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Self-Adaptive Thermal Modulation of Gas Sensors

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Abstract

Metal-oxide semiconductor gas sensors offer valuable advantages, such as high sensitivity, low cost and small dimensions. However, it is well-known that significant problems, such as cross selectivity and lack of long term stability, still affect their performance. Several studies point out that the modulation of the sensor temperature may improve the sensor performance, and different thermal modulation methods are currently available. In this work a temperature modulation scheme that needs no a priori information about the sample under test is presented. According to this method the sensor temperature value is set, through the sensor resistance value, via an Astable Multi-vibrator Circuit (AMC). The resulting output signal forms a cyclic pattern of pulses. Pulses shape depends on the sensor resistance while the pulse length depends on the measured gas. The method is here illustrated through a three-class classification instance.

Keywords: gas sensor, adaptive temperature modulation

1. Introduction

The modulation of the temperature of gas sensors has been introduced to improve the long term stability and to increase the discrimination capability of individual sensors [1, 2]. Different strategies for thermal modulation as well as optimization approaches have been proposed. For example, one approach uses a rectangular voltage signal to the sensor heater setting the temperature between two constant values. Many different shapes and periods of the sensor have been proposed depending also on the particular structure of the sensors used [3]. Other approaches have introduced an automatic procedure in order to find the optimal thermal modulation by means a preliminary analysis obtained applying pseudo random sequences to the sensors [4]. The results of this phase define the best frequencies composing the optimal thermal modulation profile [5].
Moreover the modulations of the sensor temperature evolution have also been used to extract features that are significantly more stable than those obtained with isothermal operational condition [6].
All the methods here proposed, however, are intended to optimize the temperature modulation off-line; this is,

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having previous knowledge of the application task to perform. In this work we introduce an original self-adaptive thermal modulation that is regulated by the sensor conductance change.

2. Experimental details

2.1. Sensor Interface

The proposed method uses the sensor conductance to modulate the temperature by means of an Astable Multivibrator shown in Fig.1. The output signal $x_{out}(t)$ is characterized by a square wave whose frequency depends on the actual sensor resistance value. This signal drives the temperature modulation by means of a Temperature Modulation Interface that guarantees the necessary power to heat the sensor. This module also sets the range of the operation interval of the temperature. As a result of the modulation, the output signal presents a steady temporal pattern of pulses, in which the length is correlated to the measured gas.

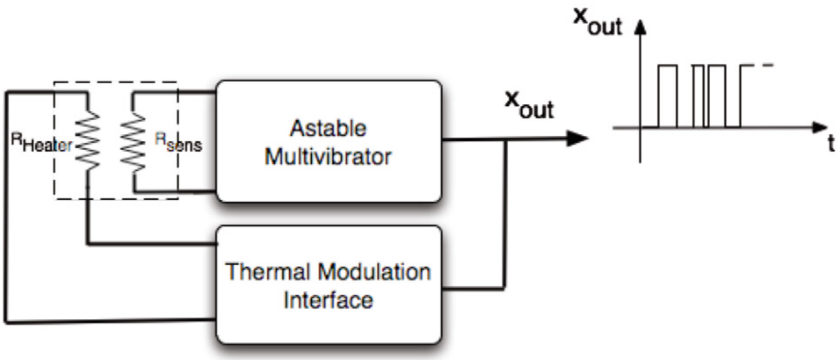

Figure 1: *Schematic block of the sensor interface.*

In Figure 2 an example of the output signal of the sensor interface (straight line) and heater signal (dashed line) are plotted when the sensor has reached a dynamic equilibrium during the exposure to a constant concentration of the volatile compound. It is interesting to remark that the Thermal Modulation Interface also performs a frequency division of the $x_{out}(t)$ signal. This operation is needed to allow a satisfactory evolution of the sensor temperature during the cooling and warming phase.

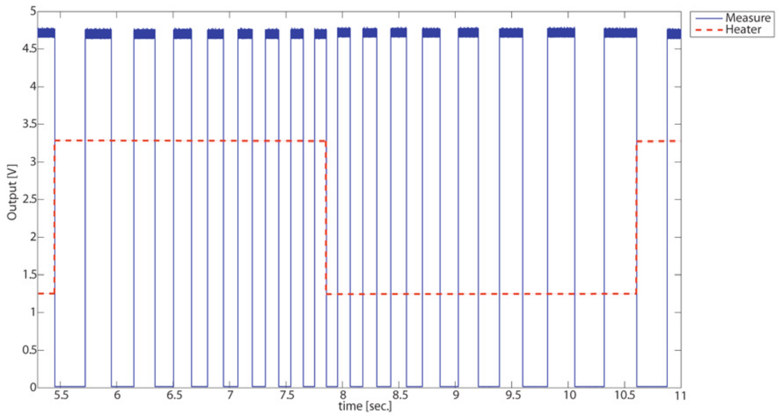

Figure 2: *Example of a single measure. As a consequence of substrate heating (dashed line) the temporal duration of output signal (straight line) changes.*

2.2. Measurement Set-up

To illustrate the method, a three-class experiment has been performed using a commercially available metal oxide gas sensor TGS2600 by Figaro Inc. This sensor was placed into a 30 ml-volume chamber where the chemical compounds of interest, such as CO, NO and nitrobenzene, dosed at concentration ranging from 0 to 50 ppm, and mixtures of nitrobenzene (26 ppm) and CO (25 ppm) were injected. The gas delivery was provided by a mass-flow controller system that set different concentrations of test gases using dry air as a carrier. The total flow was maintained constant at 200ml/minute along the whole experiment. As fig. 2 reveals, when the sensor reached the dynamic equilibrium with the gas, the output signal produces a stable and periodic pattern of pulses. The set of the time durations of the pattern pulses contains the information about the gas and its concentration. Then all the pulses lengths can be used as descriptors of the measures and processed by pattern recognition algorithms.

3. Results

The experimental results are resumed in fig. 3. In the figure the scores plot of the first two principal components of the PCA model obtained using as input the time durations of the pulses pattern are shown. From that figure we can evidence two important issues. First, the plot shows a clear discrimination among the different gases regardless the concentration. Second, with the concentration increasing the sensor responses are placed along a well defined direction for each gas. This result also confirms that the features extraction is also able to look at information about the qualitative and quantitative aspects of the sample under measure. Moreover the position of the mixture CO-Nitrobenzene measurements suggests also the possibility to observe specific region, different from the pure gases, for the gases mixture.

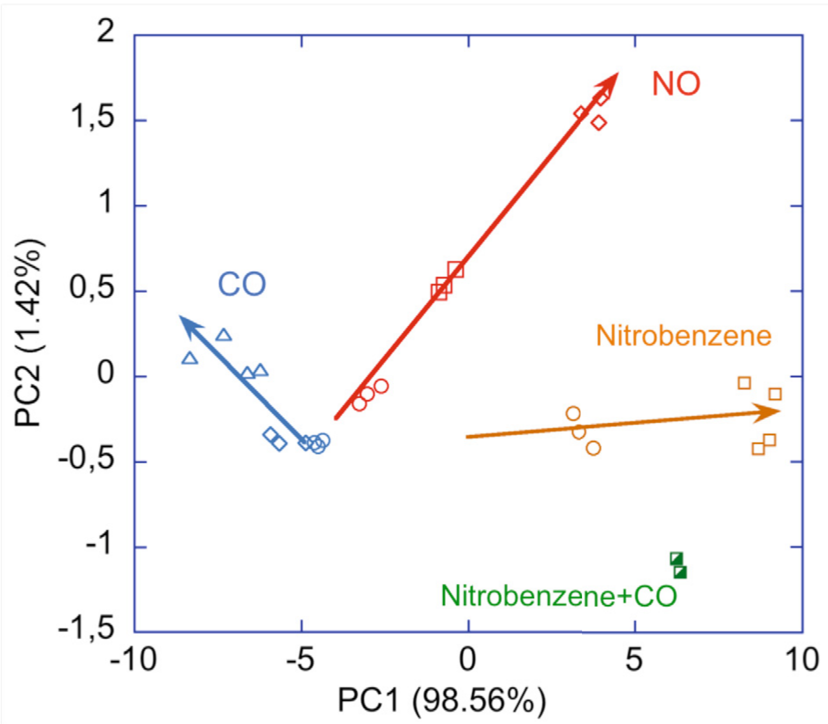

Figure 3: the scores of the first two Principal Components of pulses length of the measurements.

4. Conclusions

A novel self-adaptive thermal modulation is presented. Compared to previous methods the proposed approach does not require any a-priori optimization procedure. It is validated with an experiment aimed at classifying three gases at different concentrations showing a clear separation among the three classes. In addition, the sensor responses follow a well-defined direction for each gas-concentration, meaning that the method also looks at the different concentrations levels. Nevertheless further investigations on the role of the frequency divider and the interval of the operational temperature on the sensors performance will be done.

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