Ripening state determination of guava fruit (Psidium guajava) using e-nose with fuzzy logic as pattern recognition tool

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ABSTRACT
Electronic nose is a non-destructive artificial olfactory system to sense aroma, can be used for classification of fruits at the time of harvest, post-harvest and during storage with various conditions. This paper is about development of application specific e-nose system with fuzzy logic as pattern recognition tool. The developed systemis used for classification and identification of guava fruits at the time of pre-packaging.The developed system comprises of an array of eightSnO_2MOS gas sensors, static odor delivery system, signal conditioning circuit,data acquisition and pre-processing software using LabVIEW2012. The design of this system focused on studying the response of a gas sensor array to various VOC vapors released by fruit during ripening and optimizing the data acquisition, signal preprocessing and pattern recognition. Fuzzy logic module is designed for pattern recognition. Classification results obtained from fuzzy logic module showed 90% general agreement with the results from thehuman classifiers. The results suggest that this e-nose system with fuzzy logic based pattern recognition is capable to classify guava fruits up to the expectation and it would be a feasible system to be used in a real scenario.

Keywords - Electronic Nose, guava fruit classification, PCA, fuzzy logic, Pattern recognition

I. INTRODUCTION

Agriculture is the largest economic sector in India and it plays the vital role in economic development.There is large variety of fruits produce which is consumed in domestic market as well as export to other countries. The fruits for food industry and for export need to be sorted properly before going to package. Thedetermination of fruits ripening states since it harvest is becoming the very important issue for producers, sellers, food industries as well asconsumers due to the delicate nature of fruit and sheer volumes handling problems [1].Conventionally the fruit grading and sorting has been done by trained human graders by visual inspection of fruits skin color, shape, size or by sniffing odors. Since these methods are guided by human intervention, they may subject to some kind of errors because humans may be subjected to eye fatigues like colorblindness, tiredness, nose may get fatigues rapidly with increasing number of samples and also there may be the shortage of labors. To overcome these problems and for increase capacity and accuracy, there is need for automatedinspection system.The automated system minimizes the dependency on human graders work and also helps to reduce the time consumed by manual techniques [2].
The errors occurred in human grader based fruits classification may be overcomes by introducing new electro-mechanicalinstrument and methods. Now days there are several types of fruit classification methods which are destructive and non-destructive types [3].The non-destructive type methods are most preferred for classification because it does not harm the fruit under test. The non-destructive methods either relied on color based classification called machine vision technique or odor based classification called e-noses which uses aroma of fruit [4-5].Ane-nose solves many problems associated with human classifiers that are individual variability, adaptation, fatigue, infections, mental state, subjectivity and exposure to hazardous compounds etc. [6]. An e-Nose is an intelligent chemical-array sensor system that mimics the mammalian olfactory system. The two main components of an electronic nose (e-nose) are the sensing system and the automated pattern recognition. In e-noses the sensor array chosen according to human approach in which sensors do not respond selectively but respond with partial specificity [7].E-noses utilizes an array of independently semi-selective and reversible gas sensors for example metal oxide semiconductors (MOS), conducting polymers (CP),surface acoustic wave(SAW),metal oxide semiconductor field effect transistors(MOSFET),optical sensors etc. [8-9].Most cases electronic noses commonly use resistive sensors, whose impedance varies with the presence of certain gases. The output of sensor array is analyzed by some form of pattern recognition software.
This paper explains the utilization of application specific e-nose for classification of guava fruit in four

ripening states after harvest as green, ripe, overripe and spoiled. The pattern recognition was performed using specifically designed fuzzy logic module.The requirement of multi-target contaminants detection and the low-cost of system achieved usingeight Figaro Inc. in Japan made MOS gas sensors. The Figaro made gas sensors were selected because they have cost-effective, cross sensitive. The eight gassensors selected can detect a wide species of gases and VOCs which can basically cover the target contaminants with cross-sensitivity among sensors [10].From literature it reveals that guava fruits respiration pattern is contradictory [11] therefore, the objective of this study was to investigate the physical and chemical changes occurring in the guava fruit during different ripening states.

II. MATERIAL AND METHOD

2.1 Origin and collection of experimental material

Lucknow 49 type Guava fruitswere selected for the experimental study. The fruits were obtained from the orchard in Maharashtra state of India at altitude 504 m, latitude 19.76° north, longitude 74.48° east.Fruits were selected for uniformity of size, color andfreedom from blemishes. The trained human grader service was used for picking the fruit from tree and sorting. The fruits were sorted into four classes as green, ripe, overripe and spoiled. The harvested fruits were washed under clean running water and immersed in a 1% sodium hypochlorite solution at 25 °C for 5 minutes for disinfection.After drying the fruits were placed in carton boxes.The experimentaldesign was completely randomized with each fruitas an experimental unit. The guava fruits of different ripening class wereevaluated at the picked day (day 0) usingdeveloped electronic nose technique.

2.2 Electronic-Nose system

An application specific electronic nose system is developed and employed to obtain the odor patterns from the headspace of guava fruit samples. Fig.1 shows schematic block diagram of developed e-nose system.

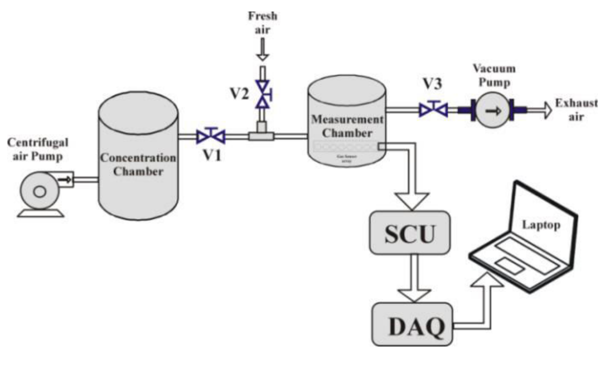

Figure 1 Block diagram of E-Nose system

The e-nose system based on an array of eight different SnO_2 based commercially available Taguchi gas sensors from Figaro Engineering, Japan.The MOS sensors conductivity changes due to adsorption of odor molecules on surface of sensing material causes subsequent surface reactions. These types of sensors show a certain degree of affinity towards a specific odor but are sensitive towards a wide spectrum of gases with overlapping sensitivities [5].Table 1 specifies the gas sensors used in array and their primary target application gases.

Table 1 E-nose sensors and their target gases

Sensor No.	Sensor Model	Target Gas Sensitivity
1,3	TGS2602	VOCs, ammonia, H_2S
2	TGS2600	hydrogen, ethanol, etc.
4	TGS2611	Methane
5	TGS2620	Alcohol, Solvent vapors
6	TGS822	Organic Solvent Vapors
7	TGS813	LPG, Methane
8	TGS832	Chlorofluorocarbon

The sensing element in the sensor is comprised of a metal oxide semiconductor (SnO_2) layer formed on an alumina substrate of a sensing chip together with an integrated heater. In the presence of a detectable gas, the sensor's conductivity increases depending on the gas concentration. A simple electrical circuit can convert the change in conductivity to an output voltage signal which corresponds to the gas concentration. Full details on the developed e-nose system implemented and used for experiment here can be found elsewhere [2].

The sensor array positioned into small plastic chamber called here measurement chamber having volume 0.6L capacity. During experimentation each fruit sample was placed into an airtight plastic jar called as concentration chamber having volume of 1 L capacity. The concentration chamber was then closed for 0.5h to equilibration of the headspace. From several experiments reveals that 0.5 h required for reaching the headspace to steady state condition, hence experiments were conducted after 0.5 h of equilibration.In measurements process consists of three different phases 1) concentration 2) measurement and 3) stand-by. The electronic solenoid valves 1-3 controlled by an indigenously programmed data acquisition and system control software. The valves guide the air flow and headspace odor though different circuits depending on the measurement phase.

In measurement phase, the headspace gas from concentration chamber was pumped over the sensors array placed inside the measurement chamber with constant air flow rate of 0.32L/min using centrifugal air pump. The volatile species from the headspace allowed to reach the measurement chamber for 30s duration. After this, measurement chamber was closed and allow the sensors to reach steady state for 1 min duration.The gas sensor array response was sampled at rate of 1 sample/s for a time interval of 100s. After measurement phase, a stand-by phase was activated for 60 s. to clean the circuit and return sensors resistance to their baseline state by flushing it with pure air. The stored data is in the form of matrix array that contains 8 columns related to eight gas sensors present in the sensor array and no. of rows related to number of data points. The generated database is used for statistical as well as neural network training and testing purpose.

2.3 Data acquisition hardware and software details

The data acquisition of e-nose system consists of hardware and software components. The major hardware components are the Intel dual core processor PC, National instruments USB6009 series DAQ card and software part consist of a specially developed GUI software using LabVIEW which facilitates the data acquisition, pre-processing and pattern recognition operations. The 8 analog inputs Channels (A0-A7) of USB 6009 DAQ card is used to acquire analog signals from the sensor array. Various activities are required for the operation of the developed electronic nose. Many of these activities are repetitive actions that must be scheduled at fixed time intervals. Figure 2 shows a flow diagram representing all the actions necessary to perform a complete measurement cycle.

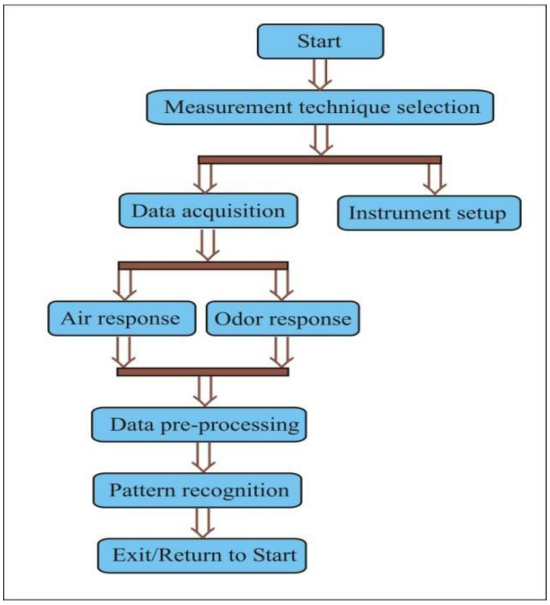

Figure 2 Macro activities in developed e-nose system operation

During data acquisition, electronic solenoid valves, centrifugal air pump and vacuum air pump are automatically controlled via DAQ cards digital I/O' s as per requirement. The LabVIEW based software handle the overall operation. A separate software GUI program is written for measurement of the air and odor volatile response of sensor array. Figure 3 shows the front panel user interface of the software.

This GUI is used to acquire the signals from sensor modules during air and odor sensing. The signals are nothing but the voltages across the load resistor RL. The voltages are then internally converted into sensor conductance value. The front panel of the software continuously show real time plot of the change in voltages and conductance of the sensor array. The numerical values of the acquired data at a particular instant is also displayed in table window on front panel. This GUI automatically control the overall operation of odor sensing system during measurement via DAQ's DIO.

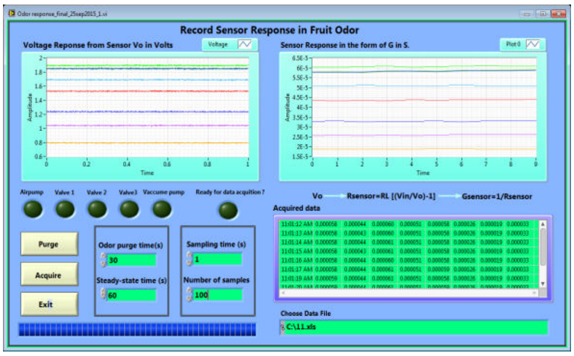

Figure 3 Data acquisition interface of developed software

The systems software generates the time-controlled pulses to DIO lines for controlling the valves, airpump and vacuum pump ON/OFF during measurement. Table 2 shows the ON/OFF state of various devices during measurement phase.

Table 2 Solenoid valve, air pump, and Vacuum pump operation during measurement

Operation Mode	Solenoid 1	Solenoid 2	Solenoid 3	Air Pump	Vacuum Pump
Purge odor	ON	OFF	OFF	ON	OFF
Acquire Data	OFF	OFF	OFF	OFF	OFF
Flushing	ON	ON	ON	ON	ON

2.4 Validation of e-nose database using PCA

The database collected during experimentation is validated using PCA analysis. PCA analysis describes the discrimination ability of developed e-nose. The relative responses of eight gas sensors array towards different ripening classes of guava fruit has been analyzed using PCA and the first two principle components are plotted as shown in figure 4. PCA analysis was applied to selective training dataset.

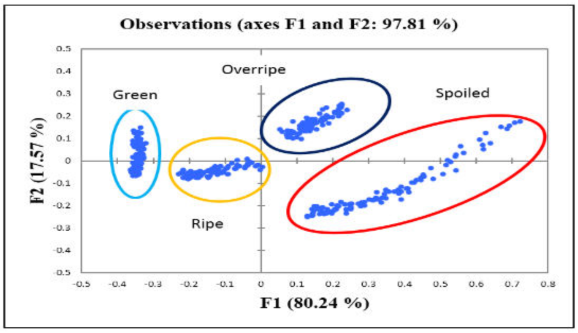

Figure 4 Two dimensional PCA plot for the response of sensor array to four ripening classes of guava fruit

The two principal components $\{PC_{1,n}, PC_{2,n}\}$ was obtained and has the two greatest variances: 80.24% and 17.57% (total variance of 97. 81%) of the variance in the input variables, respectively. The scores of the four classes of guava fruits is plotted for principal component 2 (F2) versus principal component 1 (F1).
The separation between the four ripening classes of guava can be clearly seen from the figure 4. A strong pattern separation is observed between the four ripening classes of guava fruit. The processed data show a shift of the different ripening states which coinciding with the classification by trained human sensory panel. The four clusters from left to right indicate the discrimination of fruit classes from green to spoil. This indicates the use of non-specific selective gas sensor arrays to construct an odor database.

2.5Design of fuzzy logicPARCmodule

Fuzzy logic is pattern recognition method having ability to model uncertainty and the human way of thinking, reasoning and perception. In classical models, variables have real number values, the input and output relationships are defined in terms of mathematical functions and the outputs are crisp values. In fuzzy logic, the values of variables are expressed by linguistic terms such as "few, some, more and much-more"etc. The relationships between inputs and outputs are defined in terms of if-then rules, and the outputs are fuzzy subsets which can be made "crisp" using Defuzzification techniques. A membership function is a mathematical function, which defines the degree of an element's membership in a fuzzy set [12].

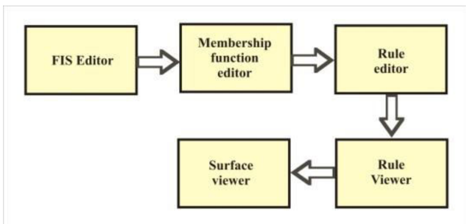

Figure 5 Steps in Fuzzy interface System

Fig. 5 shows the steps in development of fuzzylogic inference system. The process starts with deciding the systeminputs and outputs followed by the definition of input andoutput membership functions. Finally, the rules areconstructed using IF-THEN statements using rule editor. The system works according to the rules set by the expert. Hence this is a critical step in the grading process. The rule and surface viewer are the graphics that are used to view the built system[13].
Fuzzy Logic technique is chosen as pattern recognition tool for prediction of guava fruits ripeness level because it represents a good approach when we want to interpret human experience incorporated into the decision making process .Fig.6 shows the designed fuzzy logic interface system developed in Matlab using FIS editor for prepackaging classification of guava fruits. The fuzzy system has eight inputs (Eight gas sensors: TGS2602, TGS2600, TGS2602, TGS2611, TGS2620, TGS822, TGS813, TGS832) and one output (Fruit class: Green, Ripe, Overripe and spoiled).

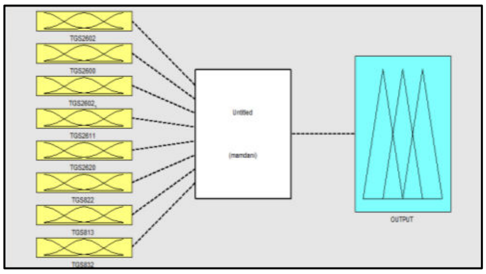

Figure 6 fuzzy logic interface system developed in Matlab

Fuzzification is the process of changing a real scalar value into a fuzzy value. To develop membership function for input variable, the range of each gas sensors pre-processed data valueswere determined for each class. Fifteen guava fruits of each ripening class were used to calculate average range values. These range values were used as reference and range input of fuzzy set. Table 3 shows the range values of eight gas sensors used for green, ripe, overripe and spoiled class of guava fruit.

Table 3 Range values of sensors array response for guava fruits

Fruit Class	Sensor response	TGS 2602	TGS 2600	TGS 2602	TGS 2611	TGS 2620	TGS 822	TGS 813	TGS 832
Green	Min	0.05	0.044	0.049	0.02	0.085	0.095	0.048	0.029
	Max	0.186	0.667	0.187	0.115	0.212	0.378	0.10	0.121
Ripe	Min	0.185	0.414	0.209	0.12	0.215	0.326	0.105	0.152
	Max	0.288	0.469	0.257	0.163	0.284	0.444	0.167	0.162
Overripe	Min	0.284	0.644	0.303	0.115	0.339	0.51	0.15	0.121
	Max	0.952	2.846	1.015	0.163	1.097	2.459	0.19	0.265
Spoiled	Min	1.308	3	1.434	0.253	1.58	4.231	0.333	0.287
	Max	1.434	3.571	1.491	0.326	1.615	4.286	0.471	0.533

All the input data was categorized into three linguistic terms by ranges as shown in Table 4. The range values are optimized according to keep completeness at 0.5 [14].

Table 4 Range values of input linguistic variables

Linguistic Term	Range	TGS 2602	TGS 2600	TGS 2602	TGS 2611	TGS 2620	TGS 822	TGS 813	TGS 832
Low	Min	0.04	0	0.040	0	0.080	0.090	0.04	0.02
	Max	0.72	1.82	0.77	0.17	0.085	2.245	0.26	0.28
Medium	Min	0.38	0.93	0.405	0.085	0.465	1.167	0.15	0.15
	Max	1.06	2.71	1.135	0.255	1.235	3.317	0.36	0.41
High	Min	0.72	1.82	0.77	0.17	0.85	2.245	0.26	0.28
	Max	1.40	3.6	1.5	0.34	1.62	4.4	0.48	0.54

The Input membership functions were built using triangular shapes. Figure 7 shows the first fuzzy input membership functions for TGS2602 gas sensor. The other 7 membership functions were also built using triangular shape and three type of linguistic terms were used. The min and max value of each linguistic term is shown in table 4.

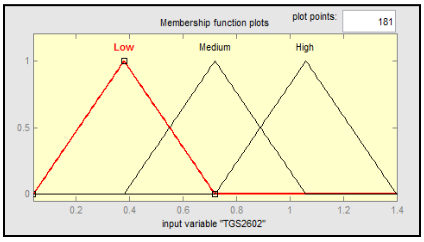

Figure 7 Input membership functions for TGS2602

Defuzzification is the conversion of membership function into Crisp value. Crisp value is nothing but the amount of ripening level of fruit. Fruit class is the output variables of the fuzzy logic module. The Universe of Discourse (UoD) of fruitclass for four ripening states is 0 to 100 partitioned in to four linguistic terms entitled as green, Ripe, Overripe and spoiled shown in figure 8.

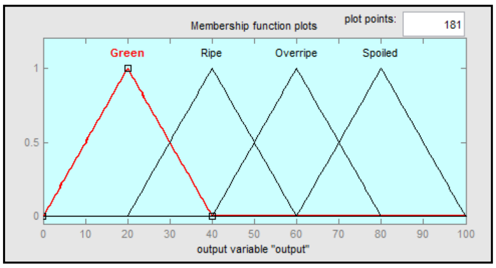

Figure 8 Output membership function

The decided range of four outputs linguistic term is shown in table 5.

Table 5 Range values of output linguistic variables

Linguistic Term	Range
Green	0-20-40
Ripe	20-40-60
Overripe	40-60-80
Spoiled	60-80-100

Total 7 rules statements were built in order to classify the guava fruit into four ripening class. The fuzzy rules created using rules editor are shown below,

- If (TGS2602 is Low) and (TGS2600 is Low) and (TGS2602_1 is Low) and (TGS2611 is Low) and (TGS2620 is Low) and (TGS822 is Low) and (TGS813 is Low) and (TGS832 is Low) then (output is Green)
- If (TGS2602 is Low) and (TGS2600 is Low) and (TGS2602_1 is Low) and (TGS2611 is Medium) and (TGS2620 is Low) and (TGS822 is Low) and (TGS813 is Low) and (TGS832 is Low) then (output is Ripe)
- If (TGS2602 is Medium) and (TGS2600 is Medium) and (TGS2602_1 is Medium) and (TGS2611 is Medium) and (TGS2620 is Medium) and (TGS822 is Low) and (TGS813 is Low) and (TGS832 is Low) then (output is Overripe)
- If (TGS2602 is Medium) and (TGS2600 is Medium) and (TGS2602_1 is Medium) and (TGS2611 is Medium) and (TGS2620 is Medium) and (TGS822 is Medium) and (TGS813 is Medium) and (TGS832 is Low) then (output is Overripe)
- If (TGS2602 is Medium) and (TGS2600 is Medium) and (TGS2602_1 is Medium) and (TGS2611 is Medium) and (TGS2620 is Medium) and (TGS822 is Low) and (TGS813 is Medium) and (TGS832 is Low) then (output is Overripe)
- If (TGS2602 is Medium) and (TGS2600 is Medium) and (TGS2602_1 is Medium) and (TGS2611 is Medium) and (TGS2620 is Medium) and (TGS822 is Medium) and (TGS813 is Low) and (TGS832 is Low) then (output is Overripe)
- If (TGS2602 is High) and (TGS2600 is High) and (TGS2602_1 is High) and (TGS2611 is High) and (TGS2620 is High) and (TGS822 is High) and (TGS813 is High) and (TGS832 is High) then (output is Spoiled)

Fig. 9 shows the rule viewer which consists of the system's input and output. It also has indicator for the Defuzzification results.

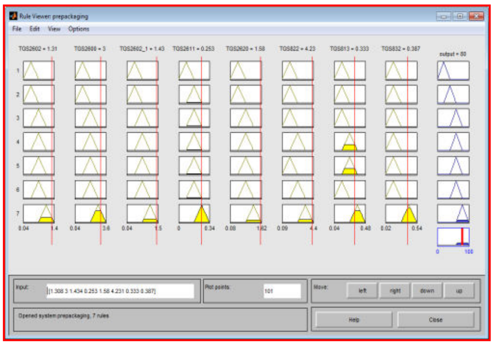

Figure 9 Rule viewer for prepackaging classification of Guava

The first to eight column are representing eight gas sensors input values while the last column is the category of ripeness. The last row of the last column which is category column shows the Defuzzification results where the category of guava fruit is obtained. This rule viewer is used for predicting the class of ripening of guava fruits.

III. RESULT AND DISCUSSION

For evaluation of the developed FIS, 10 samples of each ripening class were used. The e-nose response of each ripening class was measured in order to classify guava fruit into green, ripe, overripe, and spoiled classes. Acquired input data was transferred to rule viewer determination of ripening class. Results of comparison between human grader and proposed method is shown in Table 6.

Table 6 Performance analysis of fuzzy logic module

Ripening state	No. of samples		Classification		Performance %
	Training	Testing	Expert	System	
Green	10	10	10	10	100
Ripe	10	10	10	09	90
Overripe	10	10	10	08	80
Spoiled	10	10	10	09	90

The average efficiency achieved using developed fuzzy logic classifier is about 90%, if human grading taken as reference level is assumed to be 100% accurate. However, 10% variation is also due to individual judgment of human-graders in perceiving the ripening level of fruit during manual grading, which of course is inevitable. The repeatability of the developed system is found to be 100% from rigorous experimental work.

IV. CONCLUSION

The average prediction results obtained by fuzzy logic based pattern recognition is about 90% accuracy. The results obtained from the experiment showed a good general agreement with the results from the human sensory panels. The result reflects the expert expectations and classification standards. The results indicates that developed e-nose system is capable for classification of guava fruits with adequate resolution and it would be a feasible system to be used in a real scenario.

Acknowledgements
The author A.K. acknowledges the financial support of UGC,New Delhi, Indiafor grantingtwo year faculty improvement program fellowship to pursuePh.D and conduct research.

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