Temperature Modulation of MOS Gas Sensor for Enhanced Gas Detection

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Abstract - The response of metal oxide semiconductor (MOS) gas sensors are affected by change in temperature as the kinetics between the gaseous components and the sensor surface are temperature dependent. Temperature modulation of MOS gas sensors have been used widely for extracting features of gaseous component. However modulation of the heater voltage following a proper pattern may lead to easier and fast discrimination of gases. This paper presents results of the response of gas sensor array, as the sensor surface temperature is modulated by different waveform pattern. Principal component analysis (PCA) is applied to the response of the sensor to four different volatile components. The results indicate that the classification of the gaseous component is possible from their signature responses..

Keywords: Gas Sensor, Metal Oxide Semiconductor, Microcontroller, Principal Component Analysis, Pulse Width Modulation, Temperature Modulation.

I. INTRODUCTION

Gas sensors have a broad application for detection and identification of gases. An array of gas sensors and a data acquisition system along with pattern recognition technique can be used to characterize a wide range of odors or volatile compounds [1].This system known as Electronic nose (E-nose) is very popular as the response of the array of gas sensor is always unique for a specific gas. Commercially available metal oxide semiconductor (MOS) gas sensors are often chosen for such system as they have high repeatability, sensitivity and are inexpensive. These sensors combine a gas sensing element with a heating element because sensitivity and selectivity of gas sensing materials are temperature dependent. Metal oxide semiconductor (MOS) sensors operate at around 300^0C to 550 ^{0}C of its sensing surface. A constant temperature of the sensing surface can be maintained by applying a constant DC voltage across the resistive heater built into the device [2]. But the performance of the gas sensor can be improved easily if the temperature of the semiconductor surface is controlled properly, since the reaction rates for different volatile components are a function of surface temperature [3]-[4].Temperature modulation of the semiconductor gas sensor using periodic heating voltage has improvements in sensitivity because for each gas there is a heater voltage for which it shows maximum conductance–temperature characteristics [2].

The gas sensor heater consumes relatively large amount of power and needs specialized circuit to deliver the power to the heater. Pulse Width Modulation (PWM) is considered as a technique for applying power to a load in a very efficient manner without much loss in heat. A microcontroller can be used to control the duty cycle of a PWM output that drives the average power to the heater [5].

The aim of our work is to show that varying the temperature of gas sensor array according to a pre programmed waveforms leads to response pattern which can be used to discriminate between different gases. This would result in saving of acquisition time as well power. First the experimental set up and measurement procedure is described and in the second part the sensor response and the data analysis are presented.

II. EXPERIMENTAL WORK

A. *Experimental Setup*

The designed system has a PIC microcontroller 18F448 from Microchip Corporation which is programmed to compute and generate 10 different modulating waveform like DC, rectangular, sinusoidal, saw-tooth, sigmoid(+ve half), exponential, triangular, decreasing saw-tooth, decreasing sigmoid(+ve half) and decreasing exponential waveform having amplitude of 5v and a period of 50second.. The waveforms are encoded by 8 bit digital signal which is available at the output port of the microcontroller. The 8-bit digital signal is then converted to analog signal in the range of 0 to 5 volts by DAC506 manufactured by Maxim semiconductor. The analog voltage is then applied to the input of a comparator along with a sawtooth waveform generated by a 555 timer circuit. The output of the comparator is thus a PWM signal, the duty cycle (from 0 to 100 %) of which is controlled by the analog voltage of the digital to analog converter (DAC). The analog voltages applied are the 10 different modulating waveforms mentioned above. The PWM signal then used to drive the MOS gas sensor array whose temperature is dependent on the duty cycle as shown in the Fig2.1.

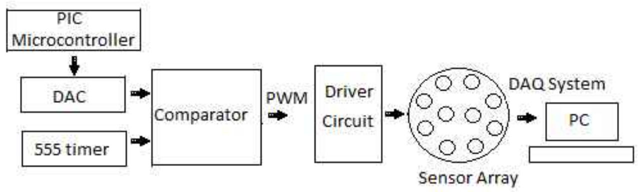


Fig. 2.1: Experimental data-acquisition setup

Sensor array of 10 commercially available FIGARO gas sensors are mounted in a chamber. The sensor resistance can be expressed as a function of output voltage [2] as shown below

$$R_s = \left(\frac{V_C}{V_{out}} - 1\right) R_L \qquad (1)$$

Thus the heater temperature affects the sensor resistance as well as the output voltage.

A data acquisition (DAQ) system is designed using PIC microcontroller 18F448 as presented in [6] and a graphical user interface is developed in the PC using LABVIEW. Through this GUI the user can control the device, can acquire the sensor output data for processing and displaying in real time and also can be stored for future use.

B. Analyzed Gases

Four different gases : *1-Butanol*, *Acetone*, *Acetic acid* and *Acetonitrile* are selected for analysis based on availability.

III. RESULTS AND DISCUSSION

A. Measurement

The PWM signal is applied across the gas sensor array and measurement is taken using sample gases. A PC based multi channel data acquisition system is designed as reported in [6] and is used to acquire the response of the eight gas sensors along with the modulating analog signal. The acquired result is displayed in PC in real time.

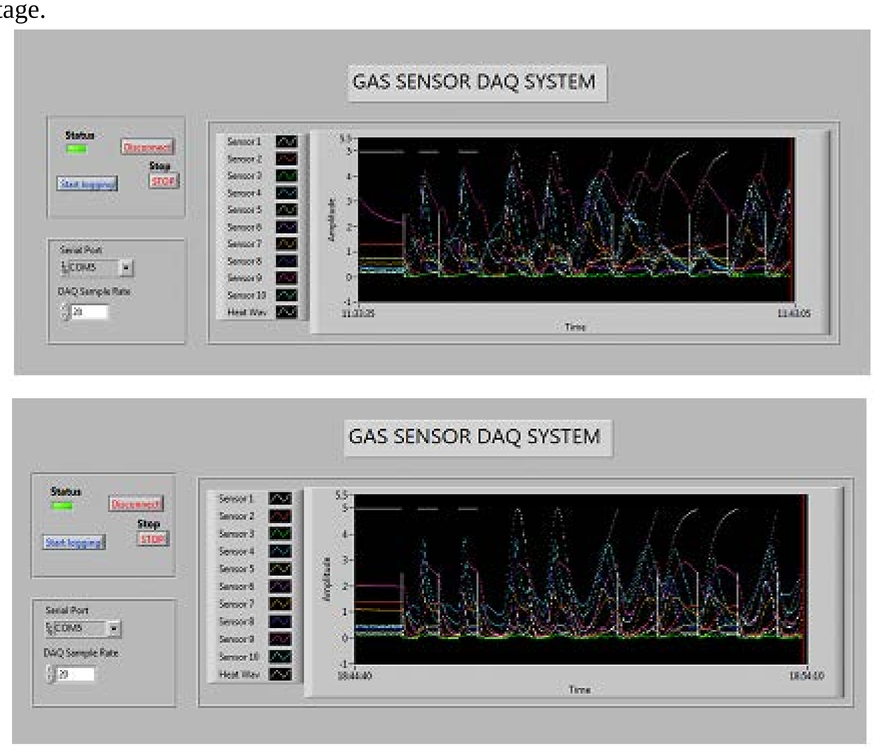


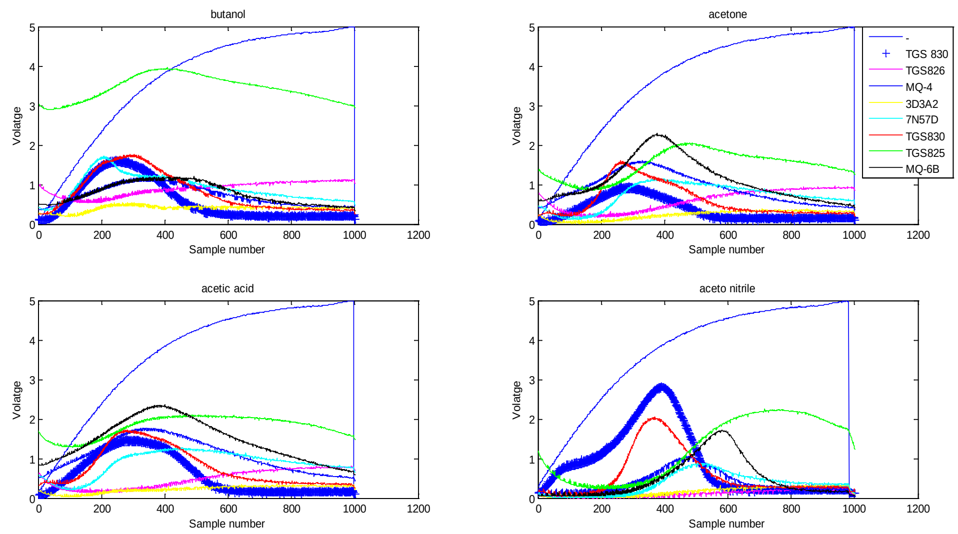
Fig 3.1: Response of gas sensors to acetone and butanol for six differently modulated heater voltages

Fig.3.1 shows the sensor conductance behaviour for acetone and butanol under different types modulating heater voltage. It can be clearly observed that the response of the gas sensor array varies as our modulating heater voltage changes in a definite pattern. It is because the gas sensor sensing surface reacts with the gas molecules differently as the temperature changes.

Each of the modulating signals is of period of 50 sec. The DAQ system collects 1000 sensor output sample at rate of

20hz. Fig 3.2(A) and fig. 3.2(B) shows the eight sensor output for one cycle of sinusoidally varying and sigmoidally varying heater voltage. Since MOS gas sensor shows a good repeatability hence the second cycle of the heating voltage waveform is selected for further analysis. For the four different chemicals the gas sensor array response becomes different. For butanol and acetone the sensor shows high conductivity if the heater voltage is modulated sinusoidally where as if the heater voltage is modulated sigmoidally the sensor array shows best response with a high conductivity for

A)



B)

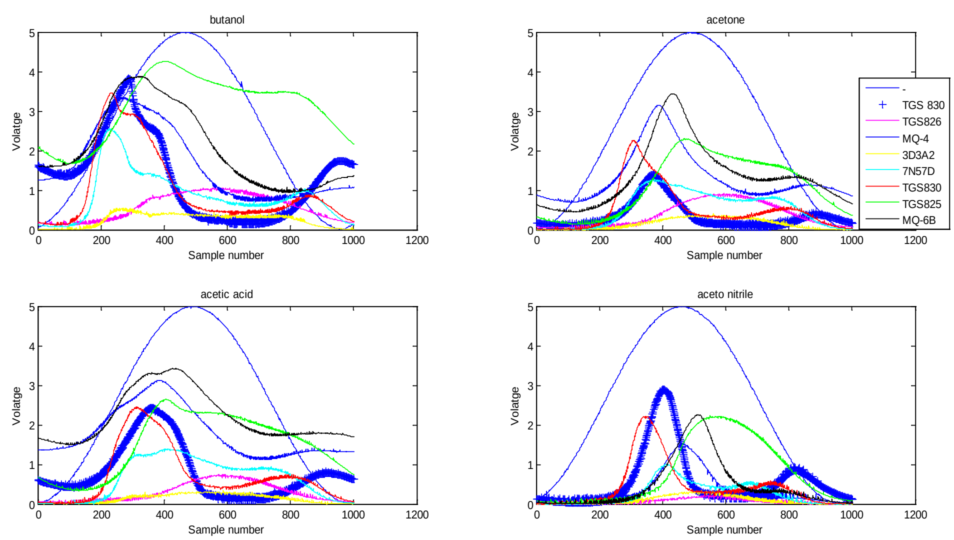


Fig 3.2: Response of the eight gas sensor to four different gases A) for sinusoidal heating waveform and B) for sigmoid heating waveform

acetic acid and acetonitrile. Thus change in the temperature of the sensor array in a definite pattern leads to fast and stable response of the sensor array in response to a volatile substance.

Several problems like lack of selectivity, sensitivity and drift are always present in the response of the gas sensor [2]. Hence pattern recognition methods are often used to extract the information from the gas array response. The similarities or the differences in the response of the gas array when the heater voltage is modulated in different pattern can be easily shown using PCA.

B. Principal Component analysis

PCA is a linear technique used mainly for feature extraction of gas sensor array [8]. PCA is a signal representation technique that generates projections along the directions of maximum variance [8]. In [9], Principal component is used to analyze the response of the tin oxide gas sensor. PCA processes the information obtained from the array of sensor into lower number variables called principal component [8], preserving as much data variance as possible [10].

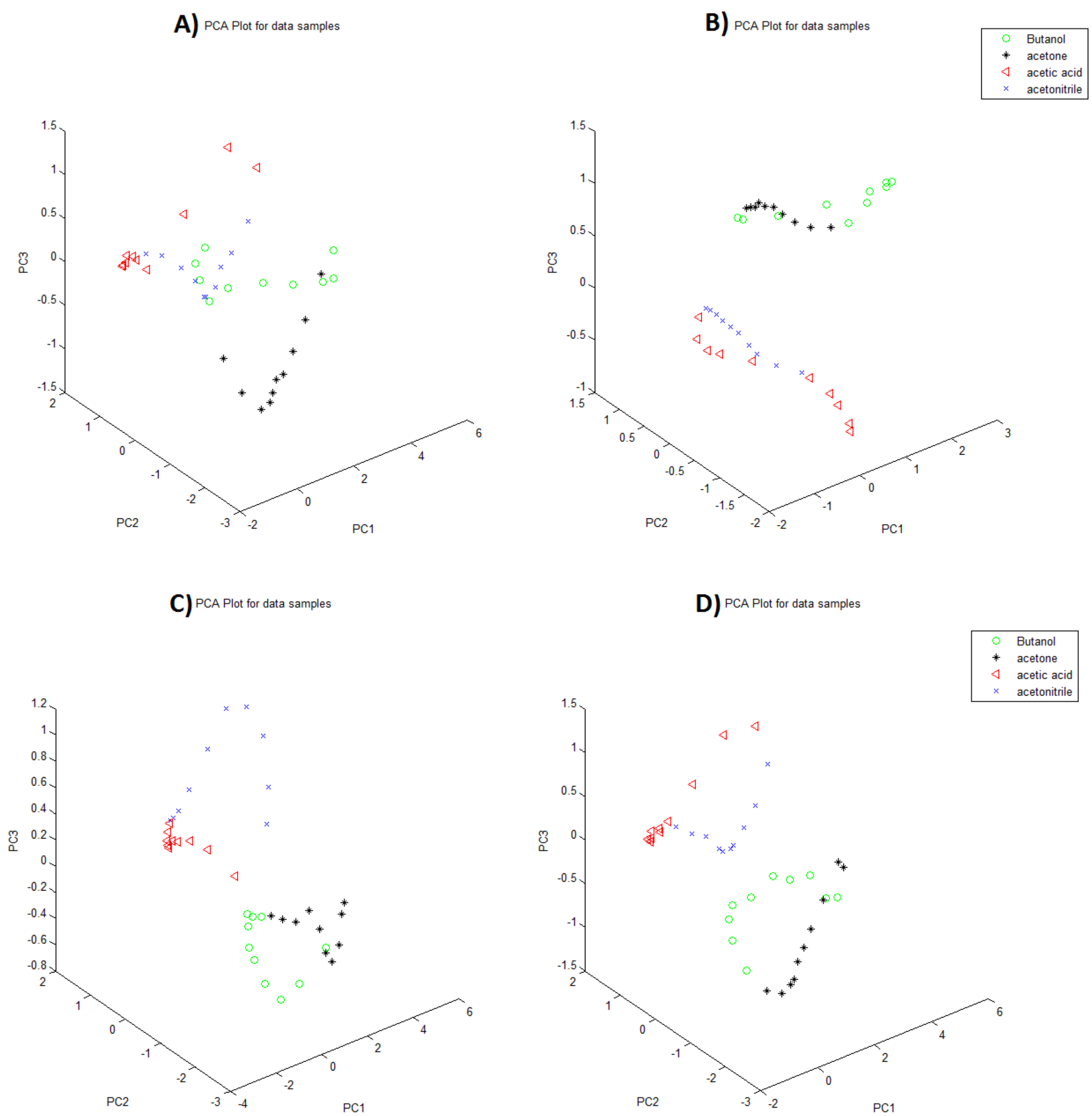


Fig 3.3: Plot of PCA analysis for A) Sinusoidal B) Sigmoidal C) Exponential and D) Triangular waveform

The first few components are based on the largest variation of the data Therefore the informatics features are concentrated in the first few components. Here the data are collected for four classes (gases) of chemicals. For each class, data is collected for four different modulating heating voltage treatment. For a modulating signal cycle of 50 sec duration 1000 data points is collected. The signals are then down sampled to 20 samples gathering the data at a rate of 1Hz for PCA analysis. A response matrix is obtained where each column represents the different sensor and the rows represents the output data related to different experiment [2].The dimensionality is reduced to few principal components using PCA. The PCA score plot is plotted using the first three major principal components as shown in Figure 4. The sensor response for each gas is marked differently in the figure. Fig 3.3 (A) show the PCA plot for the sensor array response when the heating voltage is modulated sinusoidally. The three PCA components PC1, PC2, PC3 account for 69.1% and 18% and 7.7% of the variation respectively. The result shows visually differentiable clusters for acetone and acetic acid, where as the clusters of 1-Butanol and Acetonitrile overlaps. Fig 3.3 (B) is the PCA plot when a positive sigmoid voltage is applied as a modulating voltage to the heater of the gas sensor array. This plot shows two distinct overlap clusters one clusters is overlapped data of 1-Butanol and Acetone whereas the other is for Acetic acid and Acetonitrile. Here the three PCA components accounts for 52.8%, 30.3%, 12.3% of the variation. Fig 3.3(C) and Fig 3.3 (D) shows the PCA plot for the data sample when the heater voltage is modulated exponentially and triangularly. The variation shows by the three components for exponentially modulated are 78.8%, 11% and 6%.of total variation. Whereas for triangularly modulated heater voltage the principal components varies 67.4%, 18.6%,9% of the total variation. From the figure it is clearly visible that the response of the gas sensor array varies depending on how the sensor surface temperature changes. This leads to distinct clusters in the PCA plot. So using a particular modulating voltage to the heater of the gas sensor easy identification of volatile chemical components are possible.

IV. CONCLUSION

The conductivity of the gas sensors are surface temperature dependent. Hence varying the surface temperature in a suitable way may lead to easy identification of the volatile component. Here we have presented the response of eight gas sensors in presence of each of four different gases. As an example we modulated the heating voltage with four different pattern and the results are analysed using Principal component analysis. The results shows that change in heater voltage with a definite pattern leads to easily distinguishable clusters which leads to easy identification of a particular gaseous component. With further analysis the best modulating waveform for a particular gas can be found out.

REFERENCES

[1] R.Gutierrez-osuna ”Pattern analysis for Machine Olfacetion : A Review.” ,IEEE Sensors Journal, Vol. 2 No. 3, June 2002.

[2] Sarry, Frederic; Lumbreras, M., "Gas discrimination in an air-conditioned system," Instrumentation and Measurement, IEEE Transactions on , vol.49, no.4, pp.809,812, Aug 2000

[3] N. Barsan, D. Koziej and U. Weimar, “Metal oxide-based gas sensor research: How to?”, Sensors and Actuators B: Chemical, Volume 121, Issue 1, pp. 18,35, 30 January 2007.

[4] A. P. Lee, B.J. Reedy” Temperature modulation in semiconductor gas sensing”, Sensors and Actuator B:Chemical vol. 60, Issue 1, pp. 35, 42, Nov 1999.

[5] M Amos, Dr. Bruce Segee “Microcontroller based Heater Control for Gas sensors”, Proceedings of the 2001 American Society for Engineering Education Annual Conference and Exposition,2001

[6] “R Gutierrez-Osuna, S Korah, A Perera, “Multi-Frequency temperature modulation for metal oxide gas sensors”, Proceedings of the 8th Intl. Symp. On Olfaction and Electronic Nose, Washington, DC, March 25-30, 2001

[7] A.Bora, K. C. Sarma “Design of a USB based multichannel , Low cost Data Acquisition system using PIC Microcontroller” IJCA Journal, Volume 59- Number 6,pages 5-8, 2012.

[8] R.Gutierrez-Osuma “Analysis for Machine Olfaction: A Review” IEEE SENSOR JOURNAL, vol. 2, No. 3, June 2002.

[9] J.W. Gardener ,”detection of vapors and odours from a multisensory array using pattern recognition, Part I. Principal component and cluster analysis, ”Sens. Actuators B, vol. 4,pp.109-115,1991.

[10] A. Bermak, S. Belhouari, M. Shi and D. Martinez “Pattern Recognition Techniques for Odor Discrimination in Gas Sensor Array”,Encyclopedia of SENSORS.