Fluctuation Enhanced Gas Sensing at Modulated Temperature of Gas Sensor

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ABSTRACT
Taguchi gas sensors are commonly used to measure gas concentration. The standard detection method utilizes only changes of sensor DC resistance to determine various gases concentration. Unfortunately, such technique leads to false results due to cross-sensitivity of gas sensors at presence of other gases. Such adverse effects can be reduced by applying fluctuation enhanced sensing and temperature modulation of the sensor what allows to gather more information about ambient atmosphere than the sensor DC resistance only. The measurement setup of voltage fluctuations across the gas sensor as well as the selected measurements results of DC resistance under temperature modulation are presented. New indicators of gas detection have been proposed which utilize voltage fluctuations and DC resistance measurements at two selected different temperatures of the gas sensor.

Keywords: Digital Signal Processing, Fluctuations Enhanced Sensing, Gas Detection, Gas Sensors, Noise

INTRODUCTION
The detection method in commonly used gas sensors such as Taguchi Gas Sensors (TGS) (Taguchi, 1971; Ihokura & Watson, 1994) implies measurements of the sensor DC resistance only. Sensor active layer consists of metal oxide layer (e.g.: SnO$_2$, TiO$_2$, WO$_3$, ZnO) which is heated to elevated temperature. Such layer exhibits established conductivity in dry air, which varies at presence of other gases and their different concentrations. These sensors are widely used in security systems but we can still expect increase of their applications due to trend in improving human living standards and a need of air quality monitoring or more severe demands for security in public places. The gas sensors are optimized to detect selected gas or a group of gases. Unfortunately, selectivity of TGS gas sensors is rather poor and the DC resistance changes can be induced by presence of various gases. A good example of such measurement is detection of ammonia (NH$_3$) or methane (CH$_4$) at presence of carbon monoxide (CO). In such situation
the DC resistance change would result in false detection because the same change could be induced by different mixtures of NH₃ and CO.

Gas adsorption-desorption processes which occur in the sensors active layer may result in temporary changes of electrical properties of porous gas sensitive layer (potential barrier fluctuations between the grains) (Weisz, 1953; Madou & Morrison, 1989). Such changes can be observed as resistance fluctuations, which are valuable source of information about ambient atmosphere of gas sensor. This information can be utilized to improve gas detection sensitivity and selectivity. The fluctuation enhanced sensing (FES) method allows detection and distinction between various gases (e.g. ammonia and hydrogen) or fungus and bacteria using only a single gas sensor (Kiss, Granqvist & Söderlund, patent; Kish, Vajtai, & Granqvist, 2000; Kotarski & Smulko, 2010; Vidybida, 2003; Mkhitaryan, Shatveryan, & Aroutiounian, 2007).

Taguchi gas sensors depend strongly on their working conditions, such as temperature of the gas sensitive layer. This phenomenon is used to improve gas detection selectivity by modulating sensor temperature using abrupt changes of sensor heating voltage (Lee & Reedy, 1999; Ngo, Lauque, & Aguir, 2007). This method combined with the previously mentioned FES method is considered in the paper and confirms that ammonia or methane concentration can be established even at presence of additional crossing gas – carbon monoxide. The measurement setup, applied for random data acquisition and abrupt temperature modulation is presented, together with the proposed detection parameter which is a combination of DC resistance and noise data.

MEASUREMENT SETUP

Low frequency voltage fluctuations across the polarized gas sensors are usually characterized by their power spectral density $S(f)$ that means application of FFT algorithm and averaging over spectra to limit estimation accuracy (Beeson, 1985, Clark, 1973). Thus, the data acquisition system should not measure DC resistance only but has to amplify and record voltage fluctuations.

For laboratory measurements the designed gas distribution system has been used, to obtain the desired gas concentration. The system allows mixing two various gases of a concentration accuracy about 1 ppm for the applied calibration gases. In this exploratory study we present measurement results obtained for a gas sensor placed into a gas chamber and measurements made by a low noise electronic circuit. The gas sensor was located in ambient atmosphere of a mixture of synthetic air and two other calibrating gases, which flow was controlled by separate flow-meters.

The electronic circuit used to polarize the gas sensor presents Figure 1. The sensor current is determined by the resistance $R_1$ which was equal to 100 kΩ. The reference voltage $U_{\text{ref}}$ was set to 1.25 V and the gain $K$ of voltage fluctuations was set to 500 V/V by selection of resistors $R_2$ and $R_3$. The DC voltage component $U_1$ across the sensor and the amplified AC voltage component $U_2$ were connected to the input of the 24-bits A/D converters to record the data. The frequency range where the $1/f$ noise component dominated up to tens of kHz for the investigated sensors.

The measurement setup was controlled by a microcontroller which was responsible for handling the applied precise A/D converters and for communicating with the PC where the further data processing was performed. The sensor heater was controlled by a D/A converter built in the applied microcontroller to execute the measurements and to change voltage supplied to the heater simultaneously. Such approach allows real-time measurements of voltage fluctuations at the modulated heater voltages changing sensor temperature. The system was controlled by the developed vir-