CHAPTER 2

The Artificial Olfaction System

In this chapter the overview of Biological olfaction and the basic principle of electronic nose and its different types has been described. Trying to copy the human anatomy, scientists have come out with the classified and broader steps that distinguish the pattern of human smell. The applications of electronic nose and literature review of electronic nose is also being discussed in this chapter.

2.1 The Biological Nose-

It initiates with sniffing, which takes away air samples that cleave to molecules of smells pattern rounded bony structures known as turbinate. The turbinate creates turbulent airflow patterns that grips the conjunction of volatile components to that thin mucus concealing of the nose’s olfactory epithelium where ends, if the nerve cells that feel odorants. The changeable organic compound (VOCs) responsive to odors reaches at the olfactory epithelium in gaseous form, furthermore a coating and layering on the particles that prepare the air we breathe. Particles make an access at the olfactory epithelium, when we chew and swallow the food, from the nostrils as well as from the mouth.

As the particles carrying VOCs accumulates over the mucus membrane lining and covering the nose, they are caught by the mucus and passes easily through to the next layer i.e. epithelium, as shown in fig 2.1 where the sensory cells pile up in a queue. With receptors residing on the cells
of outer membranes the cells are enclosed in multiple cilia-hair like structures. Olfactory cells are focused and neurons that are copied exactly every 30 days.

The transformation of a particle into an odor initiates when this odorant particle, as it is mentioned, binds to a receptor protein. The event starts an array of enzymatic reactions that in turn gives the depolarization of the cell’s membrane. (Ion pumps inside the cell’s membrane maintain the cell polarized in its rest, or stable state, with a typical rest impending of about 90mV across the membrane). As far as expectations are concerned there are more than 100 million protein receptors in all and probably 1000 types. For illustration one receptor type is sensitive and gets activated to a small subset domain of odorants, one of which is the organic compound octanal.

The sensory cell in the epithelium generates response by the transmission of signals along neural "wires" called axons. Such an axon primarily passes through a small hole in a bony structure in the bottom of the skull, known as the cribiform plate. Thereafter all the other neuron wends its path to the brain's olfactory bulb, where it ends up in a cluster of neural networks known as glomeruli. The 2000 or so glomeruli of the olfactory bulb
depict the primary row of central odor information execution. All sensory neurons comprising a distinct feature odorant receptor are to collect one, two or three glomeruli in the olfactory bulb so as to notify that olfactory sensory neurons in the epithelium can give response to more than one odorant. Expectedly, it is therefore the sample of response across various glomeruli that codes olfactory feature.

Olfactory information finally reaches higher up in the brain, primarily at the hypothalamus, which also executes neural signals in relation to food intake, henceforth at still high processing centers. The use of noninvasive strategies to examine the brain provides the idea that various chemical stimuli initiate different brain areas to different degrees. As the latest electronic technologies emerge, the traditional strategies to calculate odor are taken for challenge. As specified earlier, recent approaches basically engage either making use of human odor panels to quantify and differentiate the odor or gas chromatography and mass spectrometry to accurately identify the odorants rendering it.

A multiplication of either detection or recognition threshold may be expressed as the concentration of an odor. The detection threshold is stated by the American Society for Testing and Materials (ASTM) as the concentration at the lowest level which an odor is primarily detected—getting the result (identification) is not necessary by 50 percent of humans sniffing it. The detection threshold is said to be the absolute threshold of sensation for an odor. The odor concentration at this peak value is defined to be 1.0 odor unit/m$^3$. The value is created by taking the mean of the responses over a population of individuals. Certain groups of trained human “sniffers” are the best platform of odor calculation. The identification threshold is specified by ASTM as the lowest concentration at which smell is primarily identified by
50 percent of the population sniffing an odorant. In this scenario, positive detection of the odor is necessary. The recognition threshold is often 5-10 odor units, or 5-10 times greater than the detection threshold.

Gas chromatography and mass spectrometry have also been applied to detect the chemical components of an odorous mixture. Air samples are gathered in special canisters and moved to the experimental lab for identification thereafter. The odorant may be concentrated in the field or lab by applying a vapor trap comprising of an absorbent material or cryogenic device. In both the cases, a calculated volume of the sample is passed through the trap, where odorant molecules are eliminated from the gas sample and gathered at the absorbent material or cryogenic surface. Heating the trap frees the concentrated molecules very fast into the gas chromatograph. Produced along on a little volume of a pure carrier gas, which passes through the column at a fixed rate, the sample passes through the column to a detector.

2.2 ELECTRONIC NOSE PRINCIPLES

2.2.1 Need to sensitize the nose electronically

Presenting the gas sensors of the electronic nose, this fast paced, reliable and effective new technology undertakes what has been impossible to attained continuous real-time examining of odors at certain sites in the area over hours, days, weeks, or even months. An e-device can also eliminate other harms linked with the use of human panels. Individual inconsistency, adaptation (becoming fewer responsive during prolonged exposure), exhaustiveness, allergies, mental disturbance, subjectivity, and exposure to risky compounds all come to state of mind. In effect, the electronic nose can
produce odor-exposure profiles ahead of the capabilities of the human panel or GC/MS measurement techniques.

The electronic nose is a mechanism comprising of three functional units that function linearly on an odorant sample. These functional units are a sample handler, a series of gas sensors, and a signal-processing system as shown in fig 2.2. The output of the electronic nose can be the uniqueness of the odorant, an approximation of the concentration of the odorant, or the feature properties of the odor that might be perceived by humans. Fundamental to the mock nose is the idea that each sensor in the series has dissimilar sensitivity. For illustration, odorant No. 1 may give the outcome of a high response in one sensor and lesser responses in others, whereas odorant No. 2 might produce high readings for sensors other than the one that "took" to odorant No. 1. The matter of utter importance is that the pattern of response throughout the sensors is distinguishable for different odorants. This differentiating ability allows the system to detect an unidentified odor from the model of sensor responses. Every sensor in the series has a distinguish response profile to the range of odorants under examination. All sensors in the series are used to identify the model of response diagonally and provide the distinct odor.
2.3 Sensing Technologies

Inside the field of gas sensors there are various types of sensing materials that play a vital role to the gas sensor. A gist of the popularly known gas sensors with the inclusion like metal oxide semiconductor [36], conducting polymer sensors [37], acoustic wave sensors [38], field-effect gas sensors [40], pellistors [39], and fibre-optic sensors [41]. So most of the mentioned sensing technologies are explored in the investigation and have also been applied on commercially available electronic noses [34, 35]. Each of these techniques has various advantages and disadvantages above their counterpart and selecting the correct kind of gas sensor, depends on the kind of uses. However, in the mass of electronic nose uses there are a group of preferred properties that are liable to be common.
Rapid response - The sensors should be able to respond to an exposed odor during a certain time period. This is particularly important in applications that put together electronic nose with a robotic system, such as a mobile robot that should rotate around in a surroundings and measure odor gradient [42].

Low power consumption - In the majority realistic systems there is a limit of power, and thus the power usage of the sensors should be effectively low. The headspace, comprising the group of sensor array is likely to engage other electrical equipments such as pumps and valves which frequently share the same power supply.

Compact size - Lesser sensor size incorporates the addition of sensors in a variety of platforms, containing movable electronic noses [43].

High sensitivity - The sensors should display a greater sensitivity to various odorants and various concentrations of the same odorant.

Reliability - Gas sensors should act as expected particularly for prolonged duration.

Robustness - Unnecessary effects, from physical changes in atmosphere such as humidity and physical motion, should not distract the results from the sensor readings.

In the following subsections a short overview of mostly used gas sensing technologies is mentioned.
2.3.1 Gas Sensor Operation

The general motive behind encapsulating the idea is that the chemical gas sensor is based on the truth that analytes molecule approach to make contact with a chemically sensitive material which causes a modification in the properties of the material. This change is sensed by a transducer and is converted to an electrical signal. Two types of reactions may occur depending on the construction of the sensor. The first type of reaction is a reversible process where the analytes binds to the surface of the sensing material. The binding is determined by the intermolecular forces between the analyte and the sensing material but is usually characterized by a hydrogen bonding. Essentially, the analyte does not change but will dissociate from the sensing material when the odour concentration is removed. This type of reaction is similar to the interaction between odours and receptor proteins in biological systems. An example of a sensor based on this type of reaction is the conducting polymer sensors. The advantage to these particular types of sensors is that they exhibit both a rapid absorption and de-absorption to gases.

A second type of gas sensor is based on an irreversible reaction. This occurs when an analyte undergoes a chemical change at the sensor surface, i.e. catalysis. A common example of this kind of sensor is the Taguchi type SnO$_2$ sensor. The general advantages of the irreversible reaction is said to be a high sensitivity to specific odours. In these cases, the sensitivity to particular odours is determined by the choice of the catalytic surface.

There have been several kinds of sensing material used for the chemical gas sensor. Some examples include inorganic crystalline or polycrystalline, organic materials, polymers and although fairly rare even biological materials such as proteins and enzymes have also been used. In the
next few subsections, a discussion of the more common types of sensors is given.

2.4 Sensing an odorant

In a usual e-nose, an air sample is pulled through a vacuum pump by a tube into a little chamber housing the electronic sensor series. The tube might be made of synthetic or stainless steel. Next, the sample-handling element exposes the sensors to the odorant, producing a transient reply as the VOCs interrelate with the surface and mass of the sensor's active material. (Previously, every sensor has been driven to a recognized state by having fresh, dry air or several other reference gas passed above its vigorous elements.) A stable-state situation is reached in a few seconds to a few minutes, depending on the sensor type.

During this intermission, the response of the sensor's is recorded and rendered to the signal execution unit. Thereafter, a washing gas such as fumes of alcohol is implemented to the series for a trivial second to a minute, so as to eliminate the odorant amalgam from the surface and most of the sensor's active material. (Some designers opt to bifurcate this washing step).

Lastly, the reference gas is implemented to the array again, to make it ready for a new calculative cycle. The timing within which the odorant is applied is said to be the sensor’s array response time. The duration during which the washing and reference gases are implemented is coined as the recovery time. Basically, latest high-profile outbreaks of food borne illness have included polluted fresh produce; the major source of destructive bacteria in food is non cooked poultry and other flesh products. The bacteria accountable for most food borne illnesses, Campylobacter and Salmonella,
are seen on the rise in 70 percent of chicken meat checked. Taking raw meat products to eradicate pathogens before they access a consumer's home can lessen the danger of cross contamination during food preparation.

Current studies have revealed a link between people who became impure with Campylobacter jejuni, a pathogen set up in poultry, and their intactness with various chicken products that comprised the pathogen. It is also found that the Campylobacter jejuni from those products was opposed to ciprofloxacin, a synthetic antibiotic taken by humans to struggle bacterial infections.

The occurrence of Campylobacter which is a wider reason of food borne illness is general on raw poultry. Out of these bacteria, only Campylobacter jejuni is mainly pathogenic to humans. The U.S. Department of Agriculture suggests refined cooking of poultry as a safety measure against pathogenic contamination. Bacteria which reside symbiotically within the blood-sucking pests known as red poultry mites might be a new and efficient target to stop the spread of Salmonella and alike pathogens in chickens, turkeys and other table birds, according to scientists.

Salmonella is the general name known to a type of food poisoning created through the bacteria called *Salmonella enteritidis* (further types of illnesses are caused through new species of *Salmonella* bacteria, counting typhoid fever). While people take food infected by *S. enteritidis*, they suffer from inflammation of the stomach and guts, with diarrhea and vomiting. This illness is called gastroenteritis. Salmonella food poisoning is most often caused by indecently handled or cooked poultry or eggs. As chickens having the bacteria do not look ill at all, infected chickens move on to lay eggs or to be used as meat.
2.5 Types of Electronic Nose Sensors

Electronic nose sensors fall in four categories:

2.5.1 MOSFET and Metal Oxide Sensors

The general structure of the metal oxide semiconductor field effect transistor (MOSFET) is shown in Figure 2.3. The sensor contains three components: a catalytic metal, an insulator and a transistor (semiconductor). The basic principle of the device allows gaseous compounds to react with the catalytic metal and produce species that are able to diffuse through the metal film and absorb onto a metal insulator.

![Figure 2.3: MOSFET structure](image)

The absorption will cause a voltage change, $\delta V$ and change the current-voltage characteristics of the sensor (Fig.2.4). To vary the sensitivities of the sensor, different catalytic metals may be used. For example, when
palladium is used the sensing characteristics display high sensitivity to hydrogen.

The operating temperature of the MOSFET is in the area of 50°C to 150°C in order to increase the rate of catalytic reactions on the metal surface and prevent the absorption of water molecules. In the case of the hydrogen sensor, the typical response time is approximately 5 seconds for 50 ppm hydrogen in air. Some physical effects can decrease the sensitivity of the catalytic metal. These effects include a fouling of the sensor caused by deposition of other substances on the surface. Poisoning may also occur in the presence of strong substances such as sulphur and lead that are absorbed at the active sites on the catalytic metal and block them from further reaction. Finally, migration may occur from exposure to an abnormally high temperature and cause a loss of active surface area.

![Figure 2.4 Current-voltage characteristics](image)

Metal oxide semiconductors can be used as sensors by observing the electrical resistance changes that occur when vapours are absorbed onto a semiconductor surface [44-45]. Sensors, such as the Figaro, Taguchi and Nemoto gas sensors, are typically prepared by depositing a thin porous film of a metal oxide material such as tin oxide onto an electrically-heated ceramic
pellet and annealing at high temperatures. The advantage of these devices is their good sensitivity, particularly for polar analytes, as well as their "manufacturability". They are typically run at elevated temperatures up to 400°C and hence relatively high power levels are needed (which is considered to be one of the primary drawbacks of these sensor systems). The metal oxide sensor array is one of the commonly used type of sensors in the commercial Electronic Nose instruments, such as that made by Alpha-Fox.

One of the major manufacturers of the MOS sensor is the Figaro Engineering company whose sensors were developed by N. Taguchi [36]. Some examples of different types of the Taguchi Gas Sensor (TGS) and their odor sensitivities are given in Table 2.1

Table 2.1: Examples of commercially available SnO2 sensors provided by the Figaro Engineering Company.

<table>
<thead>
<tr>
<th>Sensor Model</th>
<th>Category of Odors Detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>TGS 800</td>
<td>Air Contaminants</td>
</tr>
<tr>
<td>TGS 813</td>
<td>Combustible Gas</td>
</tr>
<tr>
<td>TGS 826</td>
<td>Toxic Gases (Ammonia)</td>
</tr>
<tr>
<td>TGS 825</td>
<td>Toxic Gases (Hydrogen Sulphide)</td>
</tr>
<tr>
<td>TGS 880</td>
<td>Cooking Vapours</td>
</tr>
</tbody>
</table>

The TGS sensor operates by allowing electrical current to flow through the grain boundaries of the SnO2 micro-crystal surface. At the grain boundary, oxygen is absorbed and forms a potential barrier. The size of this potential barrier is reflected in the value of the sensor’s resistance, the higher
the barrier the more resistance across the sensor. Contrarily, exposure to a deoxidizing will deplete the grain boundaries and thus electrical charge flows more freely and the overall resistance is reduced. The relationship between the concentration of deoxidizing gas and the sensor resistance can be expressed by the following equation,

$$ R = AC^{-\alpha} \quad \text{..................}(2.1) $$

Where R is the resistance of the sensor, A and $\alpha$ are both constants and C is the concentration of the sampling gas. Typically the relationship between the sensor resistance and the concentration of deoxidizing gas is linear on a logarithmic scale within a range of concentration (up to several thousand ppm). Each sensor normally is sensitive to several deoxidizing gases, with most sensitivity to an optimized gas determined by the fabrication of the physical sensing materials. A graphical representation of the sensor’s behaviour with relation to the varying concentration of gas is shown in Figure 2.5.

A final requirement to sensor operation is to supply an input power source for the internal heater. Heating the sensors to a high temperature, between 300°C and 500°C increases the sensitivity characteristics. This is partly due to the fact that temperatures above 200°C increase the rate of reactions on the oxide surface. Additionally, to avoid covering the sensor surface with water particles, the temperature of the sensor should remain above 100°C.
Figure 2.5: Sensitivity characteristics of the TGS822 sensor to ethanol vapour and other various gases and vapours. [36].

The MOS sensor is beneficial due to its high sensitivity to specific gases in the order of 10–500 ppm. Perhaps the most attractive feature of these gas sensors is the low effectiveness and a usable life span of 3–5 years, depending on the usage of the sensor. A few drawbacks of the sensors however, include a dependency between external humidity and temperature effects to the rate of reaction to a gas, and high power consumption.
2.5.2 Piezo Electric Sensors Including the QCM and SAW

The piezoelectric family of sensors also has two members: quartz crystal microbalance (QCM) and surface acoustic-wave (SAW) devices. They can measure temperature, mass changes, pressure, force, and acceleration, but in the electronic nose, they are configured as mass-change sensing devices. The QCM types consist of a resonating disk a few millimeters in diameter, with metal electrodes on each side connected to lead wire [Fig.2.6] [47]. The device resonates at a characteristic frequency (10 MHz to 30 MHz) when excited with an oscillating signal.

The quartz crystal microbalance (QCM) sensor is made of a polymer-coated resonating disk, a few millimeters in diameter, with metal electrodes on each side connected to lead wire. Gas molecules adsorbed to the surface of the polymer coating increase the mass of the disk, thereby reducing its resonance frequency.

![Figure 2.6 The Quartz Crystal Microbalance (QCM) Sensor](image-url)
The use of piezoelectric-based sensor quartz-crystal microbalance (QCM) as transducers for chemical analysis was first suggested by Sauerbrey in 1959 [46] and demonstrated by King in 1964 [47]. This approach utilizes the frequency resonance of a piezoelectric material, such as single crystal quartz, when an acoustic waves passes through it. A sensing film coating is applied to the crystal's surface, to enable the absorption of gas molecules, which in turn, induces a shift in the oscillation frequency that is directly related to the mass of the adsorbed compounds [48-49].

Alternatively, the surface acoustic wave (SAW) device utilizes waves produced along the surface of a crystal by the electric field of surface deposited metal electrodes. Each SAW sensor incorporates four inter digitized electrodes to serve as input and output transducers for a sensing and reference pair. There is also an active membrane in between the working electrodes on the same piezoelectric substrate. An ac signal applied across the input electrode creates an acoustic Raleigh wave that "surfs" over the substrate (analogous to a shock wave during an earth-quake). When the wave reaches the output electrode, the ac voltage is shifted in phase as a result of the distance travelled as well as the mass and the absorption properties of a sensing layer deposited between the electrodes [50, 51].

### 2.5.3 Conductivity Based Sensors

Conducting polymers are another popular sensing technology that is based on measuring the resistance of a thin film polymer (electro polymerization). Recall that two different kinds of gas sensing types were mentioned, those based on reversible reaction and those based on an irreversible reaction with analyte molecules. Conducting polymers are an example of reversible reaction gas sensing type. The response given by the
sensor is created by a chemical reaction that occurs on the surface of a polymer placed between two electrodes. Typical polymers are constructed from monomers such as pyrrole, aniline or thiophene. When a polymer comes into contact with particular gases, carriers on the polymer chain become mobile and produce an electrical conductivity which is then measured. Conducting polymers differ from the metal oxide sensor in that they are sensitive to a wide variety of organic vapours, however the actual level of sensitivity is approximately one order of magnitude less than the MOS. In addition, the devices are small with low power consumption and can operate at room temperature. The response to an odor is also rapid (2 to 20 sec) and due to the reversibility of the reaction mechanism, the recovery is rapid when the vapour is removed. In this thesis the conducting polymer sensors are mostly used in experimental validations.

There are two types of conductivity sensors: metal oxide and polymer, both of which exhibit a change in resistance when exposed to volatile organic compounds [Fig. 2.7]. Of the two types, metal oxide semiconductors have been used more extensively in electronic nose instruments and are widely available commercially. Typical offerings include oxides of tin, zinc, titanium, tungsten, and iridium, doped with a noble metal catalyst such as platinum or palladium.
In conductivity sensor the usual active material is metal oxide or a conducting polymer. The electrodes may be platinum, aluminum, or gold, while the substrate may be of silicon, glass, or plastic. The heater, used only for metal oxide, is normally a platinum metal trace or wire. The interaction with VOCs alters the conductivity of the active material. The change in resistance across the electrode pair is then measured with a Wheatstone bridge or other circuitry. The doped semiconducting material with which the VOCs interact is deposited between two metal contacts over a resistive heating element, which operates at 200 °C to 400 °C. At these elevated temperatures, heat dissipation becomes a factor in the mechanical design of the sensing chamber. Micromachining is often used to thin the sensor substrate under the active material, so that power consumption and heat dissipation requirements are reduced. As a VOC passes over the doped oxide material, the resistance between the two metal contacts changes in proportion to the concentration of the VOC.
The recipe for the active sensor material is designed to enhance the response to specific odorants, such as carbon monoxide or ammonia. Selectivity can be further improved by altering the operating temperature. Sensor sensitivity ranges from 5 to 500 parts per million. The sensors also respond to water vapor, more specifically, to humidity differences between the gas sample being analyzed and a known reference gas used to initialize the sensor. The baseline response of metal oxide sensors is prone to drift over periods of hours to days, so signal-processing algorithms should be employed to counteract this property. The sensors are also susceptible to poisoning (irreversible binding) by sulfur compounds present in the odorant mixture. But their wide availability and relatively low cost make them the most widely used gas sensors today.

Conducting polymer sensors, a second type of conductivity sensor, are also commonly used in electronic nose systems. Here, the active material in Fig. 2.7 is a conducting polymer from such families as the polypyrroles, thiophenes, indoles, or furans. Changes in the conductivity of these materials occur as they are exposed to various types of chemicals, which bond with the polymer backbone. The bonding may be ionic or, in some cases, covalent. The interaction affects the transfer of electrons along the polymer chain, that is to say, its conductivity. A given compound's affinity for a polymer and its effects on the polymer's conductivity are strongly influenced by the counter-ions and functional groups attached to the polymer backbone.

In order to use these polymers in a sensor device, microfabrication techniques are employed to form two electrodes separated by a gap of 10 to 20 μm. Then the conducting polymer is electro polymerized between the electrodes by cycling the voltage between them. For example,
layers of poly pyrroles can be formed by cycling between -0.7 and +1.4 V. Varying the voltage sweep rate and applying a series of polymer precursors yields a wide variety of active materials. Response time is inversely proportional to the polymer's thickness.

To speed response times, micrometer-size conducting-polymer bridges are formed between the contact electrodes. Because conducting polymer sensors operate at ambient temperature, they do not need heaters and thus are easier to make. The electronic interface is straightforward, and they are suitable for portable instruments. The sensors can detect odors at sensitivities of 0.1 parts per million (ppm), but 10 to 100 ppm is more usual. The main drawback of existing conducting-polymer sensors is that it is difficult and time consuming to electro polymerize the active material, so they exhibit undesirable variations from one batch to another. Their responses also drift over time, and their usually greater sensitivity than metal oxides to water vapor renders them susceptible to humidity. This susceptibility can mask the responses to odorous volatile organic compounds. In addition, some odorants can penetrate the polymer bulk, dragging out the sensor recovery time by slowing the removal of the VOC from the polymer. This extends the cycle time for sequentially processing odorant samples.

### 2.5.4 Optical and spectroscopic sensors

Previously, sensors have also been developed which utilize optical fibers [52] with a thin chemically active material coating, either on their sides or ends, comprising a fluorescent dye immobilized in different organic polymers. A light source, at a single frequency is used to interrogate the active material, which in turn responds to the presence of the vapour to be detected with a change in wavelength. Such sensors give a fast response and
can be miniaturized. However, their lifetime is presently limited by photo-bleaching of the fluorescent dye. Optical measurement also requires the use of relatively sophisticated instruments, including lasers, photo-multiple-tubes, and filters, although these are becoming cheaper.

Other approaches based on impedance spectroscopy [53], surface Plasmon resonance [54], and ellipsometry [55] have also been developed for organic vapour detection. However, like optical measurement system, these methods need the use of specialized instrumentation (which is both expensive and difficult to miniaturize), and these are largely considered as "research" devices at present.

2.6 Commercially Available E-Nose Systems

There are a number of electronic nose systems available in the market (Table 2.2) [65]. This utilizes a range of sensor technologies either alone or in combination. The sensors are however one of the part of an electronic nose system. Also critical are the sampling system that takes the odor from the sample and transports it to the sensor array, the data processing and pattern recognition system that identifies the odor from the sensor output.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Company name</th>
<th>Sensor technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Airsense Analysen technique</td>
<td>10 MOS Sensors</td>
</tr>
<tr>
<td>2.</td>
<td>Alpha M.O.S</td>
<td>2x6 MOS sensors, 6 conducting polymer sensors, 6SAW sensors</td>
</tr>
<tr>
<td>3.</td>
<td>Aroma Scan</td>
<td>32 conducting polymer sensors</td>
</tr>
<tr>
<td></td>
<td>Company</td>
<td>Technology and Description</td>
</tr>
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<td>--------------------------------</td>
<td>-----------------------------------------------------------------</td>
</tr>
<tr>
<td>4.</td>
<td>Bloodhound</td>
<td>14 conducting polymer sensors</td>
</tr>
<tr>
<td>5.</td>
<td>Cyrano Sciences</td>
<td>Carbon black/polymer composite sensors</td>
</tr>
<tr>
<td>6.</td>
<td>EEV (formally Neotronics)</td>
<td>12 Conducting polymers</td>
</tr>
<tr>
<td>7.</td>
<td>Hewlett Packard</td>
<td>Mass spectrometer based</td>
</tr>
<tr>
<td>8.</td>
<td>HKR Sensorsysteme</td>
<td>6 Quartz microbalances, (mass spectrometer module under development)</td>
</tr>
<tr>
<td>9.</td>
<td>Lennartz Electronic</td>
<td>8 Quartz microbalances, 8 MOS, (calorimetric &amp; electrochemical modules under development)</td>
</tr>
<tr>
<td>10.</td>
<td>Nordic Sensor Technologies</td>
<td>2×5 Chem FET sensors, 5 MOS sensors, optional IR and 6 quartz microbalance sensors</td>
</tr>
<tr>
<td>11.</td>
<td>RST Rostock (Daimler-Benz Aerospace)</td>
<td>6 Quartz crystal microbalances, optional SAW and MOS modules</td>
</tr>
<tr>
<td>12.</td>
<td>Smart Nose</td>
<td>Mass spectrometer based</td>
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</tbody>
</table>

### 2.7 Electronic-Nose Applications

Electronic-nose systems have been designed specifically to be used for numerous applications in many different industrial production processes. A wide variety of industries based on specific product types and categories, such as the automobile, food, packaging, cosmetic, drug, analytical chemistry and biomedical industries utilize e-noses for a broad and diverse range of applications including quality control of raw and manufactured products, process design, freshness and maturity (ripeness)
monitoring, shelf-life investigations, authenticity assessments of premium products, classification of scents and perfumes, microbial pathogen detection and environmental assessment studies. In (Table 2.3) some individual examples of electronic nose applications in each of these individual industries and product areas are discussed in more detail in the following sections.

**Table 2.3 Industry Based Applications of Electronic Nose**

<table>
<thead>
<tr>
<th>Industry sector</th>
<th>Application area</th>
<th>Specific use types and examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>1. Crop protection</td>
<td>Homeland security, safe food supply</td>
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<td></td>
<td>2. Harvest timing &amp; storage</td>
<td>Crop ripeness, preservation treatments</td>
</tr>
<tr>
<td></td>
<td>3. Meat, seafood, &amp; fish products</td>
<td>Freshness, contamination, spoilage</td>
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<tr>
<td></td>
<td>4. Plant production</td>
<td>Cultivar selection, variety characteristics</td>
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<tr>
<td></td>
<td>5. Pre- &amp; post-harvest diseases</td>
<td>Plant disease diagnoses, pest identification</td>
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<tr>
<td></td>
<td></td>
<td>detect non-indigenous pests of food crops</td>
</tr>
<tr>
<td>Airline Transportation</td>
<td>1. Public safety &amp; welfare</td>
<td>Explosive &amp; flammable materials detection</td>
</tr>
<tr>
<td></td>
<td>2. Passenger &amp; personnel security</td>
<td></td>
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<tr>
<td>Food &amp; Beverage</td>
<td>1. Consumer fraud prevention</td>
<td>Ingredient confirmation, content standards</td>
</tr>
<tr>
<td></td>
<td>2. Quality control assessments</td>
<td>Brand recognition, product consistency</td>
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<tr>
<td></td>
<td>3. Ripeness, food</td>
<td>Marketable condition, spoilage,</td>
</tr>
<tr>
<td>Medical &amp; clinical</td>
<td>1. Pathogen identification</td>
<td>Patient treatment selection, prognoses</td>
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<tr>
<td></td>
<td>2. Pathogen or disease detection</td>
<td>Disease diagnoses, metabolic disorders</td>
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<tr>
<td></td>
<td>3. Physiological conditions</td>
<td>Nutritional status, organ failures</td>
</tr>
<tr>
<td>Military</td>
<td>1. Personnel &amp; population security</td>
<td>Biological &amp; chemical weapons</td>
</tr>
<tr>
<td></td>
<td>2. Civilian &amp; military</td>
<td>Safety explosive materials detection</td>
</tr>
<tr>
<td>Pharmaceutical</td>
<td>1. Contamination, product purity</td>
<td>Quality control of drug purity</td>
</tr>
<tr>
<td></td>
<td>2. Variations in product mixtures</td>
<td>Formulation consistency &amp; uniformity</td>
</tr>
<tr>
<td>Environmental</td>
<td>1. Air &amp; water quality monitoring</td>
<td>Pollution detection, effluents, toxic spills</td>
</tr>
<tr>
<td></td>
<td>2. Indoor air quality control</td>
<td>Malodor emissions, toxic/hazardous gases</td>
</tr>
<tr>
<td></td>
<td>3. Pollution abatement regulations</td>
<td>Control of point-source pollution releases</td>
</tr>
</tbody>
</table>

### 2.7.1 BEVERAGES

*For tea,* usually analyzed using a GC and sensory panel, an e-nose (a Shimadzu FF-2A Fragrance & Flavor Analyzer) was used to identify coumarin-enriched Japanese green tea using PCA and cluster analysis (CA) [56].
Coffee quality is in practice evaluated by expert tasters (“cup tests”), or by GC-MS looking for aliphatic hydrocarbons derived from oxidation of green bean lipids during storage or transport prior to roasting.

2.7.2 Cooking Oils

An e-nose with six metal oxide sensors (Italian EOS 507, Sacmi Imola, SC), was used to classify virgin olive oils with and without phenolic compounds for oxidative status [57] and correlated well to sensory analysis. Two types of e-nose (Alpha MOS and SPME-MS), along with PCA and PLS analyses, were also able to detect adulteration of extra virgin olive oil with rapeseed and sunflower oils.

2.7.3 Eggs and Dairy Products

An e-nose could distinguish eggs stored for different amounts of time and at room temperature storage [58] using PCA and LDA analyses combined with neural network. An ion-mobility based e-nose (MGD-1) was used to determine separation of hard and extra-hard cheese samples as well as discrimination of cheeses based on age (ripening time) or origin [59].

For meat, the e-nose has been used to detect bacterial spoilage during the aging process using biosensors that included a silver or platinum electrode on which the enzymes putrescine or xanthine oxidases were immobilized [60].

For fish, freshness was determined by measuring the relevant volatile compounds consisting of alcohols, carbonyls, amines and mercaptanes which showed typical concentration changes over time under specific storage conditions [61] using ampere metric sensors, a heated catalyst.
and multivariate statistics (PCA and principal components regression or PCR).

*For mangoes,* classification and differentiation has been achieved with e-nose technology. A French Alpha MOS e-nose was used to classify mango homogenate as well as whole fruit headspace for variety differences, harvest maturity, fruit size and ripening stage [62].

*For dates,* an Alpha MOS e-nose was used to distinguish between varieties using PCA, and gave distinct fingerprints for each variety that could be used following changes in maturity and identify lots of dates as well as adulteration [62]. The e-nose showed excellent sensitivity and reproducibility, which was necessary since the date volatile profile is weak.

*For pineapple,* fresh cut pineapple was followed using a portable German PEN2 e-nose with MOS sensors during storage at three different temperatures using a continuous (automatic sampling of headspace air flow) and discontinuous (headspace samples taken at various times throughout storage) approach [63].

### 2.7.4 Medical Pathology

Current medicine faces the difficulty and challenge of achieving successful disease diagnoses throughout early detections of pathogenesis or illness conditions in order to make possible the application of fast treatments, but at the similar time dramatically reducing the invasiveness of diagnostic treatments. Chemical study of human biological samples, such as blood, urine, breathing, sweat and skin, are the mainly common way of diagnosing most pathological situation. *Glycyrrhiza glabra* (liquorice) is an aromatic plant belonging to the pea and bean family and it is cultivated for its
subversive stems that are used to flavour confectionery it is also valued for its medicinal qualities.

Glycyrrhiza glabra is best known for its use in making liquorice-flavoured confectionery. Its scientific name is taken from the Greek for sweet root (glycyrr, meaning sweet, and rhiza, meaning root). It is cultivated for its rhizomes (underground stems) that contain the compound glycyrrhizin, which is 50 times sweeter than sugar. Also well-known as a medicinal plant, G. glabra is used in the production of cough mixtures and throat lozenges, as well as an ingredient to mask the unpleasant taste of some medicines.

The aforementioned summaries of commercial applications, developed for electronic-nose devises within the past twenty years, have only covered some of the more interesting, compelling and perhaps most beneficial uses of e-noses under current operation today. The intent of this paper was by no means aimed at providing a comprehensive review of all known e-nose applications that have been developed. Such an effort would require a much more extensive treatise far beyond the scope of this current summary. Obviously, many other applications of electronic noses exist that were omitted from being mentioned here. Nevertheless, a brief mention of on-going and future developments of electronic-nose technologies is warranted here in order to provide a greater appreciation of the span of research projects and operational programs that are involving routine uses and further improvements in e-nose applications.
2.8 Literature Review

“Julian W. Gardner et al. (2000) have confirmed in this paper that electronic noses are capable to recognize unknown bacteria in laboratory conditions. This offers the prospect of using electronic noses for lab-based, in-vitro diagnostics. The thought being that an electronic nose could be used for the fast screening of biological samples. For instance, the electronic nose may be capable to forecast a type of pathogen faster, than existing half-manual methods and thus allow a more suitable course of treatment. In this early stage of electronic nose technology, it will be essential to validate its predictions with existing, well tested methods. However, should the lab based electronic nose technology confirm consistent, then there is the extremely attractive choice of moving the technology near-patient.”

“Amnat Reungchaiwat et al. (2007) in this paper the author has talk about a device for the recognition and determination of ethanol and acetone was made, consisting of a packed column, a compartment with a sensor top, 2 dc power supplies, a multimeter and a computer. A commercially accessible TGS 822 detector top (Figaro Company Limited) was used as the sensor top. The TGS 822 detector comprise of a Silicon dioxide wide film deposited on the facade of an alumina clay tube which have a heating component within itself. An analytical column was attached with the system to improve the taking apart of ethanol and acetone before they reached the sensor head. Best possible system conditions for recognition of ethanol and acetone were achieved by changeable the flow rate of the carrier gas, voltage of the circuit sensor (VC), voltage of the heating coil (VH), load resistance of the circuit sensor (RL) and the injector port temperature. The stream of the hauler gas was 15 mL/min; the circuit situation were VH = 5.5 V, VC = 20 V, RL = 68 kΩ and the injection port temperature was 150°C. In
these conditions the preservation times \( (t_R) \) for ethanol and acetone were 1.95 and 0.57 minutes, respectively. Calibration graphs were found for ethanol and acetone above the concentration series of 10 to 160 mg/L. The restrictions of detection (LOD) for ethanol and acetone were 9.25 mg/L and 4.41 mg/L respectively.”

“Chandaran, U.D. et al. (2010) they describe about sulfate reducing bacteria (SRB) that is a nonpathogenic and anaerobic bacterium which can produce enzyme to accelerate the reduction of sulfate compounds to hydrogen sulphate that corrodes metal. This paper will study the possibility of using electronic nose which consists of chemical sensing system, data acquisition system and pattern recognition system such as artificial neural network to detect hydrogen sulphide. There are a few methods of detecting SRB such as laboratory analysis and field test kit but the procedures are costly and take longer time, within 1 to 2 days. Study shows that electronic nose can be used to detect SRB by detecting hydrogen sulphide that is produced during reduction process. The electronic nose can detect hydrogen sulphide within 16 hours where the detection period is reduced from 30% to 65%. Study also shows that the electronic nose with micro hotplate sensor base will reduce 86% of power consumption compared to electronic nose with alumina ceramic sensor base.”

“Dongmin Guo. et al. (2010) discuss certain gases in the breath are known to be indicators of the presence of diseases and clinical conditions. These gases have been identified as biomarkers using equipments, such as gas chromatography and electronic nose (e-nose). GC is very accurate but is expensive, time consuming, and non portable. E-nose has the advantages of low cost and easy operation, but is not particular for analyzing breath odor, and hence, has a limited application in diseases diagnosis. This paper
proposes a novel system that is special for breath analysis. They selected chemical sensors that are sensitive to the biomarkers and compositions in human breath, developed the system, and introduced the odor signal preprocessing and classification method. To evaluate the system performance, they captured breath samples from healthy persons and patients known to be afflicted with diabetes, renal disease, and airway inflammation, respectively, and conducted experiments on medical treatment evaluation and disease identification. The results show that the system is not only able to distinguish between breath samples from subjects suffering from various diseases or conditions (diabetes, renal disease, and airway inflammation) and breath samples from healthy subjects, but in the case of renal failure is also helpful in evaluating the efficacy of hemodialysis (treatment for renal failure).”

“Trincavelli, M. et al. (2010) they introduce a method for classification of bacteria in human blood culture samples using an electronic nose. The method uses features, which capture the static (steady state) and dynamic (transient) properties of the signal from the gas sensor array and proposes a means to ensemble results from consecutive samples. The underlying mechanism for ensembling is based on an estimation of posterior probability, which is extracted from a support vector machine classifier. A large dataset representing ten different bacteria cultures has been used to validate the presented methods. The results detail the performance of the proposed algorithm and show that through ensembling decisions on consecutive samples, significant reliability in classification accuracy can be achieved.”

“Lorwongtragool, P. et al. (2010) discuss about an efficient air quality management in live stocks, a standardized measurement technology
has always been requested in order to assess the odor, of which results are acceptable by every party involved, i.e., the owner, the state and the public. This paper has reported on a prototype of portable electronic nose (e-nose) designed specially to assess malodors in swine buildings atmosphere in the pig farm. The briefcase formed e-nose consists of eight chemical gas sensors that are sensitive to gases usually presented in pig farm such as ammonia, hydrogen sulfide, hydrocarbons etc. The system contains gas flow controller, measurement circuit and data acquisition unit, all of which are automated and controlled by an in-house software on a notebook PC via a USB port. We have tested the functionality of this e-nose in a pig farm under a real project aimed specifically to reduce the odor emission from swine buildings in the pig farm. The e-nose was used to assess the air quality inside sampled swine buildings. Based on the results given in this paper, recommendations on appropriate feeding menu, buildings' cleaning schedule and emission control program have been made.”

“Patel, H.K. et al. (2011) discuss the generalized response of electronic nose sensors to odorant and reviews the range of sensors used in electronic nose (e-nose) systems. The response of the sensor is analyzed as first order time response. This paper outlines the operating principles and important features of each sensor type as well as the applications in which the different sensors have been utilized. It also outlines the advantages and disadvantages of each sensor for application in a cost-effective e-nose system.”

“Kladsomboon, S et al. (2011) discuss an optical electronic nose (olfactory sensing) technologies have recently become a convenient technique to identify the quality of food and beverage products based on the odor classification. In this paper, we reported an optical-based electronic nose
system consisting of thin-film sensing materials, array of light emitting diode (LED), photo-detector and pattern recognition program. The organic mixtures thin film gas sensor was prepared by spin coating of Zinc-2,9,16,23- tetra-tert-butyl 29H, 31H-phthalocyanine (ZnTTBPc), Zinc-5,10,15,20-tetra-phenyl-21H,23H-porphyrin (ZnTPP) and manganese(III) 5, 10, 15, 20-tetraphenyl-21H,23H-porphyrin chloride (MnTPPCI) onto a clean glass substrate. The electronic nose system was developed by using the low-cost LED array as a light source. Then the light intensity that is transmitted through the organic thin film during the experiment was detected by the color light to frequency converter device (photo-detector). The ability of this system was tested by using volatile organic compound (VOCs) vapors such as methanol, ethanol, and isopropanol. Principal component analysis (PCA) has been used as the pattern recognition for this electronic nose system. The result confirms that the sensing layer that composed of the three types of organic compounds described the groups of chemical vapors by using the array of LED.”

“Dymerski, T. et al. (2011) they examines gas sensor array technology combined with multivariate data processing methods and demonstrates a promising potential for rapid, non-destructive analysis of food. Main attention is focused on detailed description of sensor used in e-nose instruments, construction, and principle of operation of these systems. Moreover, this paper briefly reviews the progress in the field of artificial olfaction and future trends in electronic nose technology, namely, e-nose based on mass spectrometry. Further discussion concerns a comparison of artificial nose with gas chromatography-olfactometry and the application of e-nose instruments in different areas of food industry.”

“Green, G.C. et al. (2011) describe about the use of continuous odor monitoring in a smart home represents a novel sensor modality with the
potential to recognize various activities of daily living and identify unsafe conditions for the occupant. In this paper, they focus on food spoilage as one such condition. Using a metal-oxide sensor (MOS) based electronic nose, they measured the odor signatures of two common foods (milk and yogurt) that were stored at 25°C during a week-long period. Feature vectors were constructed using the maximum absolute sensor responses, and their components exhibited a smooth trajectory as the samples aged. Applying principal component analysis (PCA) revealed that the two substances followed distinct trajectories during spoilage. They conclude that an electronic nose can be used to track the spoilage of various foods in a manner that is (a) repeatable for a specific food and (b) unique for different foods. Additionally, they found that the sampling protocol used in this work resulted in better repeatability than our previous work in this area. This result demonstrates the potential of using an electronic nose for smart home monitoring.”

“Dutta, A. et al. (2011) discuss the process of evaluating the quality of black tea by human sensory panel known as “Tea Tasters” is very subjective and its accuracy is questionable. As a result various instrumental setups have been investigated in the past for quality determination of black tea. The electronic nose is one such instrument, consisting of sensor arrays, odor detection and data acquisition system. Many clustering algorithms are available that can be used to differentiate between tea with various scores as given by the “Tea Tasters”, the data for which is obtained by an electronic nose. Recently, a heuristic algorithm called the Artificial Bee Colony (ABC) has been devised by Karaboga mainly for solving optimization problems but which has also been applied for data clustering. In this paper, the algorithm devised by Karaboga has been used on the data obtained by an electronic nose.
to distinguish among the various scores of black tea. Also the results obtained by ABC have been compared with the well known Fuzzy C-Means (FCM) algorithm. The paper is concluded by some observations made by the authors.”

“Xiaodong Wang et al. (2011) discuss about the gas sensor array that is an important part of electronic nose. The recognition ability of electronic nose is affected by the cross sensitivity of gas sensor array. They propose a pattern recognition method for electronic nose by combined use of kernel independent component analysis (KICA) and least squares support vector machine (LS-SVM) in this paper. In the proposed method, the KICA algorithm based on an entire function space of nonlinear subspace is firstly used for preprocessing gas sensor data in order to reduce the data correlation, and then a LS-SVM carries out the gas recognition. The measuring data was obtained from a gas of butane and ethanol for experiments. The results indicate that the proposed technique is effective in gas quantitative analysis, and gets higher precision than traditional techniques.”

“Nagel, D et al. (2011) they describe about using Electronic scanning (E-scan) radars it is possible to employ multichannel processing algorithms such as STAP to suppress clutter. A further significant advantage of E-Scan radars is the rapid look-back capability for simultaneous Search and Track operation. A great deal of experience and know-how on radar mode scheduling exists for Mechanical scanning (M-scan) radars. This should be used in combination with the new range of capabilities for E-scan radars. For both Air-to-Air and Air-to-Ground operation, E-scan radar multichannel processing can greatly improve present mode performance. Currently, for Air-to-Air operational modes, HPRF waveforms are used to detect targets in nose-on aspect. Tangential or rear aspect targets often disappear in the main lobe or
side lobe clutter echoes. In these circumstances, airborne radars usually switch to MPRF modes to exploit the all-aspect capability of these modes. However, one disadvantage of MPRF modes is their reduced detection range as well as the requirement for a guard antenna. For E-scan radars it is also possible to use STAP processing algorithms for clutter suppression. For Air-to-Ground operational modes, LPRF waveforms can detect ground targets with velocities in antenna bore sight direction exceeding a minimum detectable velocity that depends on the clutter Doppler extension. Using E-scan radars, the antenna beam width is dependent on the beam look direction. For off-bore sight angles, this has the effect that the Doppler width of the main lobe clutter is wider compared to that for M-scan radars. In this case too, STAP processing with E-scan radars can help to suppress clutter and to detect ground targets below the minimum detectable velocity given by conventional processing. The purpose of this paper is to highlight the possibility of detecting both Air-to-Air and Air-to-Ground targets with the most suitable waveform. For example, for closing Air-to-Air targets, the use of HPRF waveforms provides the greatest detection range and obviates the need for a guard antenna, while the use of STAP with multi channel processing provides better performance when the air target is in tangential or rear aspect. First, when an E-scan instead of a M-Scan radar is used, the differences in clutter returns for HPRF waveforms are highlighted. Then, depending on targets velocity and aspect angle, conditions are defined for which the radar can use a HPRF or MPRF waveform or for when STAP processing is necessary so as not to lose the target.”

“Wongchoosuk, C. et al. (2011) they describe about homeland security basically needs devices that can detect, track, and identify a terrorist from a distance. Body odor recognition offers an opportunity to confirm a
person's identity based on one's unique odor pattern. In this paper, we have reported how to invent a networked electronic nose (E-nose), which can detect and recognize human odors from the armpit region. An array of metal oxide sensors was used to detect human odor. Principal component analysis (PCA) was employed to perform pattern recognition and discrimination. The method for correction of the sensor drift has been proposed. The results show that the networked E-nose has a capability to detect human body odor and can create the unique smell print of each person. Based on PCA with 95% confidence ellipse, this E-nose can identify a person from four persons by detecting odor from armpit region.”

“Jana, A. et al. (2011) discuss classification of rice is carried out by human experts in the industry and apart from other attributes like grain size, elongation ratio, aroma plays a significant role in the classification process. On the basis of aroma, the rice samples are manually categorized as strongly aromatic, moderately aromatic, slightly aromatic and non aromatic. Instrumental evaluation of aroma of rice is much needed in the industry and in this paper, they describe an electronic nose instrument, that has been developed for aroma characterization of rice. Artificial neural network is used for the pattern classification on data obtained from the sensor array of the electronic nose. With unknown rice samples, aroma based classification accuracy has been observed to be more than 80%.

“Qingmei Chen. et al. (2011) discuss olfaction guides many significant behaviors for creatures so that study on olfactory transduction mechanism is being attended. In the present paper, they present a novel bio electronic nose with microelectrode array, whose sensing element is the in vitro olfactory sensory neural networks by culture. Using this electronic nose, they observed the spontaneous signals of OSNs as well as the induced
response to Acetic acid. Under the action of Acetic acid, the firing rate of neurons increased distinctively. Moreover, at different site of OSNs networks, OSNs appeared different firing pattern. The bio electronic nose based on OSNs with MEA provided multi scale olfactory information and show electrophysiological characteristics at different position, which is favorable for further modeling the olfactory neuronal networks.”

“Bag, A.K. et al. (2011) describe about the electronic nose that is the most important component is the sensor array and the classification accuracy of an electronic nose that depends significantly upon the choice of the sensors in the array. While deploying an electronic nose for a specific application, it is observed that some of the sensors in the array may not be required and only a subset of the sensor array contributes to the decision. Thus, the number of sensors used in the electronic nose may be minimized for a particular application without affecting the classification accuracy. In many cases, the sensor array produces an imprecise, incomplete, redundant, and inconsistent dataset and thus the classification accuracy degrades due to these redundant sensors. The rough set theory is a mathematical tool capable of selecting the most relevant and non redundant feature from such datasets. In this paper, the notion of rough set theory is utilized for pattern classification in an electronic nose with black tea samples and at the same time optimization of the sensor set is carried out.”

“Lorwongtragool, P. et al. (2011) they describe about a portable electronic nose (e-nose) was appropriately designed for investigating quality of beverages such as juice or wine, etc. The e-nose system comprises of sample and reference containers, air flow unit, sensing unit and data acquisition unit. All of the hardware units were controlled by in-house software under LABVIEW program via USB port of a DAQ card. The
sensing unit includes eight different metal oxide gas sensors from Figaro Engineering Inc. Principal component analysis (PCA) was used as a statistical method in order to discriminate and assess the experimental data as defined by the percentage change in sensor resistances that correlates directly to difference in the aroma characteristics. Drift compensation model was applied to the raw data that sometimes suffer from the effects of sensor drift. Constructed portable e-nose has been tested on-field in a winery to evaluate wine aroma during process of wine bottling. The e-nose using PCA algorithm can distinguish the wine bottling under nitrogen from the bottling under partial vacuum. We also demonstrated that e-nose can be used to help wine maker to design the appropriate process of wine bottling achieving a high quality of wine product.”

“Lessard, M-C et al. (2012) discuss the use of e-nose for sensing smell of the insulation paper used in transformer to determine its quality. The ultimate life of a transformer primarily depends on the insulation of its active part, i.e., mainly the oil and paper complex. At present, the tools used to directly determine the state of solid insulation require transformers to be detanked in order to take paper samples for laboratory analysis. Indirect methods (oil analysis) require a complex separation system and need accurate calibration of a detector.”

“Chutia, R et al. (2012) they describe an online dimension reduction of feature vector of metal oxide semiconductor (MOS) based electronic nose, operated in static temperature measurement for identification of gas. The sample space of gas consists of eight chemicals. They have used twelve number of MOS gas sensors, manufactured by Figaro sensors, Japan. The responses of the sensors to the volatile organic compounds (VOC’s) at different concentration of the VOC’s were acquired. The pattern of response
of MOS sensors was normalized to produce a consistent pattern independent of concentration. The native dimension reduction technique, principal component analysis (PCA) is being used for dimension reduction. The reduced feature vector is used as features for the pattern classifier based on neural network. Result clearly indicates that the VOC's can be distinguished using the reduced feature set.”

“**Abdullah, A.H et al. (2012)** they discuss about electronic nose (e-nose) as an intelligent instrument that is able to classify different types of odours. The e-nose applications include food quality assurance, fragrance industry, medical diagnosis, environmental monitoring, agricultural industry and homeland security. The current e-nose design trend are portable, small size, low power consumption, high processing power using embedded controller and easy to operate to enable it to perform the designed tasks effectively. This paper deals with the design issues of a hand-held e-nose based on sensor selection and optimum embedded controller capabilities. A summary of proposed hardware and software solutions are provided with emphasis on data processing. The data processing utilizes multivariate statistical analysis i.e. Principal Component Analysis (PCA), Hierarchical Cluster Analysis (HCA) and Linear Discriminate Analysis (LDA). The developed instrument was tested to discriminate the Ganoderma boninense fruiting body (basidio carp). Initial results show that the instrument is able to discriminate the samples based on their odor chemical fingerprint profile.”

“**Wongchoosuk, Chatchawal et al. (2012)** discuss several indoor chemical contaminants such as CO and NO\textsubscript{2} are highly toxic. Inhalation of CO or NO\textsubscript{2} as low as ppm level may cause respiratory distress or failure. Therefore, detection of indoor air is very important in the industrial, medical, and environmental applications. In this paper, a new electronic nose
(E-nose) architecture has been proposed for the real-time quantification and qualification of indoor air contaminations. The metal oxide TGS gas sensors were used as the sensing part. The principal component analysis (PCA) method and a set of mathematical model were employed in data analysis. By combining with the proposed mathematical model, this E-nose can estimate the amount of CO gas contaminations in air at ppm levels. Moreover, the PCA results can clearly show a classification between two different rooms.”

“Hung-Yi Hsieh et al. (2012) they discuss a low-power, neuromorphic spiking neural network (SNN) chip that can be integrated in an electronic nose system to classify odor. The proposed SNN takes advantage of sub-threshold oscillation and onset-latency representation to reduce power consumption and chip area, providing a more distinct output for each odor input. The synaptic weights between the mitral and cortical cells are modified according to an spike-timing-dependent plasticity learning rule. During the experiment, the odor data are sampled by a commercial electronic nose (Cyranose 320) and are normalized before training and testing to ensure that the classification result is only caused by learning. Measurement results show that the circuit only consumed an average power of approximately $3.6 \mu W$ with a 1-V power supply to discriminate odor data. The SNN has either a high or low output response for a given input odor, making it easy to determine whether the circuit has made the correct decision. The measurement result of the SNN chip and some well-known algorithms (support vector machine and the K-nearest neighbor program) is compared to demonstrate the classification performance of the proposed SNN chip. The mean testing accuracy is 87.59% for the data used.”

“Petrescu, V. et al. (2012) discuss a hybrid combination of piezoelectric MEMS resonators and CMOS oscillator readout circuit forms
the necessary ingredients of a new generation of electronic nose (e-nose) devices that, owing to their form factor and power consumption, enable a range of novel applications. This paper presents a hybrid low-power, high-resolution e nose system, including the necessary digital interface. An integrated readout was designed for the tracking of resonant frequency shift due to a change in the VOC environment concentration. It interfaces a piezo-actuated functionalized doubly clamped beam resonator that combines low actuation power (μW), high VOC sensitivity but low quality factor in air, large parasitic capacitance and multiple resonance modes. The sensor characteristics translate into a challenging readout design, as high gain-bandwidth product versus low power and low noise are required for optimal detection resolution.”

“Bagchi, P. et al. (2012) discuss about the application of smoothing of 3D face images followed by feature detection i.e. detecting the nose tip. The present method uses a weighted mesh median filtering technique for smoothing. In this present smoothing technique they have built the neighborhood surrounding a particular point in 3D face and replaced that with the weighted value of the surrounding points in 3D face image. After applying the smoothing technique to the 3D face images there experimental results show that they have obtained considerable improvement as compared to the algorithm without smoothing. They have used here the maximum intensity algorithm for detecting the nose-tip and this method correctly detects the nose-tip in case of any pose i.e. along X, Y, and Z axes. The present technique worked successfully on 535 out of 542 3D face images as compared to the method without smoothing which worked only on 521 3D face images out of 542 face images. Thus they have obtained a 98.70% performance rate over
96.12% performance rate of the algorithm without smoothing. All the experiments have been performed on the FRAV3D database.”

“**Harun, F.K.C. et al. (2012)** they study the report on the development of a new type of electronic nose (e-nose) instrument, which the authors refer to as the Portable electronic Mucosa (PeM) as a continuation of previous research. It is designed to mimic the human nose by taking significant biological features and replicating them electronically. The term electronic mucosa or simply e-mucosa was used because our e-nose emulates the nasal chromatographic effect discovered in the olfactory epithelium, located within the upper turbinate. The e-mucosa generates spatio-temporal information that the authors believe could lead to improved odor discrimination. The PeM comprises three large sensor arrays each containing a total of 576 sensors, with 24 different coatings, to increase the odor selectivity. The nasal chromatographic effect provides temporal information in the human olfactory system, and is mimicked here using two-coated retentive channels. These channels are coated with polar and non-polar compounds to enhance the selectivity of the instrument. Thus, for an unknown sample, the authors have both the spatial information (as with a traditional e-nose) and the temporal information. The authors believe that this PeM may offer a way forward in developing a new range of low-cost e-noses with superior odor specificity.”

“**Kumbhar, Amit et al. (2012)** they describe details development of a low cost, small size, portable embedded electronic nose (e-nose). The odor Sensor array is composed of commercially available metal oxide semiconductor sensors by Figaro. The embedded E-nose consists of PIC18F4520 and has an RS 232 interface to Desktop PC for data acquisition,
storage and analysis of the odor signals. The developed system is used to analyze odors of onions and oranges."

“Chutia, R et al. (2012) they describe an online dimension reduction of feature vector of metal oxide semiconductor (MOS) based electronic nose, operated in static temperature measurement for identification of gas. The sample space of gas consists of eight chemicals. They have used twelve number of MOS gas sensors, manufactured by Figaro sensors, Japan. The response of the sensors to the volatile organic compounds (VOC's) at different concentration of the VOC's was acquired. The pattern of response of MOS sensors was normalized to produce a consistent pattern independent of concentration. The native dimension reduction technique, principal component analysis (PCA) is being used for dimension reduction. The reduced feature vector is used as features for the pattern classifier based on neural network. Result clearly indicates that the VOC's can be distinguished using the reduced feature set.”

“Najib, M.S et al. (2012) describe an array of sensors (E-nose) to classify agar wood has proven to be successful and produced performance close to an expert level (90% of expert level performance) but it has proven difficult to eliminate misclassifications without over-fitting. In our effort to improve our result we explored a self-improving Case-Based Reasoning approach and reached 100% correct classification. Case-Based Reasoning is an approach that will learn from every new classified case and hence the risk for misclassification is reduced. Also when new cases have to be classified that have never occurred before the system will avoid misclassification (similarity measurement is low). The approach also enables indeterminism in reality a sample may be both close to a good case and a bad case and need
further exploration by experts. The approach also handles natural variants in the wood samples well both low-quality and high-quality samples may spread considerably in the context of E-nose readings and there is no model available of low or high quality.”