

LINEAR DISCRIMINANT ANALYSIS BASED SENSING CHARACTERISTICS STUDY OF ZnO THICK FILM GAS SENSOR

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Abstract- Driving under the influence (DUI) is a synonymous term that represents the criminal offense of operating a motor vehicle while being under the influence of alcohol. Semiconductor oxides such as SnO₂, TiO₂, and ZnO have been more successfully employed as sensing materials compare to organic semiconductors for the detection of ethanol gas concentration. This work investigates the fabrication and characterization of the thick-film gas sensor based on Zinc-oxide on an Alumina substrate. The sensor exhibits excellent ethanol sensing characteristics at temperatures between 175°C to 300°C and the characteristics of the sensor for different concentration of the ethanol gas has been successfully studied using Linear Discriminant Analysis (LDA). This system can be used to detect alcoholic driving for automotive safety applications. The system is designed to detect the exact concentration of ethanol gas using virtual instrumentation software and data acquisition hardware. This work presents the data analysis results of 230 samples of each concentration levels of ethanol gas using Linear Discriminant Analysis (LDA) technique. The overall system can be tested with the engine ignition system for automotive safety and warning applications in the prevention of a crash during drunken driving.

Keywords-Linear Discriminant Analysis (LDA); Engine ignition System; Zinc Oxide Thick film sensor; Driving under the influence (DUI); Virtual Instrumentation.

INTRODUCTION

Driving under the influence (DUI) (drinking and driving, and drink-driving) is the act of operating any motorized machinery after or during the consumption of alcohol or other drugs. DUI is synonymous term that represents the criminal offense of operating a motor vehicle while being under the influence of alcohol or drugs or a combination of both. It is a criminal offense in most countries. This system will detect and display ethanol concentration in the LabView front panel. The sensor is a thick film based zinc oxide gas sensor. The sensor is having an inner heating coil which is heated up to a temperature range of 75°C to 300°C. The use of resistive, adsorption-based sensors has been increasing over the past few years for the purposes such as detection of smoke, oxidizing or reducing gases (O₂, CO, Ethanol, CH₄, CO₂, etc) and humidity [1]. A large number of materials have been used for gas sensing, including ceramics that often consist of a combination of metal oxides. ZnO is one of the semiconductor materials that are sensitive to many gases of interest like hydrocarbons, hydrogen, volatile organic compounds etc. They exhibit high sensitivity, satisfactory stability and rapid response to even small concentrations of gases (ppm level). In this paper we will concern ourselves with the sensitivity of ZnO thick film resistor for sensing ethanol gas at 100ppm. of gas concentration at various temperatures from 75°C to

300°C in order to find the temperature for maximum sensitivity [2]. Also the sensitivity for different concentrations of ethanol (from 5ppm. to 95ppm.) was tested. The sensor characteristics can be studied using various data clustering techniques like Linear Discriminant analysis (LDA). In this paper we have done the analysis using Linear Discriminant analysis (LDA). This sensor can easily be implemented as an engine ignition system during drunken driving [Figure 1].

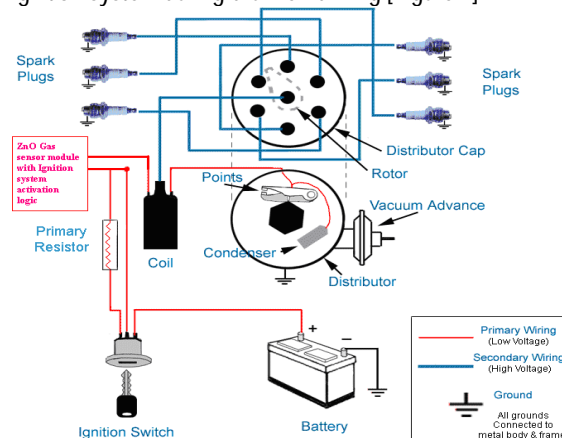


Fig. 1- Zinc Oxide Gas Sensor used for detection and warning of DUI and engine ignition system.

A. Linear Discriminant Analysis (LDA):

Linear Discriminant Analysis (LDA) is a commonly used technique for data classification and dimensionality reduction. Linear Discriminant Analysis easily handles the case where the within-class frequencies are unequal and their performance has been examined on randomly generated test data. This method maximizes the ratio of between-class variance to the within-class variance in any particular data set thereby guaranteeing maximal separability. The use of Linear Discriminant Analysis for data classification is applied to classification problem in speech recognition. Data sets can be transformed and test vectors can be classified in the transformed space by two different approaches. In this type of LDA, each class is considered as a separate class against all other classes. The class category or the group ("equal" and "not equal") is what we are looking for (it is also called dependent variable). Each measurement on the product is called features that describe the object (it is also called independent variable). Thus, in discriminant analysis, the dependent variable (Y) is the group and the independent variables (X) are the object features that might describe the group. The dependent variable is always nominal category variable while the independent variables can be of any measurement scale i.e. nominal, ordinal, interval or ratio. If we can assume that the groups are linearly separable, we can use linear discriminant model (LDA). Linearly separable suggests that the groups can be separated by a linear combination of features that describe the objects. If only two features, the separators between objects group will become lines. If the features are three, the separator is a plane and the number of features (i.e. independent variables) is more than three, the separators become a hyper-plane. The classification rule is to assign an object to the group with highest conditional probability. This is called Bayes Rule. Fortunately, there is a relationship between the two conditional probabilities that well known as Bayes Theorem.

$$P(i | x) = \frac{P(x | i) \cdot P(i)}{\sum_{\forall j} P(x | j) \cdot P(j)}$$

We want to know the probability $P(i | x)$ that an object is belong to group 'i' n a set of measurement x . In practice however, the quantity of $P(i | x)$ is difficult to obtain. What we can get is $P(x | i)$. This is the probability of getting a particular set of measurement 'x' given that the object comes from group 'i'. Prior probability $P(i)$ is probability about the group 'i' known without making any measurement. In practice we can assume the prior probability is equal for all groups or based on the number of sample in each group. In practice, however, to use the Bayes rule directly is unpractical because to obtain $P(x | i)$ need so much data to get the relative frequencies of each groups for each measurement. It is more practical to assume the distribution and get the probability theoretically. If we

assume that each group has multivariate Normal distribution and all groups have the same covariance matrix, we get what is called Linear Discriminant Analysis formula.

$$f_i = \mu_i C^{-1} x_k^T - \frac{1}{2} \mu_i C^{-1} \mu_i^T + \ln(P_i)$$

Assign object 'k' to group 'i' that has maximum f_i .

LITERATURE REVIEW

1. M. Fleischer, H. Meixner Siemens AG, Corporate Research and Development, Department ZT KM 2, Otto-Hahn-Ring 6, D-81739 Munich, German, in their paper "Selectivity in high-temperature operated semiconductor gas-sensors" published in Elsevier Sensors and Actuators B 52 (1998) 179–187, High-temperature operated metal oxides like Ga₂O₃ developed in the last years show certain advantages like reproducibility and robustness resulting from a conduction mechanism which is independent on grain boundary effects. But similar to the lower temperature operated oxides like SnO₂ and ZnO they also possess broad band sensitivity characteristics, i.e. they respond to all gases with similar chemical properties. This paper shows to which extent strategies to achieve selective gas detection with one single sensor are applicable with these metal oxides.

2. Hyung-Ki Hong, Hyun Woo Shin, Dong Hyun Yun, Seung-Ryeol Kim, Chul Han Kwon, Kyuchung Lee, and Toyosaka Moriizumi, LG Electronics Research Center, 16 Woomyeon-dong, Seocho-gu, Seoul 137–140, South Korea, Department of Electrical and Electronic Engineering, Tokyo Institute of Technology, Tokyo 152, Japan, in their paper "Electronic nose system with micro gas sensor array", they have fabricated an electronic nose system using a thin film oxide semiconductor micro gas sensor array which shows only 65 mW of power consumption at an operating temperature of 300°C. Principal component analysis and neural network pattern recognition analysis were used to identify 12 gas samples (CH₃SH, (CH₃)₃N, C₂H₅OH and CO gases in the concentration range of 0.1–100 ppm) or six flavor samples (carrot, green onion, woman's perfume (eau de cologne), man's perfume (eau de toilette), 25% liquor (Korean soju) and 40% liquor (whisky)).

ZnO SENSOR PREPARATION

ZnO has been traditionally employed as a gas sensor by making use of change in resistivity on exposure to the relevant gas. We employed ZnO thick-films prepared on an alumina substrate for sensing ethanol. The substrate was an alumina tube about 2cm long. Electrodes were wound over it using nichrome wires. Thick film preparation method was very simple and inexpensive. First, the commercial ZnO powder was reduced to a very fine powder by constant grinding for about an hour. A paste of it was then prepared by simply adding few drops of distilled water. Finally the thick film was made by applying the paste of the grinded commercial ZnO

powder over an alumina tube (substrate) containing the electrodes using a fine paint brush. Care was taken to apply a smooth coating such that no air gaps or cracks were present between the coating and the electrodes. The sample was then dried in the air for 24 hours and finally annealed at 300°C for 2 hours. The coating that we got was very smooth and had good adherence with the alumina tube after annealing. Finally a coiled nichrome wire was inserted through the tube to act as a heater. The complete structure of the thick film over the alumina substrate is shown in the Figure 1.

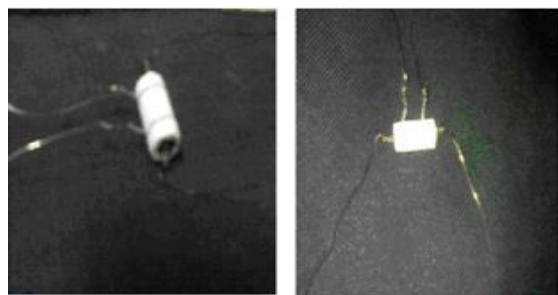


Fig. 2- Zinc Oxide Gas Sensor with heating coil arrangement.

EXPERIMENTAL PROCEDURE

In the system we have used a Zinc Oxide based thick-film sensor with its arrangement, Internal Heating Coil, Data Acquisition (DAQ) hardware and software, Digital temperature recorder, Power supply Unit, Power source for heating coil. Gas sensing characteristics of ZnO thick-film sensor were measured with a testing glass chamber, sensor holder, RTD, heating coil arrangement, temperature controller, National Instruments data acquisition software and hardware module, digital temperature detector, required circuitry. The sensor was tested for ethanol vapor in the temperature range of 75°C to 300°C range. 100ppm of ethanol was injected by micropipette into the testing chamber. The working temperature of the sensor was adjusted by changing the voltage across the heater side. The working circuit shown in the Figure-3 is used to monitor the output voltage across the load resistor, corresponding voltage across the sensor and the resistance of the gas sensor in dry air as well as in test gas to measure the concentration level.

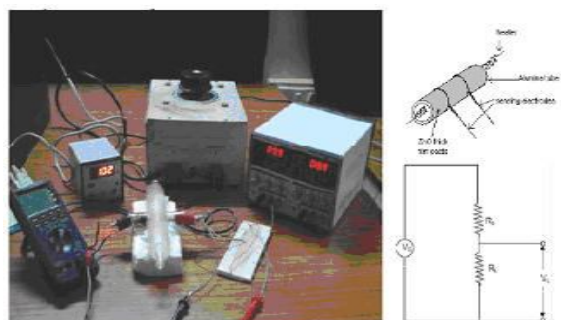


Fig. 3- Experimental setup and circuit for ZnO thick-film gas sensor measurement.

The experimental setup with heating coil at 250°C is shown in the figure-4. The Zinc-Oxide gas sensor is placed inside a glass envelop with its inlet valve [Figure-5] for the gas testing and concentration measurement.



Fig. 4- Experimental setup with heating coil at 250°C



Fig. 5- Glass chamber with inlet, outlet and emergency valve at the top.

RESULTS AND DISCUSSIONS

From Table-I. V_{air} and V_{gas} are the voltage obtained across the load resistor R_L . The gas sensitivity, S , was determined as $(R_{air} - R_{gas})/R_{air}$. Where R_{air} is the resistance of the gas sensor in the dry air while R_{gas} is that of the sensor in the test gas. The sensor resistance can be found out from the simple formula: R_S (sensor in air or gas) = $R_L * (V_S - V_L) / V_L$, where V_S is the source voltage (here 10 volts) and V_L is the load voltage which we are measuring directly as V_{air} and V_{gas} . As soon as ethanol gas was introduced into the sensing chamber, the electrical resistance (R_{gas}) of the thick film sensor started to decrease as compared to what was in dry air (R_{air}). It is clear that the resistance of the sensor was in the 160KΩ to 17MΩ range in the dry air and was in the 60KΩ to 15MΩ range for ethanol at 75-300°C. The sensor responses can also be affected by the slight change of temperature. In Figure 8, we have shown the sensitivity measured at different temperatures. It should be noticed that at 250°C the sensor shows highest sensitivity which is around 75%. Above this temperature the sensitivity starts decreasing.

TABLE 1. SENSITIVITY OF THE GAS SENSOR AT DIFFERENT TEMPERATURE RANGES AT 100P.P.M CONCENTRATION

Temp. (°C)	V _{air} (Volts)	R _{air} (KΩ)	V _{gas} (Volts)	R _{gas} (KΩ)	Sensitivity (%) $S = \frac{(R_{air} - R_{gas})}{R_{air}} \times 100$
75	0.187	16.79E03	0.23	13.59E03	19.05
100	1.062	2.693E03	1.35	2.050E03	23.86
125	1.917	1.349E03	2.389	1.024E03	24.06
150	2.540	939	3.95	490.12	47.80
175	2.50	960	4.2	441.90	53.90
200	3.19	683.13	5.40	275.59	59.66
225	3.75	533.33	6.15	200.32	62.43
250	4.03	474.04	7.09	131.33	72.29
275	5.54	257.61	7.97	81.50	68.36
300	6.63	162.6	8.43	59.596	63.16

Also the response for different concentrations of ethanol was tested. The thick film was tested for various concentrations of ethanol gas varying from 5ppm to 95ppm. It was found that with the increase in concentration of ethanol the resistance continuously decreased. Thus the corresponding sensitivity also increased. The response time for the sensor was also calculated. The rise time defined as the time required for the conductance to reach 90% of the equilibrium value after the gas is injected. The fall time is the time needed by the sensor to acquire 10% of the above the original value in air after the gas is removed.

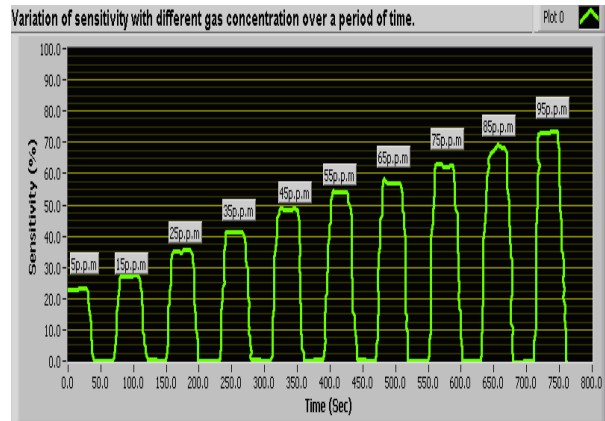


Fig. 6- Calibration of Ethanol Gas sensor and sensitivity curve at different concentration levels.

In Figure 6, we display the variation in voltage of the sensor at the different concentration ranging from 5 to 95ppm at 250°C. The sensor data has been analyzed using Linear Discriminant Analysis (LDA) algorithm on different ppm label of ethanol concentrations. The plots clearly points out the existence of distinct clusters of the gas sensor patterns with respect to the ideal concentration data. Linear discriminant analysis has been widely used in modeling the statistics of a set of multi-dimensional data [13]. By using these techniques the sensor data may be expressed and presented in such a way as to highlight their similarities and

differences. It can be noted from the Linear Discriminant Analysis (LDA) [Figure-8] plot that the formations of clusters for samples belonging to a particular concentration are more distinct with normalized than data without normalization. The rise time of the gas sensor was measured [Figure-6] to be about 30 sec while the fall or recovery time of the sensor was observed to be 10 sec. From the sensitivity curve [Figure-7] the temperature for maximum sensitivity is found out (T=250°C).

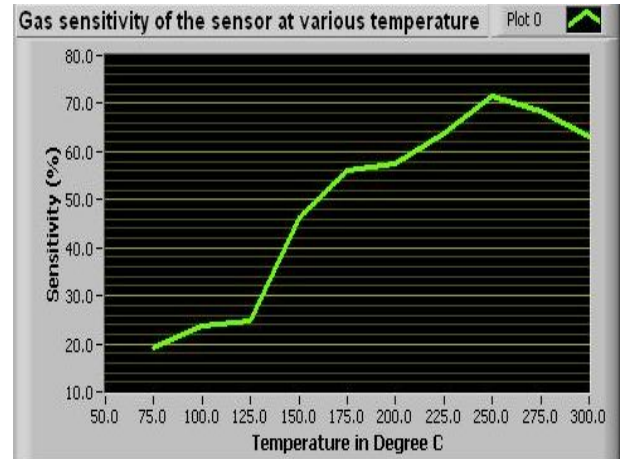


Fig. 7- Sensitivity curve of the sensor using LabView.

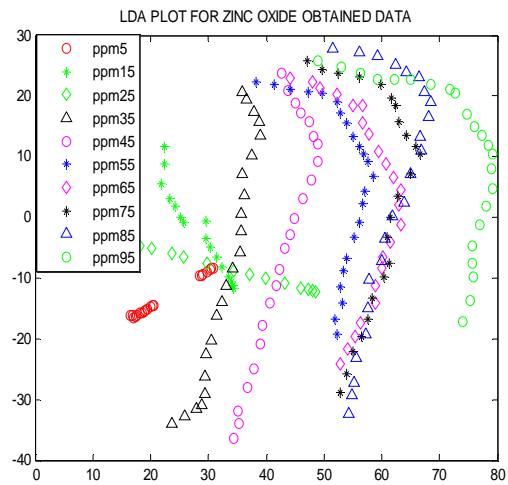


Fig. 8- LDA plot for different concentrations 5 to 95 p.p.m.

SOFTWARE IMPLEMENTATION

The method of working is based on simple measurement procedures. The sensor is connected to a resistive voltage divider circuit as the output of the sensor is a resistance change with respect to the input gas concentration. Data acquisition hardware and software are used for signal processing of the sensor data. The gas concentration [Figure-13] and temperature characteristics [Figure-12] were calculated using Virtual Instrumentation software (LabView).

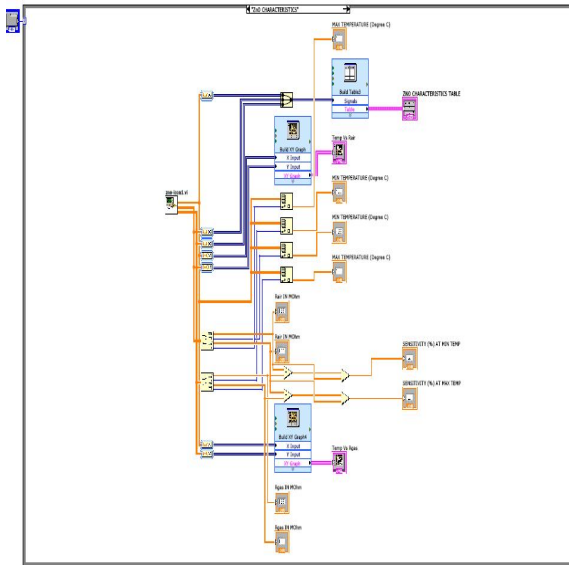


Fig. 9- ZnO Characteristics study using LabView.

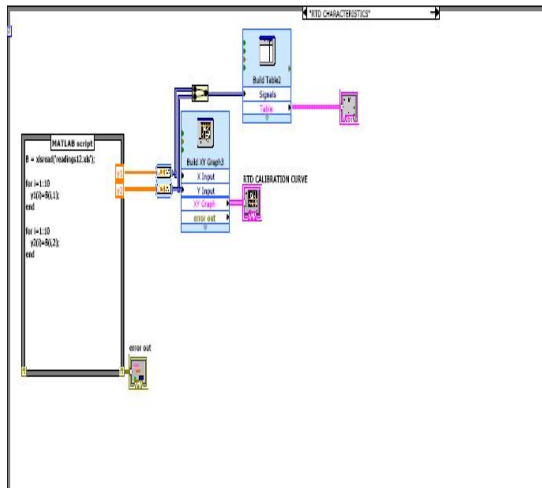


Fig. 10- RTD Characteristics study using LabView.

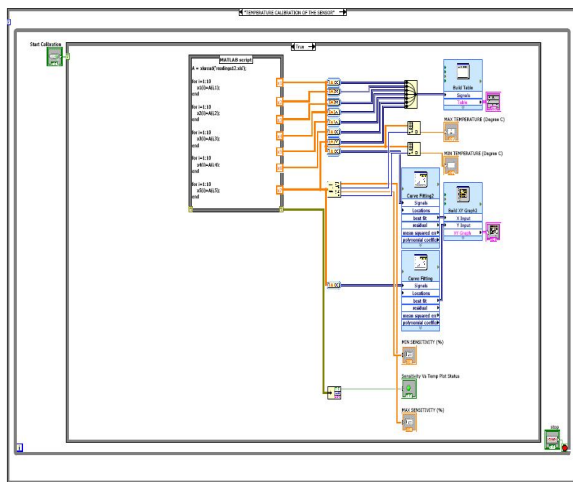


Fig. 11- Temperature Calibration of the sensor using LabView.

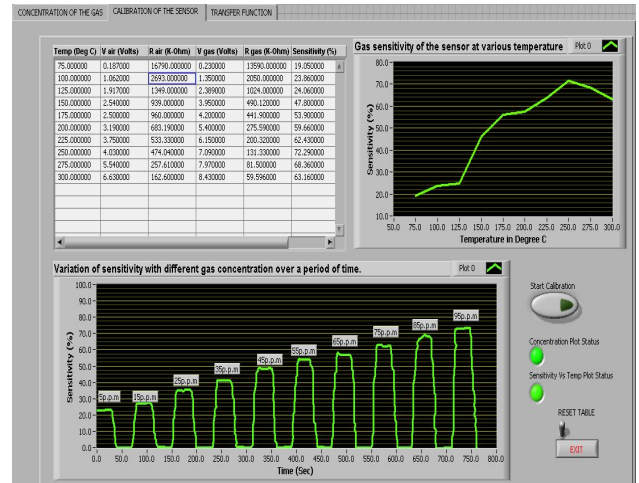


Fig. 12 - Concentration of Ethanol Gas over a period of time for rise time and fall time calculation.

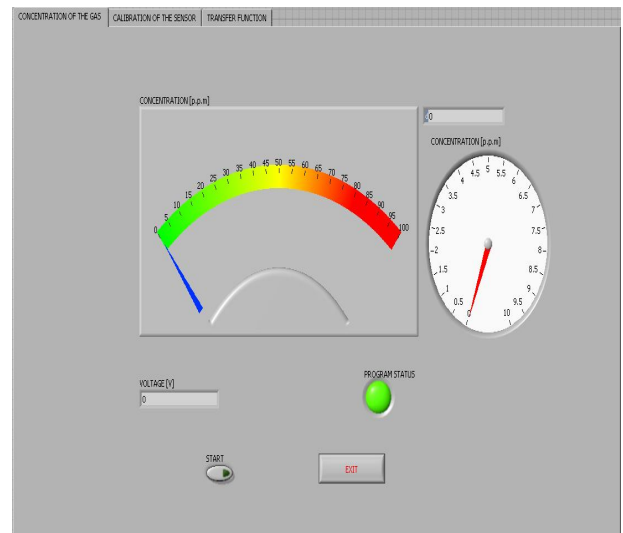


Fig. 13 - Concentration of Ethanol Gas and output voltage from the sensor.

The overall system contains a Zinc-Oxide thick-film sensor and engine ignition logic for enable and disable of engine at drunken conditions. The device controls the operation of a vehicle as follows:

- When the key is turned a voice prompts the driver to prepare to give a breath test.
- The driver has over 50 seconds to provide a deep lung breath sample.
- The breath sample is analyzed in 15 - 30 seconds. Allows 6-8 second resample as needed.
- After test completion, a voice either prompts the driver to start the car or lets him/her know it will not start (a lockout condition).
- If a retest is failed, a voice instructs the driver to pull over and shut off the car.
- If this instruction is ignored, the horn sounds and the lights blink until the car is shut off.

CONCLUSION

Zinc Oxide thick-films sensor fabricated was used to monitor gas concentrations with fast response time and excellent sensitivity. The sensor exhibits excellent ethanol sensing characteristics with highest sensitivity at the temperatures of 250°C. Also sensitivity for the different concentration of the gas over a period of time was observed and the rise and the fall time for sensing were measured to be 30 and 10 seconds respectively using data acquisition technique. The overall system can monitor different gases like carbon dioxide, carbon monoxide and other toxic gases. Appearance-based methods are widely used in pattern recognition systems. Within this paradigm, LDA is one of the classification techniques have been demonstrated and found drastic result for the detection of ethyl alcohol concentration at different ppm label by using zinc oxide gas sensor which has been tested for the detection and warning of DUI.

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