOR COMPENSATION OF DISTURBING FACTORS

Artificial neural networks are widely used to detect gases, characterize products, control of environmental parameters, etc. [12-14]. They are used to solve problems of sensor calibration, detection of odors in environments with different disturbing factors and approximation of sensor characteristics [15-18].

The proposed ANN-based method aims at increasing the accuracy of measurements of gas concentrations by compensation of the impact of temperature and humidity. The method is based on the training of ANN with gas sensor characteristics that relate changes in their parameters due to changes in gas concentration as well as changes in temperature and humidity. Consequently, three-dimensional approximation of the sensor characteristics is conducted, linking the output parameter of the sensor and the gas concentration, temperature and humidity of the controllable air environment. Apart from the measurement of the gas sensor parameter, the implementation the method requires measurement of temperature using a temperature sensor and air humidity using a humidity sensor. Figure 1 shows a schematic of the implementation of the ANN-based method and the respective input and output parameters for measurement and control of a gas pollutant.

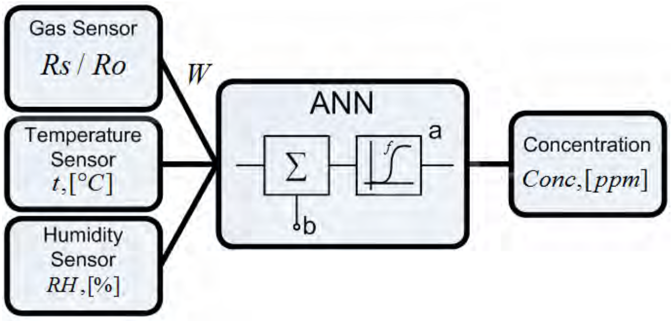

Fig. 1. Schematic of implementation of the ANN-based method for compensation of temperature and humidity on gas sensor

Thus after the training of the neural network approximated relation of the following type is obtained

$$Conc = f\left(Rs / Ro,\ t,\ RH,\ W,\ a,\ b\right) \quad , \qquad (1)$$

where Rs is the measured gas sensor resistance, Ro – is resistance at pre-specified reference concentration, Rs/Ro is the relative change of the gas sensor resistance, t – is temperature measured by the temperature sensor, RH – is the relative humidity measured by the humidity sensor, W, a, b are ANN parameters.

The gas concentration measured can be determined using relation (1), which takes into account the impact of the ambient temperature and humidity.

III. Method Implementation

The method is applied to compensate the impact of temperature and humidity of TGS813 type gas sensor in the control of methane pollution. The characteristics of the sensor from the manufacturer have been used, connecting the concentration of methane with the relative change Rs/Ro of the sensor resistance at -10°C/0%RH, 20°C/65%RH, 40°C/100%RH and the characteristics of the sensor at 1000ppm for changes in temperature and relative humidity of 0, 20, 40, 65 and 100%RH [2]. Ro is resistance at pre-specified reference concentration of 1000ppm and 20°C/65%RH. Under these experimental relations in logarithmic scale the change in temperature leads only to offset these characteristics to Rs/Ro. Given this and the characteristics of the sensor at 1000ppm in case of changes in temperature and relative humidity of 0, 20, 40, 65 and 100%RH [2], the characteristics of $Rs/Ro = f(Conc)$ in the temperature range -10°C...40°C and fixed values of relative humidity 0, 20, 40, 65 and 100% RH are obtained analytically. Figure 2 shows a set of characteristics $Rs/Ro = f(Conc)$ at 65%RH, showing the impact of temperature of the air environment, and Figure 3 – a set of characteristics $Rs/Ro = f(t)$, indicating the impact of humidity in case of basic concentration of 1000 ppm.

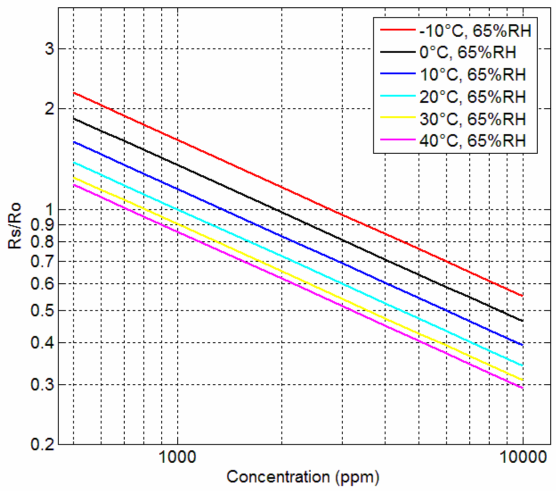

Fig. 2. Impact of temperature on the characteristics $Rs/Ro = f(Conc)$ at 65% RH

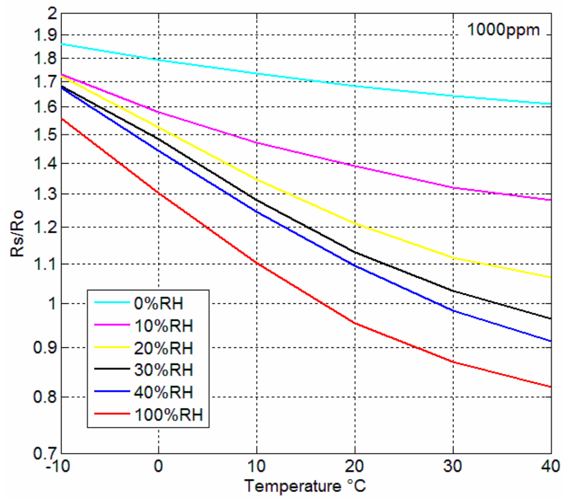

Fig. 3. Impact of humidity on the characteristics $Rs/Ro = f(t)$ in case of basic concentration of 1000 ppm

The entire range of characteristics obtained was used for training of backpropagation ANN. Experiments were conducted with different algorithms for training. The best convergence for the lowest number of neurons was obtained by training with Levenberg-Marquardt (LM) backpropagation algorithm. Moreover, the resulting backpropagation ANN has three layers - two hidden and one output. The number of neurons is determined by trading off the training time and the approximation error [19]. Thus it is established that the first layer is composed of three neurons - one for each input variable, the second layer is composed of five neurons, and the third layer has one neuron (Figure 4).

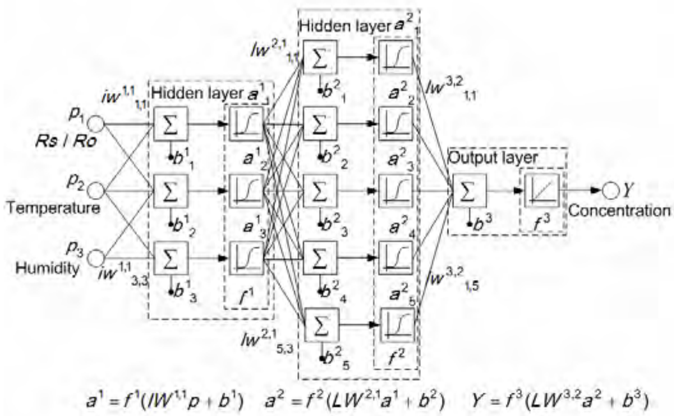

Fig. 4. ANN for approximation of gas sensor characteristics

In the first and second layer transfer function of neurons (f^1) and (f^2) is sigmoid and the third layer (f^3) - linear.

The neural network has the following form

$$Y = f^3\left(LW^{3,2} f^2\left(LW^{2,1} f\left(IW^{1,1} p + b^1\right) + b^2\right) + b^3\right), \qquad (2)$$

where $Y = Conc$, $p_1 = Rs/Ro$, $p_2 = t$, $p_3 = RH$.

Figure 5 shows the results of the output of the trained neural network. Thus based on three-dimensional approximation of the characteristics of the sensor obtained as a result of training of ANN, the value of the concentration of methane can be obtained while compensating the impact of temperature and relative humidity.

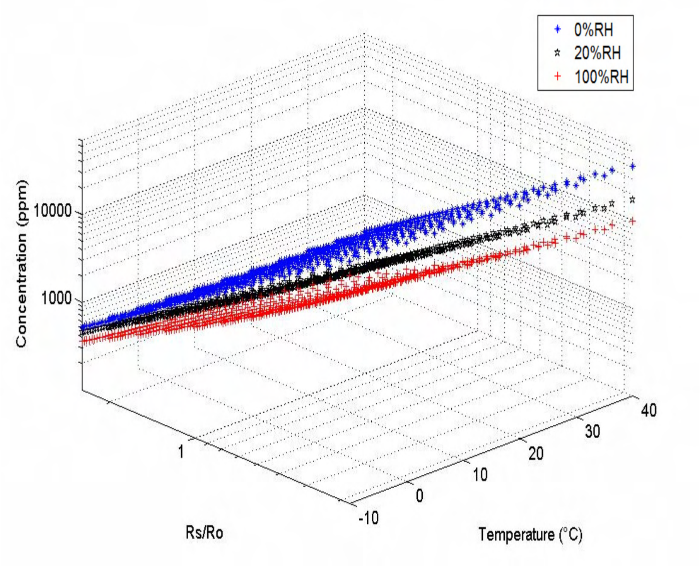

Fig. 5. Results of output of the trained ANN

Figure 6 shows the algorithm to compensate the impact of temperature and humidity on the reading of the gas sensor through the ANN.

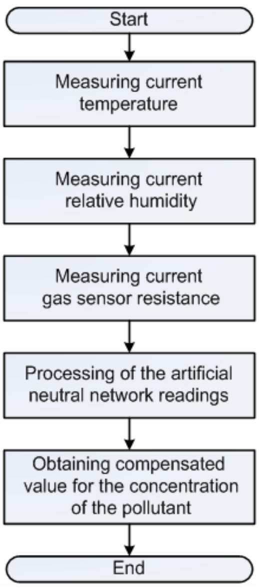

Fig. 6. Algorithm for ANN-based compensating method

Using the trained neural network after compensating the impacts of temperature and humidity the methane concentration values $Conc_{ANN}$ are obtained. Based on them the absolute error from the approximation is

$$\Delta Conc_{appr} = Conc_{ANN} - Conc \quad (3)$$

and the normalized error from the approximation

$$\varepsilon_{n\ appr} = \frac{\Delta Conc_{appr}}{Conc_{\max} - Conc_{\min}} \cdot 100\% , \quad (4)$$

where *Conc* is the measured value of the concentration for given temperature and humidity; $Conc_{\max} - Conc_{\min}$ is the concentration measurement range.

Figure 7 shows the actual and ANN-approximated characteristics at different values for temperature and relative humidity.

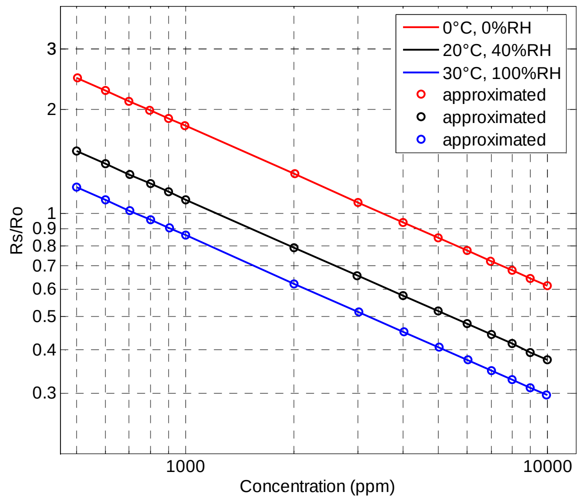

Fig. 7. Real and ANN-approximated characteristics of the gas sensor

The normalized error from the approximation has been calculated for all points obtained by ANN and the values of this error do not exceed ±0.05%.

For comparison the errors without compensation of the impact of disturbing factors has been determined when a reference characteristic for the sensor is used. The absolute and normalized errors are determined by

$$\Delta Conc = Conc_{ref} - Conc \quad (5)$$

and

$$\varepsilon_n = \frac{\Delta Conc}{Conc_{\max} - Conc_{\min}} \cdot 100\% , \quad (6)$$

where $Conc_{ref}$ is the concentration from the reference characteristic.

For the TGS813 gas sensor the characteristic at 20°C/65%RH is taken as the reference. The normalized error is 2,1% and -3,5% respectively for a temperature change of ±10°C and 0,4% and -0,6% for relative humidity change of ±10%RH. For a simultaneous change of both temperature and relative humidity from 20°C/65%RH to 30°C/75%RH and 10C/55%RH, the normalized error is 2,5% and -4,1% respectively, and at 40°C/100%RH and -10°C/0%RH it is 3,7% and -28,7 % respectively.

This confirms the need to perform compensation of the disturbing factors and increase the accuracy of measurements through the described method of the compensation using ANN.

IV. CONCLUSION

The following conclusions can be drawn based on the investigations made:

- temperature and humidity have significant impact on the readings of metal oxide gas sensors;
- a method is proposed to compensate the impact of temperature and humidity on the readings of gas sensors by using ANN;
- to compensate the impact of the disturbing factors on TGS813 gas sensors used for measurement and control of methane, a backpropagation ANN with two hidden and an output layer is obtained;
- three-dimensional approximation of TGS813 gas sensor characteristics with the trained neural network allows for compensation of the temperature and humidity impact, with the normalized error from the approximation of around ±0,05%.
- the proposed ANN based compensating method can be used with other types of gas sensors as well.

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