CHEMICAL ENGINEERING TRANSACTIONS
VOL. 40, 2014
Guest Editor: Renato Del Rosso

ISBN 978-88-95608-31-0; ISSN2283-9216
A publication of AIDIC
The Italian Association of Chemical Engineering
www.aidic.it/cet
DOI: 10.3303/CET1440044

Generic Handheld E-Nose Platform for Quality Assessment of Agricultural Produces and Biomedical Applications

Alokesh Ghosh*, Hena Ray,Tarun Kanti Ghosh, Amritasu Das, Nabarun Bhattacharyya

Centre for Development of Advanced Computing, Plot-E2/1, Block-GP, Sector-V, Salt Lake, Kolkata-700091, India
alokesh.ghosh@cdac.in

Electronic Nose (E-Nose) has been found suitable to assess quality of many agricultural and food products as well as this have immense potential in biomedical applications for early detection of diseases. However, the major challenge here is to develop a generic E-Nose platform that can be used in various application domains by the researchers. Since apart from sensors and electronic components, an E-Nose involves electromechanical parts for odour delivery to the sensors this is extremely difficult to develop a small, portable, low power device that would be rugged enough for continuous field usage.
This paper describes a generic handheld E-Nose platform that is rugged enough for field usage and suitable for applications in various domains like Agricultural and Horticultural produces and biomedical applications.
The E-Nose was first developed for applications in the tea industry to solve the following two problems:

- Assessment of quality of tea based on its aroma
- Detection of optimum Fermentation time during tea manufacturing process

Based on the preliminary success in the tea domain, effort was made to make this platform generic so that various other domains may also be served. Effort towards miniaturization, reduction in power consumption, convenience of use were also given priority and finally we came out with a perfectly handheld, battery operated and field deployable generic E-Nose platform.
This generic platform is in use by the researchers in domains like tea, different spices, jasmine, cheese ripening, waste water quality detection, early detection of diabetes, etc.
This generic handheld E-Nose platform is developed on a 16-bit microprocessor platform, experimental data are stored in a SD Memory Card, user-input is through Touch Screen interface and results are displayed onto a Graphics display. A rechargeable battery pack powers the system continuously at least for 10 hours and miniature pump and valve are used for the odour delivery mechanism. A sensor array consisting of five MOS sensors are used for aroma sensing purpose.

1. Introduction

Although the advent of Electronic Nose opened up a plethora of possibilities in food and beverage industry, environment monitoring, biomedical applications and many other domains, but almost all commercially available E-Noses are intended for laboratory usage. They are very expensive and high performance equipments analogous to HPLC/GC and spectrometer. They need to be individually calibrated for a particular application. It is not possible to develop an application using one device and then apply that model to another device of the same type without using actual calibration measurements with the same type of samples. These equipments also require trained and skilled operators. Proliferation of the E-Nose technology to the mass and industry did not really take place because of the above limitations.
Our approach was not to address the laboratory market but to address the non-existing mass market by developing a small, portable, low cost, low power, battery operated, rugged, simple, user friendly and mass-employable E-Nose. The target device also required to be generic in architecture, so that it could be

Please cite this article as: Ghosh A., Ray H., Ghosh T., Das A., Bhattacharyya N., 2014, Generic handheld e-nose platform for quality assessment of agricultural produces and biomedical applications, Chemical Engineering Transactions, 40, 259-264
DOI: 10.3303/CET1440044

used in different application domains with minor modifications. “Calibrate on one unit, apply to all units” was another major objective to ensure mass-employability.
The first prototype of Handheld E-Nose (HEN) was tried in the Tea industry and based on the success the architecture was modified to give it a more generic form to be applied in variety of applications. The following sections describe the experiments and results on Tea with HEN, followed by description of the generic architecture and operation of HEN and finally application of HEN in various other domains.

2. Problem definition in Tea

Tea is one of the mostly consumed beverages across the world and is rich in medicinal values also. Aroma is one of the major quality determinants of Tea that also plays a vital role in determining the pricing of Tea. Quantification of quality of black tea is complex because numerous compounds present in tea contribute in a multidimensional way to determine the final quality. Conventionally, human tea tasters judge the quality of tea relying on their human sensory organs and assign scores in the range 0 to 10. However, the method is highly subjective and inaccuracy may occur because of various physiological and environmental factors.
Fermentation is one of the important processing stages of Tea and is the major determinant of the final quality of finished tea. Determination of the proper end-point of fermentation is very important since both under and over fermentation lead to severe degradation of the quality of the final produce. End-of-fermentation is detected by experienced factory supervisors manually by monitoring the change of grassy smell to floral smell where a sharp peak of smell appears known as the “second nose” in Indian tea industry parlance. This method is again subjective and highly error-prone.
In order to minimize the errors associated with the age-old conventional methods in tea industry and to aid the human experts, we proposed the use of handheld E-Nose that would objectively and repetitively do the followings:

- Evaluation of quality of Tea based on aroma.
- Detection of optimum end-point of Fermentation during tea manufacturing process.

3. Methodology

The research effort was divided into two parallel paths; design and development of the Hardware, Software and Odour delivery system of HEN in one hand; and selection of Sensor Array, Data Collection, Data Analysis, Training and Algorithm development for Tea on the other hand.

3.1 Selection of Sensor Array

As a result of extensive research, Tea Research Association, India has identified bio-chemical compounds that are available in black tea and are responsible for aroma as given in Table-1.

Table 1: Bio-chemical compounds present in Tea responsible for Aroma

Compounds	Flavour
Linalool, Linalool oxide	Sweet
Geraniol, Phenylacetaldehyde	Floral
Nerolidol, Benzaldehyde, Methyl salicylate, Phenyl ethanol	Fruity
Trans-2-Hexenal, n-Hexanal, Cis-3-Hexenol, Grassy, b-Ionone	Fresh Flavour

Metal Oxide Semiconductor (MOS) sensors were selected because of their stable performances and commercial availability compared to the other options. In order to select the most suitable set of sensors, we exposed each sensor to equal amount of these bio-chemical compounds one by one in a controlled environment and studied their responses. We shortlisted a set of five commercial sensors initially, based on the sensitivity and selectivity of these sensors towards the tea volatiles. After finalizing the Sensor Array, we exposed different varieties of black tea to this array and found that the array was successful in classifying different varieties of black tea. Eventually, we could replace three of these sensors by indigenous sensors developed through our collaborator, Central Glass and Ceramic Research Institute, Kolkata. These three indigenous sensors showed better selectivity and sensitivity towards tea aroma volatiles compared to their commercial counterparts. The PCA plot of Figure 1 shows the classification ability of the sensor array consisting of indigenous sensors, 1% Ag-SnO_2, 5% Ba-SnO_2 and 5% Sr-SnO_2 and commercial Figaro make sensors, TGS 2600 and TGS 2602 for five different varieties of tea.

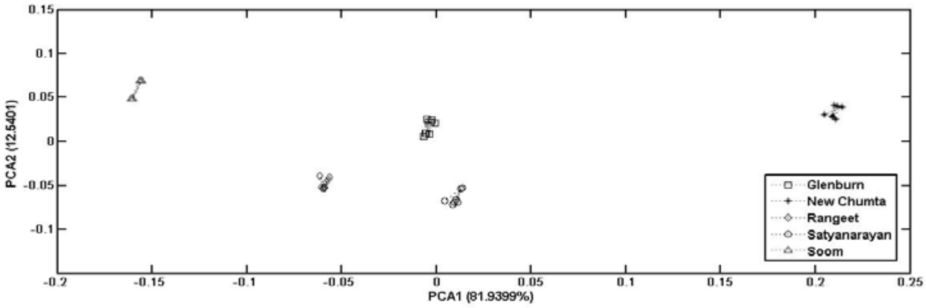

Figure 1: PCA plot for five different varieties of Tea

3.2 Data Collection

Data was collected on hundreds of tea samples of different varieties like Darjeeling Tea, Assam Tea, Dooars Tea and South Indian Tea. Data collection was made through a sniffing cycle (280 sec) comprising of Headspace generation (50 sec), Sampling (50 sec) and Purging (180 sec). Tea sample (50 ml) was taken in a Sample Chamber. During Headspace generation, air pressure was raised in the sample chamber so that aroma volatiles got emanated from tea samples. During sampling phase, the generated aroma volatiles were released to the sensor array and the data were recorded. During purging phase, the sensors in the array were exposed to fresh air so that the sensors got back to their base values.

3.3 Data Analysis

The data analysis technique employed here was identical in both the cases of quality estimation of Tea and Fermentation end-point detection. The quantitative measurement of data was done by multivariate data analysis of data matrix that was generated from the sensor array. The Response matrix consisted of five individual sensor responses during its sampling phase. Individual sensor response was considered to be the difference or the distance calculated from its base value to its ultimate stable value. The quantitative analysis of this multivariate data matrix was done by Principal Component Analysis (PCA) using Singular Value Decomposition (SVD) algorithm. The implementation of SVD on the response matrix gives the Norm Aroma Index (NAI) of the Tea sample that was directly proportional to the aroma strength of the sample. The SVD computational algorithm is given in the flowchart of Figure 2.

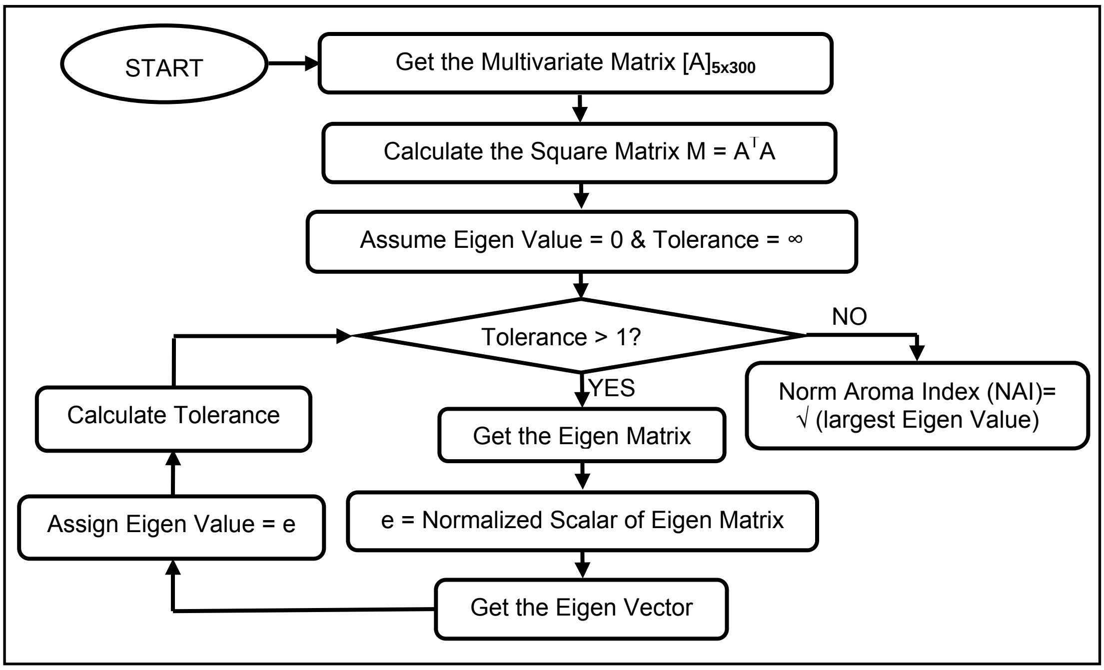

Figure2: Flow chart of Data Analysis Algorithm

3.4 Training and Quality Evaluation of Tea

The NAI generated by the SVD algorithm is a machine (HEN) generated value which is directly proportional to the aroma intensity of the sample. For training of HEN, supervised learning mechanism was employed. This supervised training was done by feeding Human Taster's Score for known samples. HEN generated NAI coupled with Taster score were stored in the database. Finally, HEN evaluates the quality (Aroma Score) of an unknown sample of Tea in the range 0 to 10 by correlating the generated NAI with the training database.

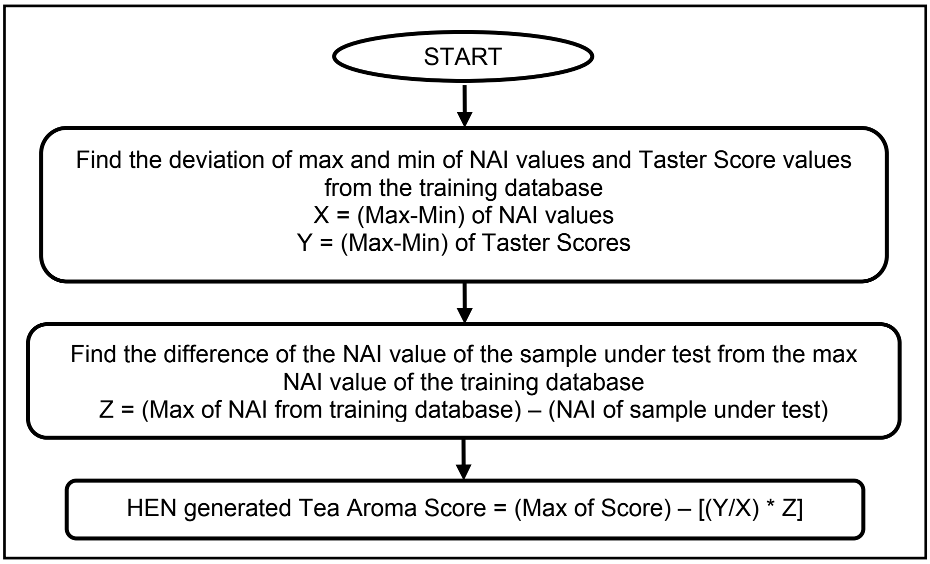

Figure 3: Flow chart of the statistical correlation algorithm used for Aroma Score Generation of Tea sample under test

4. Description of Handheld E-Nose (HEN)

4.1 Construction

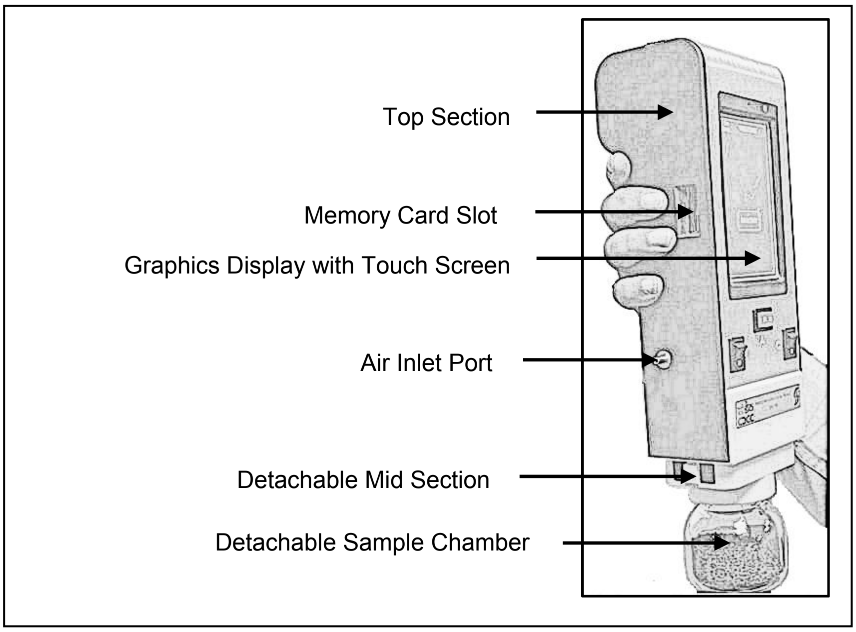

Figure 4: Diagram of the generic Handheld E-Nose

The features of the generic Handheld E-Nose (HEN) are small, portable, battery-operated, integrated simplified odour delivery system, rugged for field usage, touch-screen based user inputs, results in graphics display and data storage in SD memory card. The hardware was built on a 16-bit microcontroller with a 4.3 inch Graphics Display (with Touch Screen). The odour delivery system consists of a 12 volt micro-pump and 12 volt solenoid valve. The whole system draws power from a 12 volt Li-ion rechargeable battery and can run the HEN unit uninterrupted for at least 10 hours. The HEN device comprises of Top-section, Mid-section and Sample Chamber. Top-section houses battery, micro-pump and the three PCBs namely, HEN Motherboard, DAQ board and Sensor board. The Display is fixed on the reverse side of the Motherboard. Motherboard and DAQ board are placed back-to-back whereas the Sensor board is placed at right angles to the other boards with the sensors facing downwards. The detachable Mid-section houses the valve and connects the Top section and the Sample Chamber. Mid-section also provides one channel from pump outlet to the Sample chamber; and another channel from the Sample chamber to the Sensor Array through the valve. The Sample chamber is made of glass and 100 ml in volume. Provision is kept to fix the Sample chamber to the Mid-section in an air-tight fashion. In the absence of operating system, the Graphical User Interface (GUI) based application software was developed in Firmware. The event driven user interface was implemented using a State Machine. In absence of any kind of RDBMS, data storage and retrieval was implemented in FAT32 file system with the help of a data structure.

4.2 Operation

The procedure for quality evaluation of an unknown Tea sample is described first. Tea sample (50 ml) is first taken into the Sample Chamber and the Sample chamber is fitted to the Mid-Section. The Mid-section is then fitted to the Top-section. Once testing for Tea is started, the Pump is made ON and the Valve closed, so that air pressure is raised to 350 mm of Hg inside the Sample Chamber (Headspace: 50 sec). A LED indication is kept to check whether pressure is really built and aroma volatiles generated. The valve is then made open (Sampling: 50 sec) so that aroma volatiles reach the sensor array. Sensor data are acquired and stored during this phase. NAI is computed on the recorded 300 samples and final Aroma Sore (scale: 0 – 10) is generated by correlating the training database. Finally, the sensors need to be purged for at least 180 sec to get them back to their base values. For purging, the Mid-section is detached from the Top-section and the sensors located at the bottom of the Top-section are exposed to fresh air.
The operation for Fermentation end-point detection is almost identical. Tea leaves from the fermentation bed are taken into the Sample chamber at an interval of 5 minutes and NAI computed each time. The computed NAI is plotted against time until the second aroma peak (second nose) is detected.

4.3 Results for Tea

Experimental results on quality evaluation matched almost 90% for Darjeeling Tea with the perception of human experts (Tea Tasters) but less (~70% and ~80%) in case of Assam and Dooars Tea respectively. The detection of Fermentation end-point matched nearly 95% in case of Dooars, Assam and South Indian Tea but did not match properly for Darjeeling Tea with the perception of the experienced Factory experts.

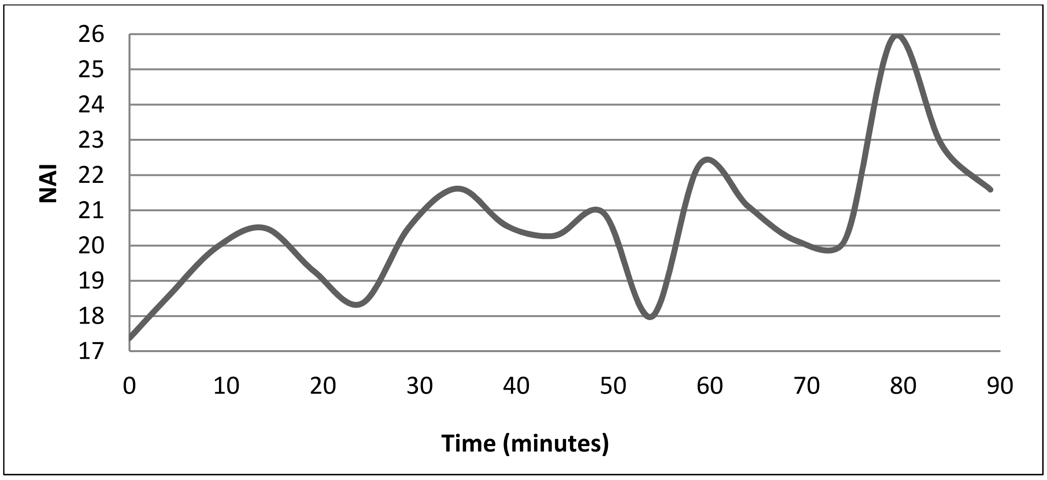

Figure 5: Fermentation profile plot for Reconditioned CTC Tea at UPASI, South India showing the arrival of 2nd Nose at 79th minute

5. Use of the generic Handheld E-Nose (HEN) in other domains

5.1 Quality evaluation of Jasmine and its Concrete

There is no objective way available to evaluate the quality (and hence price) of Jasmine and its processed extract called concrete. Linalool, Benzyl benzonate and Benzyl acetate are the key chemicals responsible for aroma of Jasmine. Presently, HEN is in use by researchers at Tamilnadu Agricultural University for this very purpose. TGS832, TGS823, TGS826, TGS2620 and TGS2602 have been identified as the sensors. Initial study shows very good classification amongst different varieties of Jasmine and it has been found that quality of concrete prepared from fully blossomed jasmine is better than that prepared from buds.

5.2 Estimation of Soil Fertility

HEN is in use by researchers at PES Institute of Technology, Bangalore to estimate the presence of Humic acid and Fulvic acid in soil, thereby estimating the fertility of soil. After extensive study, TGS830, TGS2600, TGS2611, TGS823 and TGS2620 have been identified as the prospective sensors. Results show that HEN can be used as a good screening tool to assess biological fertility of soil.

5.3 Quality estimation of Cardamom

Research is in progress on estimation of Cardamom quality using HEN at Indian Institute of Spice Research, Calicut. Initial study shows marked differences in the NAI of fresh cardamom compared to that of stored ones, as well as in cardamoms with and without husk.

5.4 Detection of disease through breath analysis

Literature shows that in case of diseased person certain chemical compounds will be obtained in abundance in breath; like, acetone in case of diabetes, ammonia in case of renal disease, pentane in case of acute myocardial infarction, etc. A customized HEN can be a prospective low cost tool for early detection of many such diseases. Breath samples can be collected in Tedlar gas sampling bags with arrangement for moisture removal. For testing of a breath sample, the bag needs to be fitted to the air inlet port of HEN. When in operation, the pump will suck the breath sample from the bag and will deliver that to the sensor array for analysis. However, proper sensors need to be selected for each individual disease.

6. Conclusions

Although the present form of HEN promises to be a low cost, user friendly, mass employable and fully production worthy prototype, there is still huge scope of improvement. There are a few limitations like the MOS sensors get affected easily by moisture, power requirement is high and selectivity is low. Lot of scope is there in improving the sensor technology. The number of sensors in the array needs to be increased for better result.The application software should have different algorithms in-built, so that researchers can pick and choose the right one for their intended application.

References

B. Banerjee, 1993, Tea Production and Processing. New Delhi, India: Oxford & IBH.

Nabarun Bhattacharyya, Rajib Bandyopadhyay, Manabendra Bhuyan, BipanTudu, Devdulal Ghosh, Arun Jana, July 2008, IEEE Transaction on Instrumentation and Measurement, vol. 57, no. 7, Electronic Nose for Black Tea Classification and Correlation of Measurements With “Tea Taster” Marks.

N. Bhattacharyya, S. Seth, B. Tudu, P. Tamuly, A. Jana, D. Ghosh, R. Bandyopadhyay, M. Bhuyan, and S. Sabhapandit, Mar. 2007 Sens. Actuators B, Chem., vol. 122, no. 2, pp. 627–634, Detection of optimum fermentation time for black tea manufacturing using electronic nose.

DongminGuo, Zhang D, Naimin Li, Zhang D, Jianhua Yang, 2010, IEEE Transactions on Biomedical Engineering, Vol:57, Issue:11, A Novel Breath Analysis System based on Electronic Olfaction.

Adnan Younis, Aqsa Mehdi, Atif Riaz, December 2011, Pak. J. Bot., 43: 163-168, Special Issue, (Medicinal Plants: Conservation & Sustainable use), Supercritical Carbon Dioxide Extraction and Gas Chromatography Analysis of Jasminum Sambac Essential Oil.