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# Temperature Modulation of Gas Detection System Using Different Heating Voltage Waveform

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***Abstract*—Temperature modulation is considered as one of the procedure to obtain enhanced gas sensor performance. It is because the gas sensor kinetics between the gas sensor and the gas, depends on the sensor surface temperature. In this research we have studied the effect of the temperature modulation on the gas sensor array in presence of different gases. Responses for different heating waveform are compared based on the clusters of extracted features and finally conclusion can be drawn that temperature modulation leads to distinct clusters of target gases which helps in easy identification**

***Keywords*—Metal oxide gas sensor, Temperature modulation, inter-intra cluster distance ratio.**

## I. INTRODUCTION

Metal Oxide Semiconductor (MOS) gas sensors recently gained wide popularity as a gas detector, due to its low cost and repeatability. These sensors combine a gas sensing element with a heating element because sensitivity and selectivity of gas sensing materials are temperature dependent. Usually a constant voltage is applied to gas sensor whenever used for differentiating multiple gases. But the application of a constant heating voltage provides a set of limited features. Limited features may result in weak classification performance of a pattern recognition system [1]. Researchers are working on temperature modulation of MOS gas sensors for generating rich set of features that may lead to higher classification performance.

In temperature modulation, a cyclic heating voltage is applied to the gas sensor heater, so that it leads to the variation of its operational temperature depending on the amplitude of the applied voltage. The rate of kinetics between the gas sensor and the gas follows the variation of the surface temperature and it produces unique features for each gas. Temperature modulation may provide large set of features which helps in easy identification of gases [2].

Temperature modulation of MOS gas sensors using various shaped heating voltage have been investigated by many researchers. In [3], Nakata *et al.* applied sinusoidal temperature modulation to $SnO_2$ gas sensors to the obtained multi dimensional information in order to quantify mixtures of hydrocarbon. In [4], Heilig *et al.* also used the sinusoidal temperature modulation to analyze a mixture of CO and NO in air. In [5], Cavicchi *et al.* used a cyclic pulsed heating waveform for temperature modulation of the gas sensors. In [6], Bukowiecki *et al.* used heating waveforms like triangular, sawtooth , square wave etc. to identify CO, Methane, Ammonia and Hydrogen. In [7], Ngo *et al.* employed temperature modulation using triangular waveforms and neural networks to identify three gases- CO, acetylene and hydrogen sulphide. In [8], Ding *et al.* experimented with sinusoidal temperature modulation applied to a single MOS sensor. and used wavelet transform to extract features from the thermally modulated senor's response for identification of hydrogen, CO and their mixture.

## II. ACQUISITION OF ODOUR DATA

In this investigation, we have used an array of 4 sensors namely TGS826, TGS821, TGS2611 and TGS825 for data acquisition. A total of 9 different temperature modulation waveforms are considered which were rectangular, sinusoidal, saw-tooth, sigmoid, exponential, triangular, decreasing saw-tooth, decreasing sigmoid and decreasing exponential having the time period of 50 seconds and amplitude of 5v. The waveforms are generating circuit is designed using a PIC microcontroller [9]. As target gases, 8 gases as listed in Table1 are selected. The data acquisition was performed at 20 Hz using a developed DAS [10]. This resulted in a 1000 point response waveform during a period of a waveform. All the response waveforms are very slow varying signal. Each of the 1000 point signals were filtered using moving average filter to remove high frequency noise and sub-sampled to 1 Hz for data compression. Subsampling reduces to the total collected samples to 50 samples for each gas sensors. Hence for four gas sensors the total collected data becomes 50 x 4 for each heating waveforms. Figure 1.1 to 1.3 shows the plot of the response waveforms of gases to some of the temperature modulation waveforms. The figures show the variation of the response of the four gas sensors as the applied heating voltage waveforms are varied.

 

Table 1 Prepared gas-air concentration and amount of liquid chemical

| Serial no. | Chemical | Amount of liquid chemical and prepared concentration (ppm) |
|---|---|---|
| | | 4 (µl) |
| 1 | 1-Butanol | 490 |
| 2 | Acetone | 1220 |
| 3 | Acetic acid | 1567 |
| 4 | Di methyl sulfoxide | 1262 |
| 5 | Ethanol | 1535 |
| 6 | Petroleum benzine | 712 |
| 7 | Pyridine | 1113 |
| 8 | Formaldeh yde | 2433 |

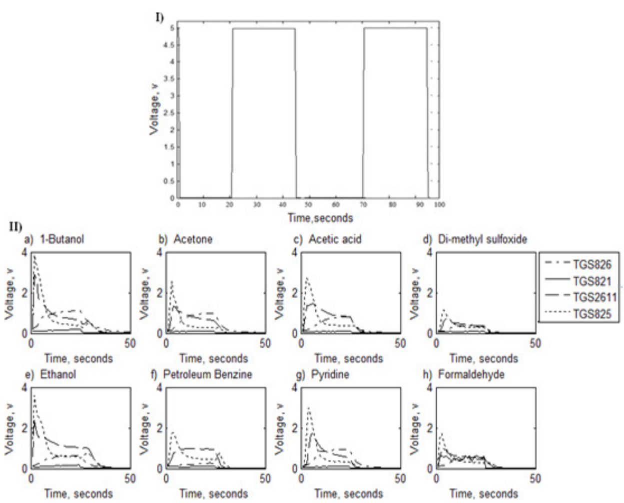


Figure 1.1: Plot of I) the rectangular modulating waveform used as heating voltage and II) the corresponding 50 samples collected from 4 sensors for 16 gases for concentration corresponding to 4 ul of liquid analyte

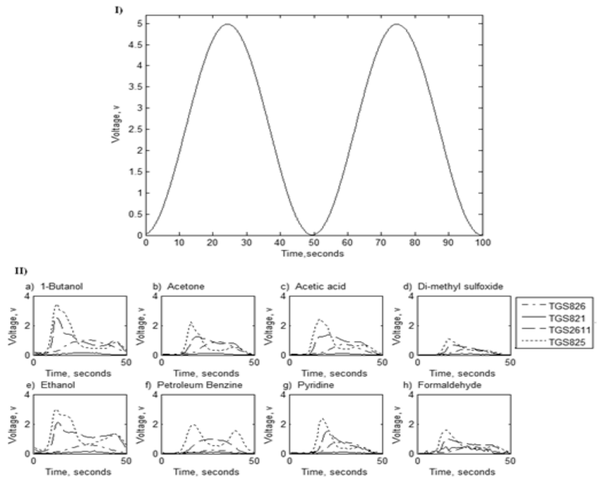


Figure 1.2: Plot of I) the sinusoidal modulating waveform used as heating voltage and II) the corresponding 50 samples collected from 4 sensors for 16 gases for concentration corresponding to 4 ul of liquid analyte

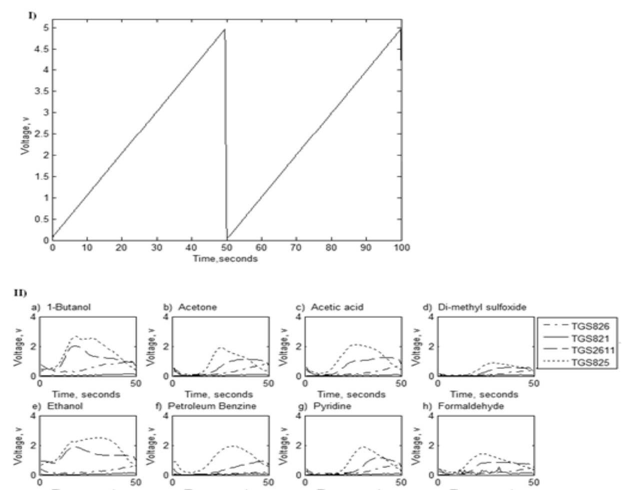


Figure 1.3: Plot of I) the sawtooth modulating waveform used as heating voltage and II) the corresponding 50 samples collected from 4 sensors for 16 gases for concentration corresponding to 4 ul of liquid analyte

## III. RESULTS

The 50 point response waveforms were normalized by dividing each sensor response by the maximum value of the responses. Normalization is required to eliminate the effect of drift of sensors as well the variation due to change in concentration. Figure 2 shows the result of normalization of response of Acetone for 4 sensors. The figure shows the normalized waveforms for all the heating waveform types.

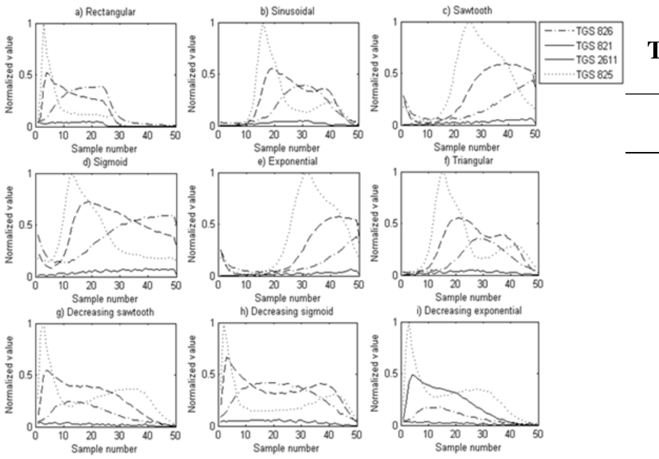


Figure 2: Plot of normalized response waveforms of Acetone (4ul) for 4 sensors and various heating waveforms

The feature extraction was accomplished by sampling one point in every 5 seconds from each of the 50 point normalized response waveforms so that four sensors set the length of the feature vector is 40 for each heating waveform. The performance of the heating waveforms are determined based on their classification properties. In this research, we have used the *Euclidean* inter-intra cluster distance ratio for feature (and the corresponding heating waveform) evaluation. Table2 lists the calculated *Euclidean* inter-intra cluster distance ratio for various waveforms. It is seen from the table that the inter-intra cluster distance ratio varies for the different waveforms and becomes maximum maximum 1.5594 for the decreasing sigmoid heating waveform. Thus the decreasing sigmoid heating waveform produces the best features with best cluster separation for better classification.

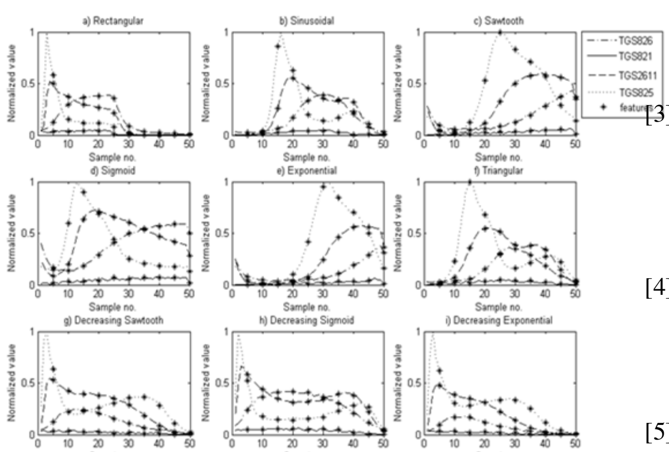


Figure 3: Plot of normalized response waveforms and extracted features of Acetone (4ul) for 4 sensors and various heating waveforms

**Table 2 *Euclidean* inter-intra cluster distance ratio for various waveforms**

| Heating waveform | Euclidean inter-intra cluster distance ratio |
|---|---|
| Rectangular | 1.3058 |
| Sinusoidal | 1.2532 |
| Sigmoid | 1.3325 |
| Sawtooth | 1.0624 |
| Triangular | 0.859 |
| Exponential | 1.1173 |
| Decreasing Sigmoid | **1.5594** |
| Decreasing Sawtooth | 0.7224 |
| Decreasing Exponential | 0.6348 |

## IV. CONCLUSION

In this work, the evaluations of nine heating waveforms were done to study the effect of temperature modulation on the gas sensor responses. The quality of the features obtained from the gas sensor array was measured by the *Euclidean* inter-intra cluster distance ratio for each of the heating waveform. The ratio shows the variation of qualities of clusters of the gases with the applied voltage waveforms. The same procedure can be used to find out the best heating voltage waveform to obtain the best response from the gas sensor array.

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