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High performance of a gas identification system using sensor array and temperature modulation

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Abstract

A sensor array based on metal oxide gas sensors has been used to identify three single industrial and environmental gases (carbon monoxide, acetylene and hydrogen sulphide). A temperature modulation method is applied to a sensor array and compared to experiments with different constant temperatures. The former shows more powerful ability in gas discrimination than the latter. Both principal component analysis (PCA) and artificial neural networks (ANN) are performed to classify and identify the target gases. The classification results show the potentiality of the system. Moreover, unknown gases are tested and they are well identified.

Keywords: Sensor array; Selectivity enhancement; Temperature modulation; Pattern recognition

1. Introduction

The advantages of metal oxide sensors in comparison with classical methods are well known like low costs, short response time and versatility. Currently, the sensors are sufficiently sensitive for the majority of applications [1–4]. However, the use of these sensors is limited due to their lack of selectivity. In order to overcome this disadvantage, several methods are carried out and they can be classified into three main groups [5,6]: (i) strategies in material science (catalysts, filters, etc.) [7–10], (ii) strategies in sensor measurement (sensor array, static and dynamic measurements, etc.) [11–16] and (iii) signal processing algorithms (pattern recognition methods, artificial neural networks, etc.) [17–19].

During the last decade, multisensors analysis of gases has induced the development of systems using non-specific chemical sensors, currently called electronic noses [20]. In this case, information should be extracted from a sensor array by an appropriate pattern recognition technique. Besides, recent works have showed that temperature modulation of metal oxide sensors improves selectivity [21–27]. In this case, the kinetics of adsorption and desorption are modified when the heating temperature of the sensor is modulated and the sensors have specific response patterns to different gases. Usually, an electronic nose measures the stationary response of the sensors working at one constant temperature. Because the response of a sensor depends on its working temperature, the combination of the standard approach and a temperature stepping increases the number of signatures specific to each gas without increasing the number of sensors. In addition, a modulation of the working temperature of the sensors reduces the time of measurement because the stationary response of the sensors is not reached. These two improvements are investigated and reported in this paper.

In this work, metal oxide sensors are used with constant heating voltage or modulation of the heating voltage in order to classify and identify three reducing gases: two toxic gases (CO and H_2S) and a volatile organic compound (C_2H_2). The in situ detection of H_2S is important in many technological fields, such as oil and petrochemical industry, water treatment plants and biogas applications. The development of a system for CO detection is important in general industry and in indoor environments (100 ppm detection threshold limit), particularly in parking garages and tunnels. Acetylene is a common combustible gas with a lower exposure limit of 2.5 vol%. Electrochemical cell sensors are the most widely used in commercial devices for monitoring these gases, with usual measurement scales

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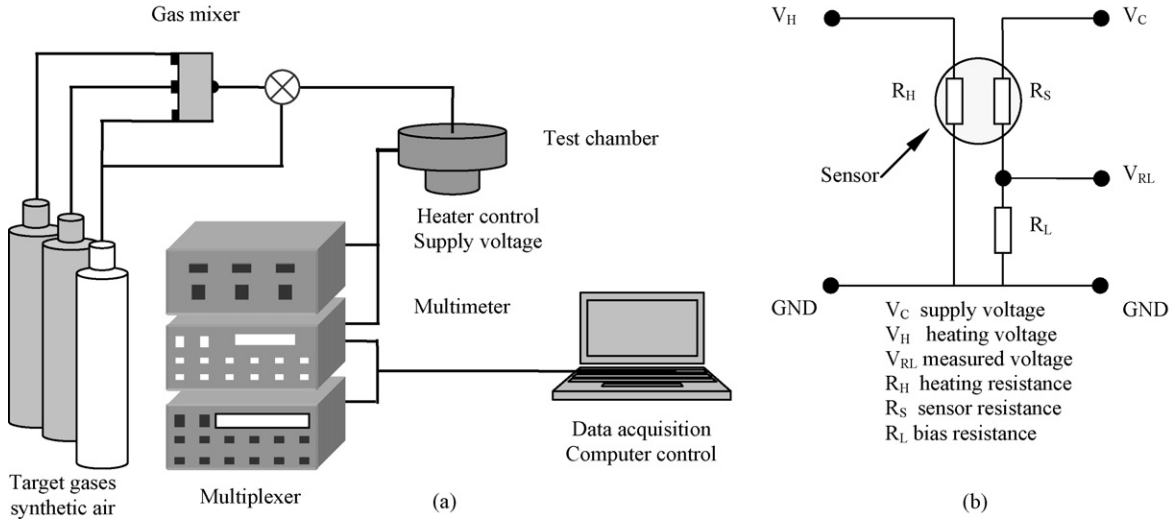

Fig. 1. (a) Experimental set-up for gas testing and (b) measurement circuit.

of 50 ppm or higher. However, electrochemical gas sensors have some drawbacks, such as a quite long response time and a short lifetime. Moreover, they are dedicated to only one gas.

The aim of this study is the development of a system for CO, H_2S and C_2H_2 identification in the range of 25–100 ppm. For this purpose, a sensor array composed of commercial metal oxide gas sensors was used. First, a selected temperature profile was chosen for each sensor of a six-sensor array. In a second way, the temperature modulation technique was applied to a four-microsensor array. We performed the pattern recognition with both principal component analysis (PCA) and artificial neural networks (ANN) [28].

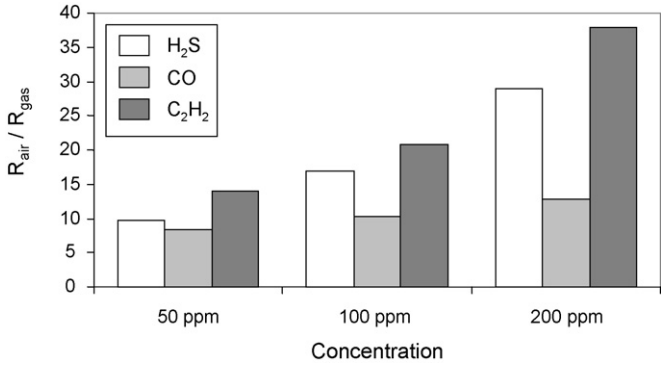

Fig. 2. Response of TGS825 sensor in presence of H_2S, CO or C_2H_2 at nominal heating voltage (5 V).

2. Experimental

2.1. Experimental set-up

The experimental set-up is shown in Fig. 1a. The chamber containing the set of sensors is connected to a gas mixer using mass flowmeters. The chamber volume is 300 ml. A 10-channel multiplexer (Keithley 7001) was used to scan each sensor of the array. A multimeter (Keithley 2000) measures the voltage V_{RL} across the bias resistance R_L (Fig. 1b). The data acquisition is controlled by a PC via a HP-VEE program and stored for the further analysis. The value of sensor resistance is deduced from V_{RL}. The target gases include three reducing gases (carbon monoxide, acetylene and hydrogen sulphide) diluted in synthetic air at different concentrations with a constant total flow of 100 ml/min.

The array is built with sensors from Figaro Inc. (Japan) and MicroChemical Systems SA (Switzerland). We constituted a matrix of six sensors of different structures in order to have different signatures. Table 1 presents the sensor characteristics and the target gases given by the respective manufacturer. Fig. 2 shows the poor selectivity of a metal oxide sensor. Similar results were obtained with the other sensors. This six-sensor matrix is used in the first study, based on a heating of the sensors in steps. The second study relates to the modulation of the temperature of the sensors and requires sensors having a weak thermal inertia. Among the six sensors, only sensors with an integrated structure (TGS2611, MiCS2610, MiCS5131 and MiCS5133) are kept. Indeed, their temperature follows well the signal of the heating modulation, provided that the frequency of this signal remains lower than a maximum value, 25 mHz in our case.

Table 1
Characteristics of sensors used in array

Sensor	TGS825	TGS826	TGS2611	MiCS2610	MiCS5131	MiCS5133
Gas	H_2S	NH_3	CH_4	O_3	CO	C_2H_5OH
Range of detection (ppm)	5–100	30–300	500–1000	0.01–10	10–1000	–
Nominal heating voltage (V)	5	5	5	2.35	3.2	3.2