

highest capability in classifying herbs sample. Accuracy in classifying the correct herbs increases with the number of sensors used. This investigation demonstrates that the neural network-based electronic nose technique promises a successful technique in the ability to classify distinctive odor pattern for aromatic herbs species.

Index terms: electronic nose; artificial neural network; array of sensor; classification; recognition

I. INTRODUCTION

Many of the existing plant species on earth are still unknown, which might be at the margins of extinction. Each plant species has unique leaves which differ from each other in characteristics such as the shape, color, texture and the nature of odors. Therefore, it is important to correctly and quickly recognize the plant species in order to understand and managing them. However, it is difficult for a layman to recognize the plant species and currently, Botanist is the expert. The role of a botanist is very important in recognizing and characterizing plant leaf. They have to go to the field for the identification process. Due to the limited number of resources and experts, it is very important to automatically recognize the different kinds of leaves for plant classification based on their very unique characteristics.

Each plant leaf is characterized according to their physical and chemical criteria. Currently, many researchers have investigated the methods of plant species recognition based on physical or texture of leaves [1-7]. Herb is one of the plant species that each has unique odor. Odor from herb is one of the important parameter in identifying the unique criteria for different type of herbs species. This project will focus on the process of identifying herbs from their unique odors extraction by getting the unique electrical signal for each herb. Currently, the research involving herbs species recognition based on the odors is still rare. Previously, botanist uses their skill to identify the herbs species based on the odors of the herbs.

Recently a lot of researchers use chemical gas and liquid to differentiate herbs odor with very complex experiment and need huge budget for appropriate odor equipment [8- 13]. This current practice is very labour-intensive and inefficient. In this project, we proposed the E-nose system which has less complexity to do the experiment. The herbs leaves are crumpled before being tested with E-nose sensor so that the odor will be completely released from the herbs. The signal output from the sensor arrays will send to the developed pattern-recognition algorithm to

contact potential which intended to differentiate between aroma bouquets and monitor aromas respectively [17].

After several years of revolution, E-nose is first introduced in year 1982 [18]. It is said to be an intelligent chemical array sensor system for aroma classification. Initial research of E-nose focused primarily on sensor aspect of the problem exploring the use of metal oxide devices and conducting polymers. By that time, the development of computers and electronic sensors made it conceptually possible to obtain an electronic device capable of imitating the mammalian olfactory system.

Revolution continues where E-nose was introduced in 1988 and more and more sensors are developed. E-nose is re-defined as an instrument which comprises an array of electronic chemical sensors with partial specificity and appropriate pattern recognition system, capable of recognizing simple or complex odors [19]. After years of research and development, E-nose has now transformed to a system which provides a cost-effective solution to the human sensing limitations and capable in performing real time identification portable form.

III. PRINCIPLE OF ELECTRONIC NOSE SYSTEM

The mammalian olfactory system is the sensory system used for olfaction, or the sense of smell. The sensitivity and range of the olfactory system is remarkable, enabling organisms to detect and discriminate between thousands of flow molecular mass, mostly organic compounds which is commonly known as odors. Odorant molecules emanating from different sources must be sufficiently volatile to arrive at the olfactory receptors in the nose that causing patterns of brain activity which is essentially the sense of smell [20].

Despite the importance of olfactory systems of odor and flavor, more analytical approach has been developed in response to overcome dispute in comparing different person experience of smell and quantifying of odor. Research into alternative olfactorial sensing methods within an electronic nose as quantitative measurement intended to fill up this desire. The comparison between mammalian olfaction system and E-nose system is shown as in Figure 1.

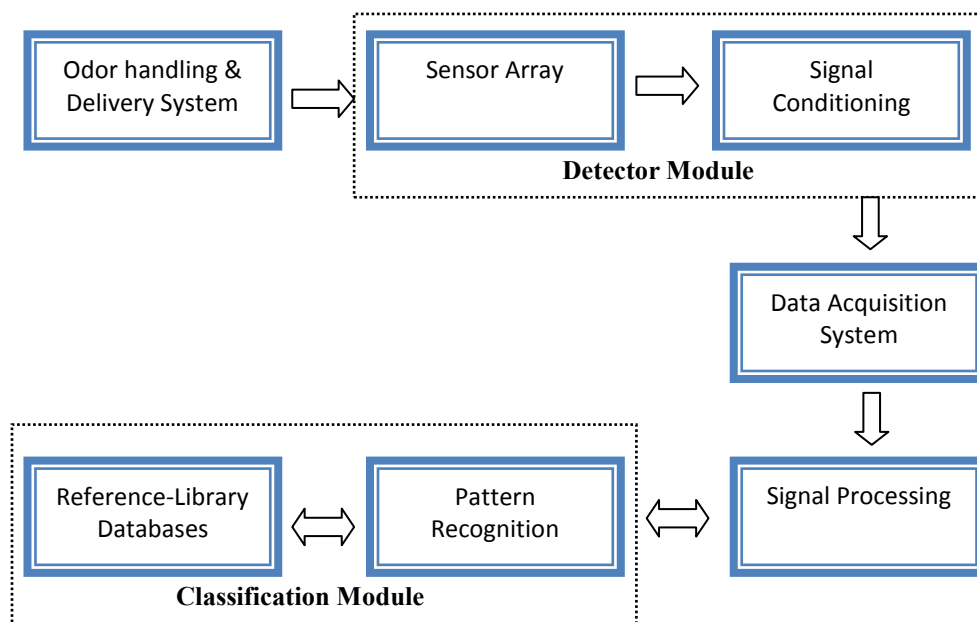


Figure 2. Block diagram of E-nose

E-nose operates when volatile organic compounds samples are placed on the odor and handling mechanism simulating a signal carrying the characteristic of the odor. The sampling technique such as headspace, diffusion methods, bubblers or pre-concentrators are being used to draw the odor molecules into the E-nose [14-15]. Odor sample particles that attracted to the sensor array will go through chemical reactions. Incrementally-different sensors are chosen to make up the cross-reactive sensor array, purposely to act in response to a vast range of chemical classes. The diverse mixtures of possible analyses are then discriminated. At the signal conditioning stage, a distinct digital response pattern is produced, using the assembled and integrated output collected from each individual sensor.

In an E-nose, the pattern recognition and data processing techniques played a very important role in the classification module. At this point, recognition of the unique aroma identity (electronic fingerprint) of collective sensor responses will accomplish the identification and classification of an analyzed mixture. The unique aroma identity pattern represents the characteristic of a simple or complex mixture that can be determined without separating the mixture into its individual components before or throughout the analysis. Preceding the analysis of unknown, digital aroma identity reference library for known samples must be constructed. Training is necessary for the pattern classifier with a database of known samples prior to E-nose commercialization in order to

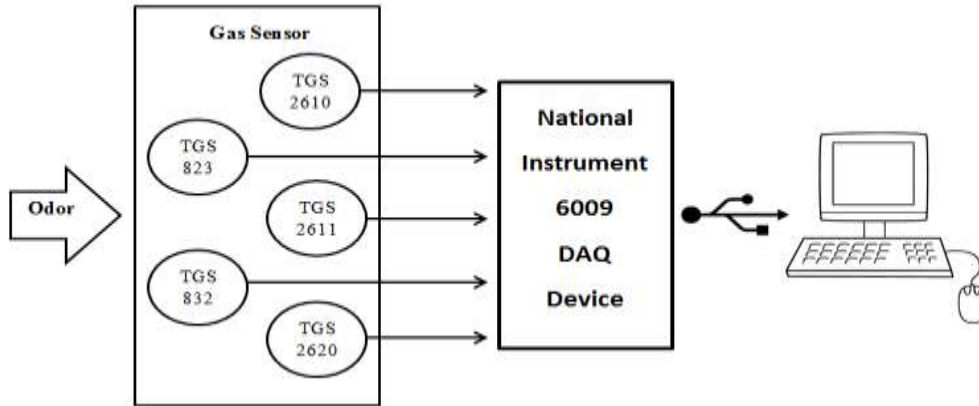


Figure 3. Block diagram of designed E-nose

a. Part 1: Hardware Development

This project started with circuit design of sensors and the simulation is done using Proteus. The designed sensor circuit is being tested on breadboard before it is printed on PCB board.

Metal oxide based gas sensor from Figaro is chosen for this project due to its high sensitivity and simple measuring circuit. There are two types of measuring circuit being used in this project and are shown in Figure 4. Both basic measuring circuits require two different types of voltage sources, one for the circuit voltage (V_C) which is required to power up measuring circuit while the heater voltage (V_H) is used to heat up heater circuit. The sensor is expected to be sensitive to a particular gas present in the air at an elevated temperature. Sensor conductivity increases and measuring circuits convert changes in conductivity to a voltage signal in presence of detectable gas.

After the designed sensor circuit has been tested on breadboard, complete circuits are drawn using ISIS (circuit design software) as in Figure 5. Circuit drawn is then imported to ARES (layout design software) for layout drawing. Afterwards, the drawn layout is fabricated and all components are being soldered to the PCB board as shown in Figure 6. The developed prototype is installed in gas chamber for data collection. Gas sensors will detect odor of the herbs and output voltage from the sensor will be sent to DAQ system. This data are then sent to the computer for classification.

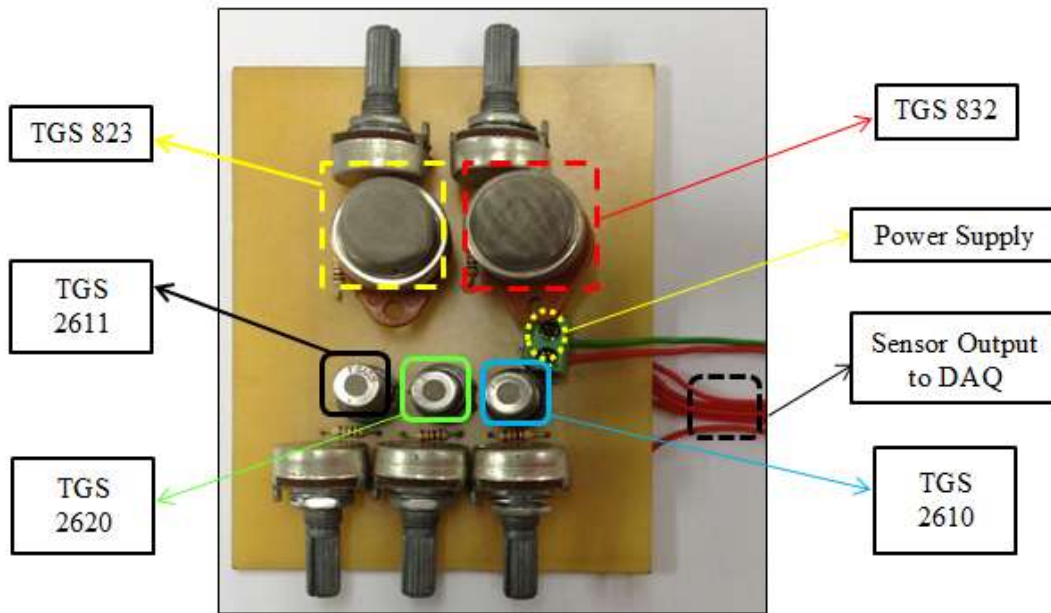


Figure 6. Prototype of detector circuit

b. Part 2: Software Development

In this part, the work is focused on designing the pattern-recognition algorithm based on artificial neural network (ANN) for classification module using MATLAB software.

ANN model is designed to have the [5 2 5] configuration (refer Figure 7) where it has 5 input layer nodes, 2 hidden layer nodes and 5 output layer nodes. Feed-forward back propagation is used as a learning algorithm in this neural network model.

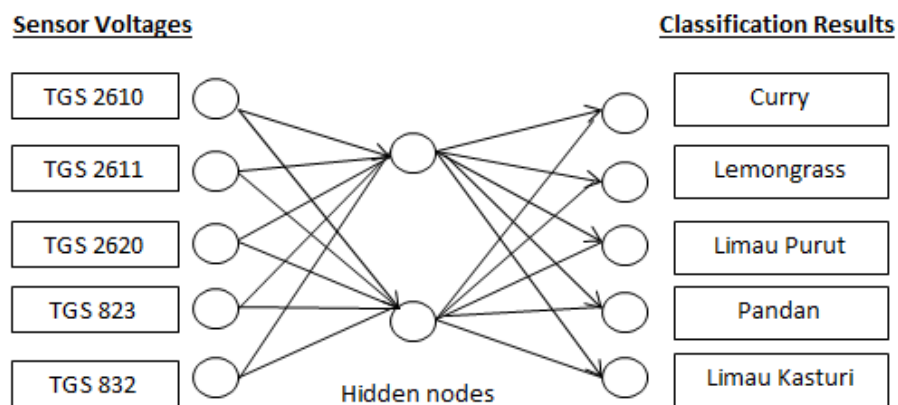
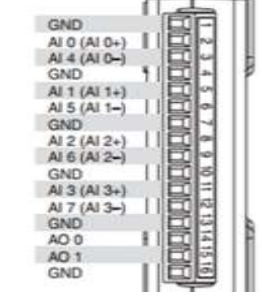


Figure 7. ANN configuration for classification module

DAQ NI USB-6009 being used to supports the eight single-ended analogue input (AI) channels, two analogue output (AO) channels, 12 digital input/output (DIO) channels, and a 32-bit counter with a full-speed USB interface. USB cable is connected to establish communication between DAQ and the computer. The DAQ input ports are connected to sensor arrays by using the configuration as in Table 2.

Table 2: List of configuration of components with respect to the port in DAQ 6009

DAQ Ports	Configuration	Sensors	Port Involved
	Analog Input	TGS 823	ai0
		TGS 832	ai1
		TGS 2620	ai2
		TGS 2611	ai3
		TGS 2610	ai4

The Measurement and Automation Explorer is used to check whether DAQ is connected successfully to the computer. If it is connected successfully, the “NI USB-6009 Dev 1” will be shown on left hand side of main panel in Figure 9 under the option of Devices and Interfaces. Now, the hardware is ready to use and can be tested by clicking the “test panel”.

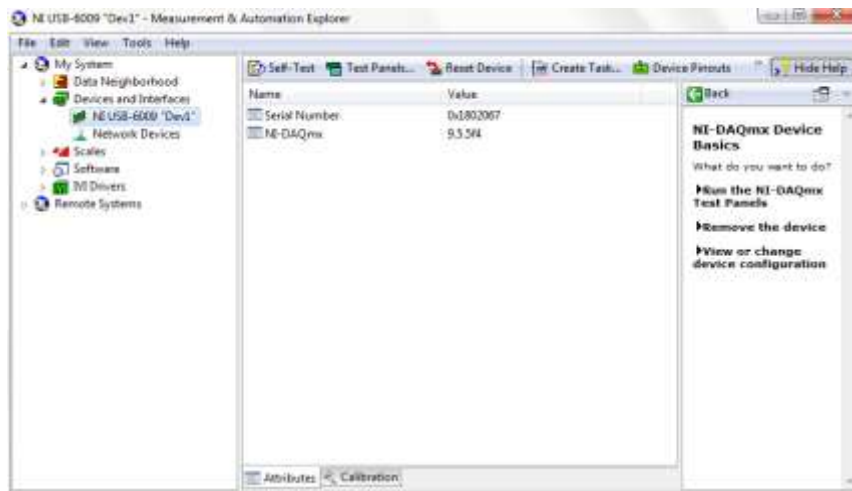


Figure 9. Main panel of the Measurement and Automation Explorer

Once the test panel is opened, it can be observed that there are 4 selectable options to be tested including the analog input, analog output, digital I/O and counter I/O. For this project, only

Lime/Limau Kasturi (*Citrus Microcarpa*). The leaves are crumpled before being tested with the E-nose sensor so that the odor will be completely released from the herbs for better recognition. The sensor arrays sense the odor and generate data which will be sent to the developed algorithm for further process.

Sample of herbs are measured by using procedures as below:

- 1) Sample is weighted as 10 grams and is ready to be put into the gas chamber as shown in Figure 11.
- 2) E-nose system is being preheated for 1 minute before samples are put into the gas chamber. Preheating time of the sensors is set to be 1 minute so that all the sensor voltages are stabilized and stop fluctuating.
- 3) Samples are crumpled before putting it into measurement chamber. Crumpled leaves emit significant odor for better recognition. The chamber lid is opened and herbs sample are put into the chamber. The net will hold the herbs to avoid direct contact with sensors.
- 4) Output voltages from each sensor are recorded with 8 time intervals of 10 seconds. Around 3 sets of data are recorded for the same herbs sample and each set of data contains 10 trials. Cooling time for each sensor is around 5 minutes before next set of data is being taken.
- 5) Steps 1-4 are repeated for four other types of herbs. Environment inside the gas chamber is ensured to have humidity between 55-65% RH and temperature of 27-30°C by conducting the experiment in the same laboratory.

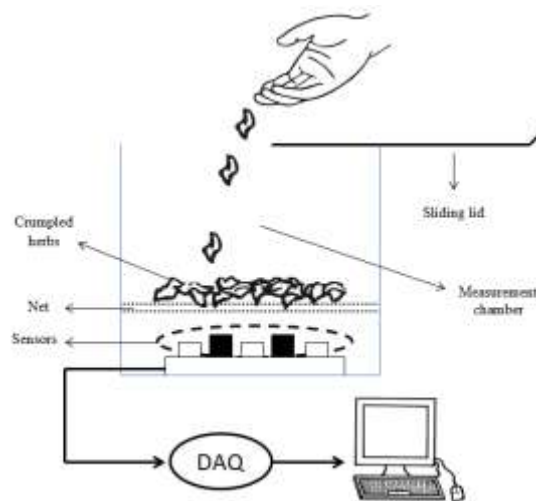


Figure 11. Experimental setup for proposed E-nose

Table 4: GC-MS analysis on herbs

Herbs	Chemical Compound
Curry (<i>Murraya Koenigii</i>)	Pinene <alpha->, Terpinen-4-ol , Caryophyllene (E-), Sabinene, Selinene <alpha->
Lemongrass (<i>Cymbopogon Citrates</i>)	Myrcene, Neral, Geranial, Intermedeol<neo-> , Valencene
Kaffir Lime/Limau Purut (<i>Citrus Hystrix</i>)	Sabinene, Linalool , Citronellal, Citronellol , Citronellyl propanoate
Pandan Leaves (<i>Pandanus Amaryllifolius</i>)	Sabinene, Tetradecanal, Menthol<iso-> , Isophytol , Phytol acetate <E->
Golden Lime/Limau Kasturi (<i>Citrus Microcarpa</i>)	Pinene <beta-> , Germacrene D, Hedycaryol , Eudesmol <gamma->

VII. RESULTS AND DISCUSSIONS

a. Data Analysis

In this section, the average values obtained from each sensor are plotted. The graph is plotted based on the features which represent the output signals from the five sensors. The analyses based on one to five features are done in order to prove that the ability of the E-nose system to classify the herbs increases as the number of sensors increases.

For the analysis in this section, the sensors are represented by sensor 1 to 5 for simplification as in Table 5.

Table 5: Representation of TGS series sensors

Sensors	Synonyms
TGS 2611	Sensor 1
TGS 2610	Sensor 2
TGS 2620	Sensor 3
TGS 823	Sensor 4
TGS 832	Sensor 5

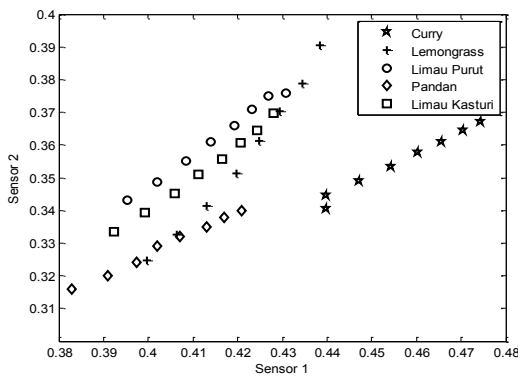
a.1 One-Feature Analysis

From Figure 12, it is concluded that all sensors are unable to show clear classification for each sample group. It is because sensor voltages detected by sensors are overlapping and are very

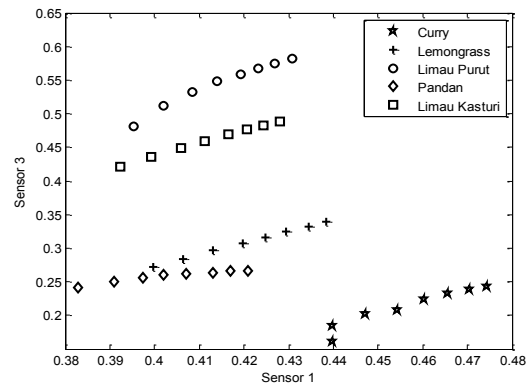
a.2 Two-Feature Analysis

Most of the graphs are able to classify Pandan Leaves (*Pandanus Amaryllifolius*) successfully from others except Figure 13(a), 13(b) and 13(e) which the data are overlapping and is close to the adjacent group. All two-feature graphs are able to classify Curry Leaves (*Murraya Koenigii*). According to all two-feature graphs, Lemongrass (*Cymbopogen Citrates*) group has higher probabilities in false identification because some points of other groups are too close.

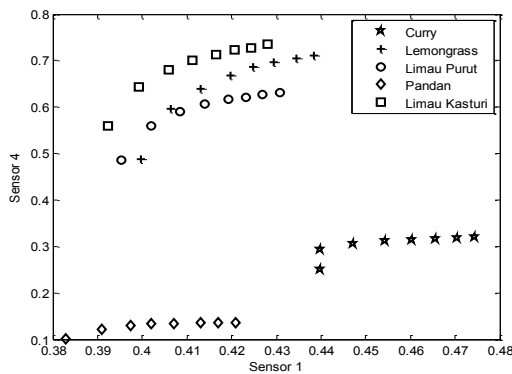
It can be seen that graph for *sensor 3 vs sensor 4* and *sensor 3 vs sensor 5* (refer Figure 13(h) and 13(i)) display a better classification of herbs because all the herbs are being separated nicely and are not close to each other. However, most of the two-feature plots are not successful in classifying the herbs.



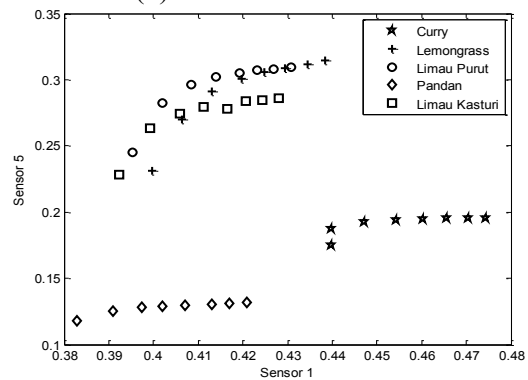
(a) Sensor 1 vs Sensor 2



(b) Sensor 1 vs Sensor 3



(c) Sensor 1 vs Sensor 4



(d) Sensor 1 vs Sensor 5

of sensors is increased. Next, the data are analysed further by using neural network to evaluate the relationship between the number of sensors and classification accuracy. Graph plotting can only support up to 3 axes, therefore five features analysis is carried out using ANN.

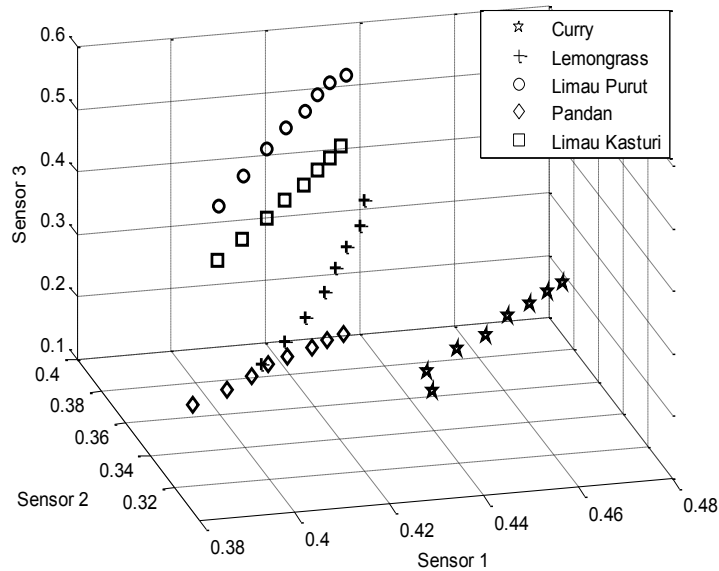


Figure 14. Graph of sensor TGS 2611 (Sensor 1), TGS 2610 (Sensor 2) and TGS 2620(Sensor 3) for five types of herbs samples

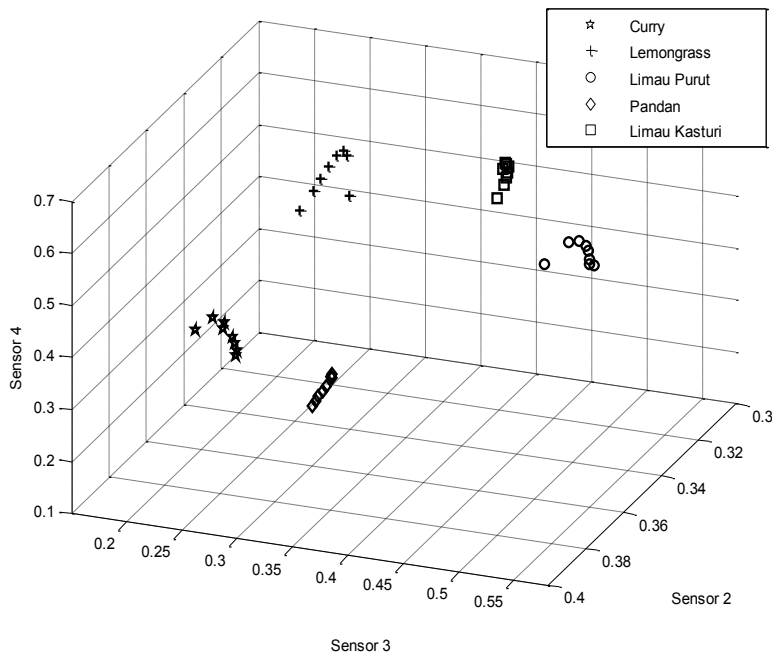


Figure 15. Graph of sensor TGS 2610 (Sensor 2), TGS 2620 (Sensor 3) and TGS 823(Sensor 4) for five types of herbs samples

50	0.4602	0.3577	0.224	0.3148	0.1947	-1		
60	0.4657	0.3611	0.232	0.3168	0.1953	-1		
70	0.4704	0.3644	0.2388	0.3182	0.1954	-1		
80	0.4744	0.3672	0.24306	0.3192	0.1955	-1		
10	0.3996	0.3246	0.27256	0.4874	0.2314	-0.5	Lemongrass	
20	0.4064	0.3326	0.28442	0.5957	0.2702	-0.5		
30	0.4131	0.3414	0.2964	0.6403	0.2908	-0.5		
40	0.4197	0.3513	0.30654	0.6684	0.3004	-0.5		
50	0.4248	0.3613	0.31638	0.6857	0.3059	-0.5		
60	0.4294	0.3702	0.3243	0.6964	0.309	-0.5		
70	0.4345	0.3789	0.33218	0.7052	0.3117	-0.5		
80	0.4384	0.3905	0.33938	0.7105	0.3143	-0.5		
10	0.3954	0.343	0.48046	0.486	0.2453	0		Kaffir Lime/ Limau Purut
20	0.4019	0.3488	0.51152	0.5589	0.2825	0		
30	0.4084	0.355	0.53226	0.5892	0.296	0		
40	0.4141	0.361	0.54786	0.6056	0.3018	0		
50	0.4194	0.366	0.55904	0.6166	0.3053	0		
60	0.4233	0.371	0.568	0.6219	0.3072	0		
70	0.427	0.375	0.57524	0.6274	0.3083	0		
80	0.4308	0.376	0.58132	0.6314	0.3091	0		
10	0.3829	0.316	0.242	0.101	0.118	0.5	Pandan	
20	0.391	0.32	0.25	0.122	0.125	0.5		
30	0.3974	0.3241	0.2566	0.13	0.128	0.5		
40	0.402	0.329	0.26	0.133	0.1287	0.5		
50	0.407	0.332	0.262	0.1347	0.1297	0.5		
60	0.413	0.335	0.2628	0.1359	0.1306	0.5		
70	0.417	0.338	0.2658	0.136	0.1314	0.5		
80	0.421	0.34	0.2662	0.136	0.1319	0.5		
10	0.3924	0.3334	0.42108	0.56	0.2286	1	Golden Lime/Limau Kasturi	
20	0.3993	0.3394	0.4362	0.6436	0.2636	1		
30	0.4059	0.3453	0.44826	0.68	0.2745	1		
40	0.4113	0.351	0.4596	0.701	0.2796	1		
50	0.4166	0.3556	0.469	0.714	0.2783	1		
60	0.4206	0.3606	0.47662	0.7234	0.2841	1		
70	0.4244	0.3645	0.48272	0.7283	0.2846	1		
80	0.428	0.3696	0.48844	0.7351	0.2858	1		

From Table 6, designed E-nose yields an average accuracy of 66 % by using two sensors while the accuracy increases to 85% when 3 sensors are used. 90 % accuracy is achieved when 5 sensors are being used. Similar trend goes to the comparison between training set and test set 2 as

a simple system, thus the botanist can handle the system easily without having to do the complex experiment as compared to the current E-nose system.

The proposed E-nose system is built using five Figaro metal oxide sensors purposely to evaluate five different types of herbs which includes Curry (*Murraya Koenigii*), Lemongrass (*Cymbopogen Citrates*), Kaffir Lime/Limau Purut (*Citrus Hystrix*), Pandan Leaves(*Pandanus Amaryllifolius*) and Golden Lime/Limau Kasturi (*Citrus Microcarpa*). Selected sensors array shows its relationship with the odor of the herbs through the GC-MS test and proves the reason why there are voltage changes when the herbs are present.

In this study, the data signal from the sensors array are plot according to one-feature analysis, two-feature analysis and three-feature analysis. The purpose of these analyses is to observe the capability of the E-nose to achieve the highest accuracy using various number of sensors to classify the types of herbs based on the odor. Also, we can check whether all the sensors are suitable to be used in this E-nose system. In this project, we use the types of herbs from different family. So, the aroma from the herbs are quite different. So, in our case it is easy to classify only using this feature. From the graphs, we can observe that the herbs are already classified according to the group. For confirmation, the data signal obtained from sensors array are sent to classification using ANN techniques. The ANN can successfully classify the herbs. Results also show that the developed E-nose system with five sensors has the highest capability in classifying herbs sample. As a conclusion, the performance of E-nose in classifying the correct herbs increases with the number of sensors used.

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