Development of an E-Nose Using Metal Oxide Semiconductor Sensors for the Classification of Climacteric Fruits

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Abstract- The present work deals with the development of an artificial olfactory system as a nondestructive instrument to be used for classification of different fruits and exploration of its application in measurement of fruit ripening stages. The fruits chosen for this study are Guava, Orange and Banana. The developed system comprises of an array of eight metal oxide semiconductor gas sensors, odor delivery system, interface circuit board, data acquisition card and self programmed Data acquisition as well as analysis software using LabVIEW. The design of this tool focused on studying the response of a sensor array to various VOC vapors released by fruit during ripening and optimizing the data acquisition, signal preprocessing, storage, feature extraction parameters using principle component analysis. It was found that developed e-nose can discriminate the patterns of volatile organic compounds (VOCs) from three fruits taken for experimentation. These three fruits, as analysed by the principal component analysis (PCA). With further validation and development, this e-nose may become very useful for monitoring the exhaled as a screening device for discriminating the fruits. This e-nose can also be used for classification and grading of different climacteric fruits on the basis of their ripening stages.

Index Terms— Electronic nose; gas sensors; PCA; Classification of Fruits; volatile organic compounds,VOC; ripening stage detection.

1 INTRODUCTION

Traditionally, fruit grading and classification has been done by trained human graders or classifiers. But this method has disadvantages in terms of objectivity and repeatability [3]. In addition, a human nose cannot sniff high number of samples because it fatigues rapidly with increasing number of samples [3]. In this paper, it is shown how an electronic nose (e-nose) may be used to resolve these issues.

An electronic nose device can also tackle many problems associated with the use of human panels. Individual variability, adaptation, fatigue, infections, mental state, subjectivity, and exposure to hazardous compounds all come to mind. In effect, the electronic nose can create odor exposure profiles beyond the capabilities of the human panel or GC/MS measurement techniques [1-4].

The developed electronic nose system consisting of four functional components that operates serially on an odorant sample- a fruit sample handler, an array of eight MOS gas sensors, a signal processing unit and DAQ card with self developed LabVIEW program. The developed electronic nose was used to collect the smell (fragrance) data related to fruits which then processed on laptop computer using pattern recognition method: Principal Component Analysis (PCA).

Fundamental of the developed artificial e-nose is the idea that each sensor in the array has different sensitivities for different odors [1-5]. The pattern of response across the sensors is distinct for different odorants [14]. This distinguishability allows the system to identify an unknown odor from the pattern of sensor responses [1-5].

Each sensor in the array has a unique response profile to the spectrum of odorants under test [1, 3]. The pattern of response across all sensors in the array is used to identify or characterize the odor. Sensing an odorant in a typical electronic nose, first an air sample is pulled by using an aquarium pump through a rubber tube into a small air tight gas test chamber housing in which MOS gas sensor array is present. The responses related to pure air is recored for preprocessing. Next, the sample–handling unit exposes the sensors to the odorant, producing a transient response as the VOCs interact with the surface and bulk of the sensor's active material. A steady state condition is reached in a few seconds to a few minutes, depending on the sensor type. The sensor's response is recorded into laptop computer by NI DAQ card and self developed LabVIEW program. Stored data is used for pre processing to evaluate the sensor response and storage. Then, the senor housing is flushed out for few seconds using vacuum pump suction, so as to remove the odorant mixture from the surface and bulk of the sensor's active material [1-5].

In the present study for verifying the capability of developed E-Nose, the three fruits are chosen they are Banana, Guava and orange. These fruit leaves a different pattern or odourrprint onto the sensors array for different ripening stages and related VOCs. The responses of the sensor array are saved in excel file .The preprocessing is done on this data and store it in the memory for future use. The principle component analysis (PCA), a statistical tool was used for classifying patterns present within the acquired and pre-processed data. This tool successfully recognizes and classifies the patterns present in stored preprocessed data related to different fruits.

In the agriculture food industries, it is very necessary to detect

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or determine fruit ripeness for its grading as well as for classification.The most of the traditional methods to assess fruit ripeness are destructive and hence not desirable [1-2]. As an example, to test the firmness of a fruit, a force has to be applied which in turn will damage the fruit resulting in spoilt produce [2, 3]. Other methods include measuring levels of chemical species and parameters that are correlated to ripeness such as pH, sugars contents and ethylene contents [2]. Besides these destructive traditional methods, there are also non destructive methods which have been developed. These methods include nuclear magnetic resonance (NMR), proton magnetic resonance (PMR), vision system and acoustics [1].All above listed methods have some drawbacks and hence another popular non destructive method is the use of electronic nose.

Although several commercial E-Nose products are available on the market, many of them are bulky, having complex odor sensing system and user interface software, which makes them unsuitable for portable applications [1-7]. There are number of modern small electronic noses, such as the “Diagnose” from C-it of the Netherlands (11 × 18 × 7 cm) and the Artinose from SYSCA AG Germany (17 × 26 × 14 cm), but they are still too expensive for widespread adoption[1]. In addition, existing electronic noses are still unable to perform particularly well because the most commonly used sensors are inadequate for the discriminating tasks required of them [1-3]. As such, E-Nose products are still difficult to commercialize and the quest for a small, lightweight, and inexpensive E-Nose system has continued in recent years [1-6].

The use of developed e-nose has many advantages over discussed erliar.This is speedy, reliable new technology undertakes what till now has been impossible – continuous real monitoring of odor at specific sites in the field over hours, days, weeks or even months. The E-Noses is more reliable and superior than human sniffing in case of fatigue, infections, mental state, subjectivity, exposure to hazardous [1-16].

We have verified the functionality and accuracy of the device with a program we developed, written in LabVIEW. The E-Nose system has successfully detected and classified the odor of three fruits, namely, Guava, banana, and Orange.

2. Experimental setup:

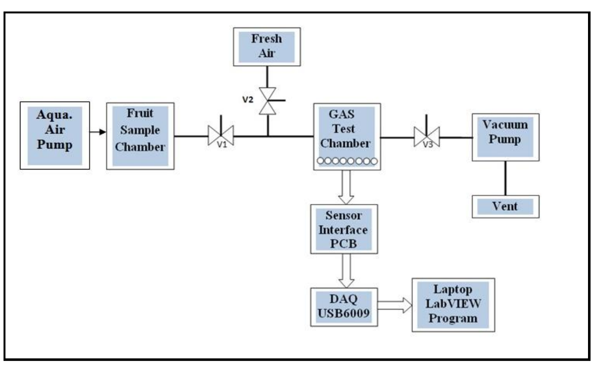

Fig.1: Block diagram of developed E-nose

Figure. 1 shows a block diagram of fabricated E-Nose system, comprising a sensor array of eight sensors, gas test -chamber, fruit sample chamber, an interface printed circuit board (PCB), and DAQ card and user interface software for data acquisition, pre-processing, storage and classification as well as verification program

The most crucial part of the e-nose is the odor delivery system. The purpose of this system is to transfer the headspace or VOC related to sample fruit to be analyzed to the sensors array. This has to done with the maximum possible efficiency without altering the composition of the VOC or headspace

2.1Sensor Array:

The sensor array employed in the design of the e-nose system is mainly composed of commercially available MQ series metal oxide semiconductor (SnO2) gas sensors by Parallax Engineering Inc.The sensing element of this gas sensors is a tin dioxide (SnO2) semiconductor which has low conductivity in clean air. In the presence of a detectable gas, the sensor's conductivity increases depending on the gas concentration in the air. A simple electrical circuit can convert the change in conductivity to an output signal which corresponds to the gas concentration. The sensors selected for target analytes are tabulated in Table 1 bellow.

[1] TABLE 1
MQ series Metal oxide gas sensors choose for E-nose Array their application gases

Sensor No.	Target Gas sensitivity	Sensor model
1	CO and Combustible gas	MQ9
2	LPG, Natural gas, Coal gas	MQ5
3,4	Alcohol, Solvent vapors	MQ-3
5	Carbon Monoxide (CO)	MQ7
6	Alcohol, Solvent vapors	MQ-303
7	General combustible gas	MQ-2
8	LPG, Propane	MQ6

2.2 Design of basic sensor module of sensor array:

The basic sensor module contains a MQ gas sensor connected in half bridge method.The variable potentiometer as load is connected in series with it. output across the Load Resistor (VRL) increases as the sensor's resistance (Rs) decreases, depending on gas concentration. The sensor needs to be put two voltages, heater voltage (VH) and test voltage (VC).VH used to supply certified working temperature to the sensor, while VC used to detect voltage (VRL) on load resistance (RL) which is in series with sensor. The sensor has light polarity, VC need DCpower. VC and VH could use same power circuit with precondition to assure performance of sensor. In order to make the sensor with better performance, suitable RL value is needed.

2.3Fabricated E-Nose System:

There are two types of printed Circuit Board used in E-Nose system i) Senor holding P.C.B. ii) Sensor signal interface P.C.B. as shown in block diagram. These PCBs were designed using OrCAD10 software. The complete fabricated E-Nose system is

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shown in fig.2

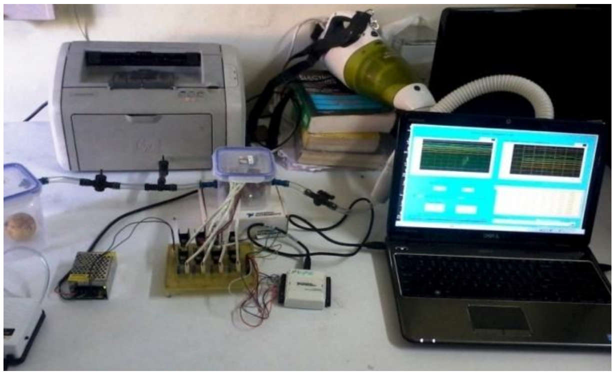

Fig.2 Fabricated E-Nose system

3. PC BASED DATA ACQUISITION, OPERATIONAL PROCEDURE AND ANALYSIS:

Figure 1 above shows the block diagram setup for the gas testing component of the developed E-Nose system, which comprises of eight MQ series gas sensor array, an interface PCB, a fruit sample chamber with air pump, a gas vacuum pump connected to gas test chamber for flush out the air inside when reading is taken out, and the verification program (a NI 6009 DAQ card and a PC with self-developed LabVIEW program). The MQ series sensor array is placed in the gas test chamber which is connected to aquarium pump for constant gas flow inside the test chamber. One of the tubes of the gas test chember is the input pathway, which is controlled by the valve1 and valve2, to sample fruit odors or fresh air. Another tube, controlled by Valve3, connects the gas test chamber to the gas vacuum pump for flushing. A signal line connects the sensor array to the interface PCB and the input for DAQ card is derived from interface PCB. The LabVIEW program is used to verify the feasibility of the system.

The electronic nose needs software for the control and functioning of hardware drivers, data acquisition, and signal preprocessing and pattern recognition. The development of a general purpose tool named e-nose software providing facilities for data acquisition, storage, preprocessing, pattern classification and realization of the e-nose.

Laptop is used for data acquisition and analysis. The national instruments USB bus based data acquisition DAQ card USB6009 is used for the study. Analog inputs are used to acquire analog signal from the sensor array. Eight analog channels A0-A7 are used for sensor array. Sensor data enters a laptop computer through data acquisition card with a LabVIEW self developed program for this study to characterize sensor and odor data and verify possible classification algorithms.

3.1The operational procedures for E-Nose:

(1) The LabVIEW program set to data acquisition mode. Select file name and path.

(2) Valve1 was closed, and Valve2 and valve3 are opened. The vacuum pump was turned on for 20sec. to pump the gas out of the gas test chamber and then OFF.

(3) Valve2 and valve3 are closed now then starts the air pump and valve1 is opened for 30sec.connecting the gas test chamber to the fruit sample chamber.

(4) Valve1 was closed, and the sensors resistance was given 100 seconds to reach a steady state. Sensors characteristic values will be recorded.

(5) The gas test chamber was disconnected from the fruit sample beaker, Valve1 was turned off and valve2 was turned on to fresh air, Valve3 was opened, the odor was pumped out, the chamber was aired out with fresh air for two minutes, before returning to Step 1 for the following operation.

3.2 E-Nose Software:

A complete library of VIs for data acquisition, signal preprocessing, feature extraction, normalization and pattern recognition is contained in the E-Nose software tool. This software is programmed using LabVIEW state machine VI. Particular states are available to user to enter into specific state for do specific work. Individual buttons are provided for the particular operation on the main menu VI as shown in Figure 4. An Exit or Back button on each VI is provided to return to the main menu VI.

3.2.1 Main Data Acquisition VI:

In main user interface, user first record the sensor response in air then record the sensor response in sample odor gas and finally do the pre-processing on stored data related to sensor response in air and in gas. The pre-processed data will be saving for analysis and pattern recognition purpose. The PCA is available for pattern recognition.

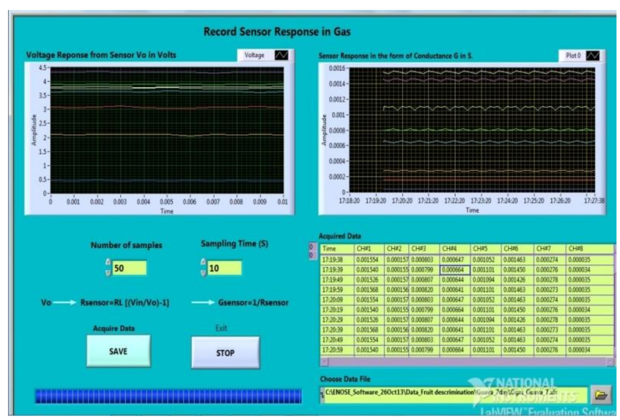

Figure 3: E-Nose Software main user interface

This VI also records the voltages from sensor modules during air environment around the sensor array, which are the voltages across load resistance RL.The user has to choice to choose number of samples and sampling time in seconds. After pressing SAVE button the acquired data shows in the waveform graph as time Vs sensor response acquired voltages. This VI automatically converts the voltage response into change in conductance of sensor (G) using below formulas. (1, 2, 3)

$$Vo = \frac{RL}{RL+Rs} * Vcc \qquad .....(1)$$

Vcc=5V constant, RL=10K constant, Vo =Sensor response in V

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$$Rs = RL\left[\frac{Vcc}{Vo} - 1\right] \qquad \text{….. (2)}$$

Rs=sensor resistance in Ω

$$G = \frac{1}{Rs} \qquad \text{….. (3)}$$

G=Conductance of sensor in Siemens

Thus sensor array data is calibrated and converted into sensor conductance. The calibration is done by writing sub VIs for the corresponding sensor types. After calibration the eight channel data is collected in an array and stored in an excel sheet for further processing. User has to choice to select or create new excel sheet. The acquired sensor responses are displayed with color codes as voltage and conductance with respect to time on the front panel of VI. The numerical value of the acquired data at a particular instant is displayed.

3.2.2 Signal Pre-Processing VI:

Each sensor produces a steady state or transient response which evolves, as the target odor / vapor exposed to the sensor array. There are several interfering inputs which affect the responses of the sensor. Drift problem occurs in the preprocessing and the recognition stage .The standard methods applied for data preprocessing is relative response (S) to a target gas / odour.

The relative response (S) to a target gas is defined as the ratio of the change in conductance of a sample upon exposure of the gas to the original conductance in air. The relation for S is given as

$$S = \frac{Ggas - Gair}{Gair} \qquad \text{…… (4)}$$

Where:
S=Relative response of sensor,
Ggas=Conductance of sensor in gas environment,(ref.exp.1
Gair=Conductance of sensor in air environment.

$$G = \frac{1}{Rs} \qquad \text{….. (3)}$$

G=Conductance of sensor in Siemens

Specificity or selectivity is defined as the ability of a sensor to respond to a certain gas in the presence of different gases.

The VI is executed by pressing the Preprocessing (S) button on main menu VI and provides the above discussed appropriate preprocessing technique in which relative sensor response S is calculated using above equ.4. First user has to open and load the sensor response file in the form of conductance's in air and in gas / odour (Gair.xls, Ggas.xls) and redirects the data to the array in VI. The loaded data is shown in table available on front panel of VI. Then Select or create new file using dialog given on front panel for saving pre-processed data. The selected preprocessing is carried out in the program and processed data is stored into the excel file chosen by the user. The transient responses to the odor (Ggas), reference ambient air (Gair) and preprocessed fractional change responses are displayed in the VI in the form of numeric array.

4. Experimental Proceudure and analysis:

The fabricated E-Nose system was tested with odors of three fruit, namely Guava, Orange and Banana. The odors were prepared by placing a sample in experimental fruit sample chamber sealed with a membrane. The aquarium air pump is connected to the fruit sample chamber, which is necessary to maintain constant air flow inside the chamber during the purging process. One end of this chamber is connected to gas test chamber through valve1.

Fresh mature guava, Orange and banana fruits were acquired market and placed in plastic container named as fruit sample chamber .The data regarding the fruit odors was collected over 3day span. On first day, samples of Guava, orange and banana were collected. The response of it is recorded using self developed E-Nose data acquisition software; the individual average response of it was used as the odor signature for the fruit. Same process is repeated for next two days. The data saved in excel file.

In data acquisition interface user must have to select name of respective excel file for storing sample data. The three excel files for three fruit data storage are created and within a day 50 readings were recorded for each sample in matrix array format having eight columns corresponding to eight sensors and 50 rows corresponding to 50 readings. User also has flexibility to choose number of sample data readings and sampling time. This acquired data is in the form of matrix array e.g. we select 50 sample data readings and there are 8 sensors so the matrix array is 50x8 in size. In each day we record readings for one samples of each type. Hence for 3 different day's data we get 3X3=9 matrix array of size 50x8 each. This stored data is having patterns related to guava, orange and banana .The PCA tool is used for pattern recognition and classification purpose.

5. Result and Discussion:

From preprocessed data, RADAR plot is ploted.Below pattern cleared that E-Nose successfully gives the different odorprint for different odors. That means it distinguishes the fruits correctly and leaves unique odorprint for it.

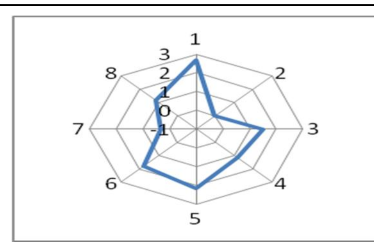

Fig4 (a) Radar pattern of Guava

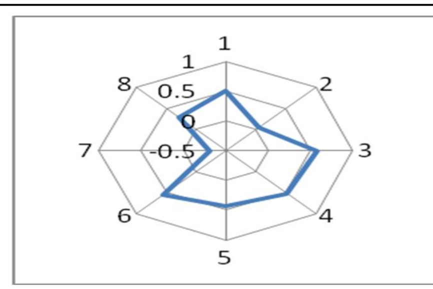

Fig4 (b) Radar pattern of Orange

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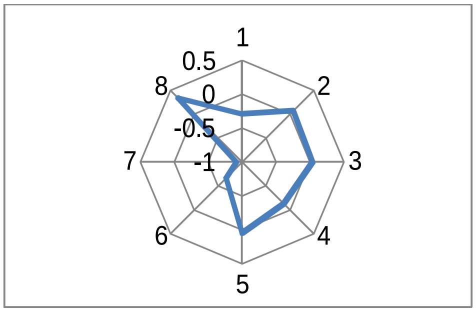

Fig4 (c) Radar pattern of Banana

Figure 4.Radar pattern of (a) Guava (b) Orange (c) Banana

5.1 Classification of fruit samples by using Principle Component Analysis (PCA):

The pattern related to different fruits within preprocessed data is evaluated using statistical analysis tool, Principle component Analysis PCA. The PCA is used to know the clustering within the data.PCA is a statistical method and has been efficient to distinguish the response of electronic nose. This algorithm helps to compress the vectors for each measurement and show result in simple two dimensional plots. In short we can able to show multidimensional data into only two dimensional using PCA plot.

The data matrix 150X8 (50 rows for each sample fruit) is input for principle component analysis (PCA) tool available in LabVIEW/Matlab. This tool performs various statistical operations on it like subtract mean from each of the data dimension, Calculate covariance, calculate the eigenvectors and eigenvalues of covariance matrix, choosing components and forming a feature vector from covariance matrix, the eigenvectors with highest eigenvalues is the principle component of the data set, calculate feature vector, Deriving the new data set etc.The builded matrix array data of 150x8 were also used with mapcaplot tool available in MATLAB and do the classification job.

Principal component analysis (PCA) is an unsupervised statistical method that generates a new set of variables, called principal components. Each principal component is a linear combination of the original variables (rs, n).

$$PC_{p,n} = \alpha_{p,1}\gamma_{1,n} + \alpha_{p,2}\gamma_{2,n} + \cdots + \alpha_{p,s}\gamma_{s,n} \qquad (5)$$

Where $PC_{p,\,n}$ is the notation for the p-th order principal component for the overall n number of data and is termed as scores. Coefficients transformations $\alpha_{p,s}$ referred as loadings, are obtained by taking elements of the eigenvectors from the covariant of the original data. The eigenvalues represents the variance associated with each principal component.

By using self developed/MATLAB software, the two principal components {$PC_{1,n}$,$PC_{2,n}$} are obtained and have the two greatest variances: 98.9% and 1.0% (or total cumulative variance of 99. 9%). The results of the PCA analysis are shown in Figure 13. The scores of the three groups of fruits are plotted for principal component 2 (PC2) versus principal component 1 (PC1). The discrimination between the different types of fruits can be clearly seen from the figure.Fig.5 shows cluster related to guava fruit data in data file having row1 to row50; cluster related to orange fruit data in data file having row51 to row100, cluster related to Banana fruit data in data file having row101 to row150.

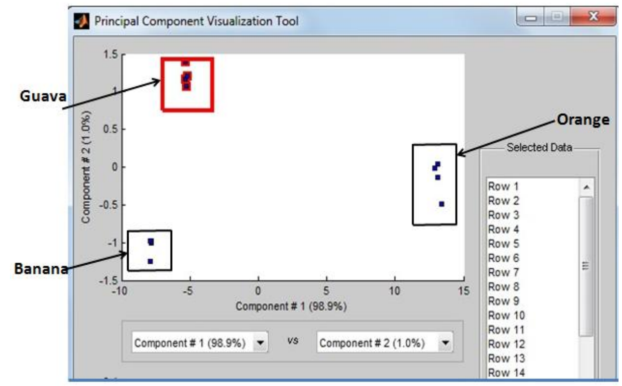

Fig.5. PCA plot highlighting clusters for Guava, Orange and Banana fruit

Principal components score plot proves the capability of e-nose to classify the different types of fruit as Guava, Orange and Banana

5. Conclusion:-

The literature study regarding climacteric fruit ripeness, gas sensors made up of metal oxide semiconductor, different electronic circuit required for E-Nose, Data acquisition, software development, PCA algorithm is carried out successfully. The PCB designed and soldered successfully. The mechanical system for E-Nose is designed and fabricated. The user interface software is developed using LabVIEW and it runs successfully. Based on the study conducted, it has been proven that this electronic nose system is capable of determining fruit ripeness and thus we say that it is capable of classify different fruits. The sensor array successfully leaves a characteristic pattern or fingerprint for each stage of ripeness for fruit. The PCA tool appropriately distinguishes the ripening stage of fruit and also type of fruit.

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