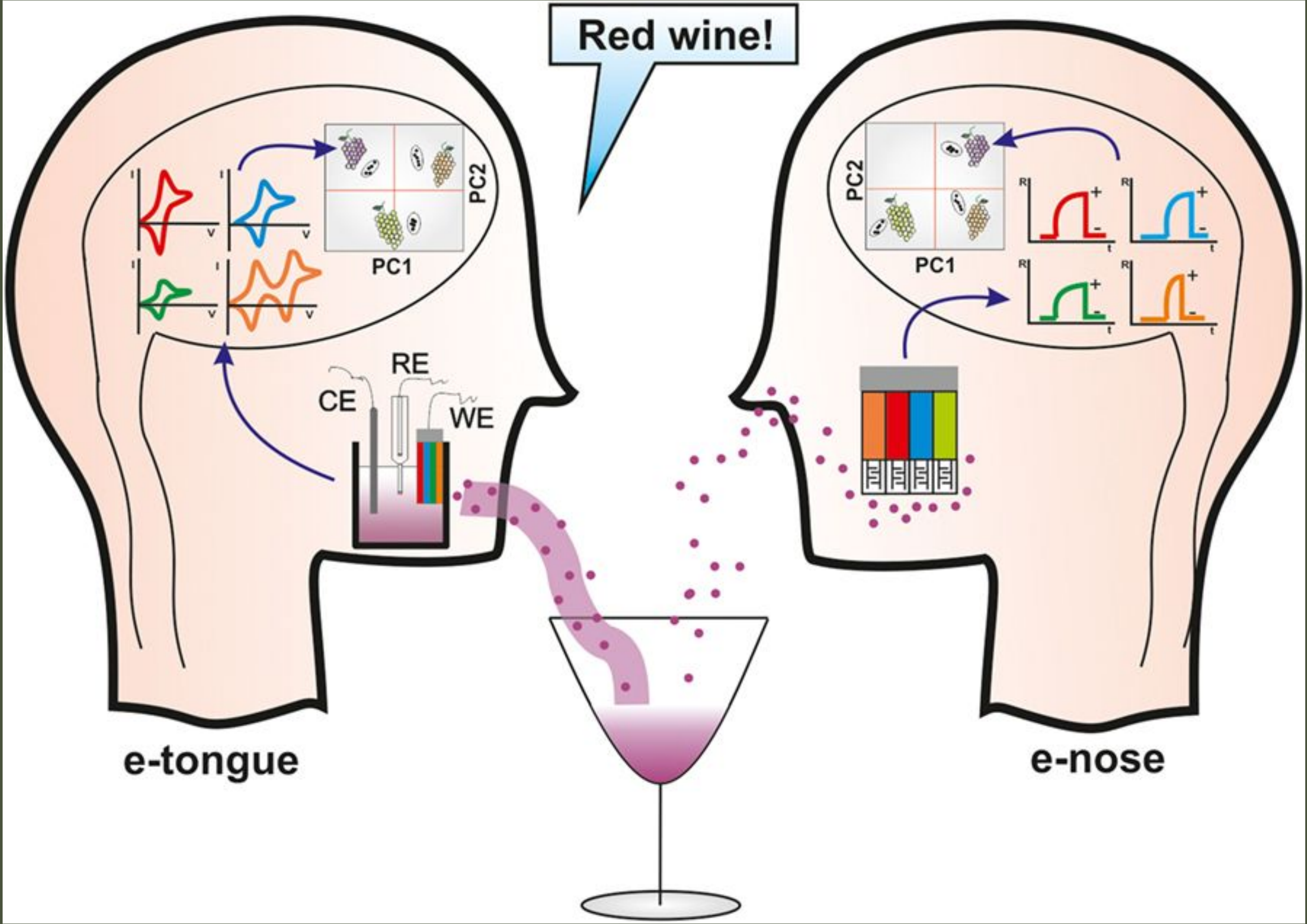
Automatic sensory evaluation – electronic nose and tongue



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Introduction

- Electronic noses (e-noses) and electronic tongues (e-tongues) crudely mimic the human smell and taste sensors (gas and liquid sensors) and their communication with the human brain.

- The human olfactory system is by far the more complex and contains thousands of receptors that bind odor molecules and can detect some odors at parts per trillion levels and include between 10 and 100 million receptors

- Apparently some of the receptors in the olfactory mucus can bind more than one odor molecule and in some cases one odor molecule can bind more than one receptor.

- The electronic nose often consists of non-selective sensors that interact with volatile molecules that result in a physical or chemical change that sends a signal to a computer which makes a classification based on a calibration and training process leading to pattern recognition.
- The non-selectivity of the sensors results in many possibilities for unique signal combinations, patterns or fingerprints.

- The human tongue contains sensors, in the form of 10,000 taste buds of 50–100 taste cells each for sweet, sour, bitter, salty and umami and is much less complicated than the human olfactory system.
- The e-tongue then uses a range of sensors that respond to salts, acids, sugars, bitter compounds, *etc. and* sends signals to a computer for interpretation.
- The interpretation of the complex data sets from e-nose and e-tongue signals is accomplished by use of multivariate statistics including principal component analyses such as (PCA), linear discriminant analysis (LDA), discriminant function analysis (DFA), hierarchical cluster analysis (HCA), soft independent modeling of class analogy (SIMCA) and partial least squares (PLS). For non-linear responses, artificial neural networks (NAA) can be used for modeling the data.

Advantages of e nose and e tongue

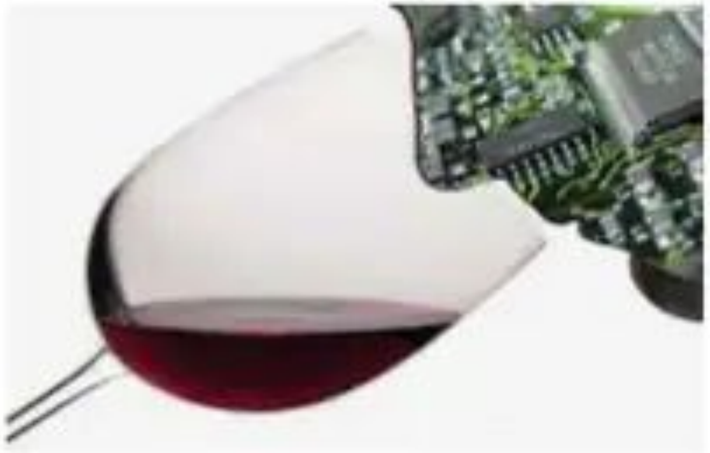
- In the human sensory system the brain receives signals from both olfactory and tongue receptors and integrate both sets of data to form classifications and/or judgments.
- The e-nose and e-tongue are not integrated since each has its own software package, but the data from both instruments could be imported into another program and integrated.
- The disadvantage of the human sensory system is that no two brains are alike (of course from another point of view, this is a good thing), and the same brain may react differently from one day to the next, depending on an individual's health, mood or environment, making the data subjective.
- On the contrary, e-nose and e-tongue instruments can be calibrated to be reliably consistent and can give objective data for important functions like quality and safety control. These instruments can also test samples that are unfit for human consumption

Disadvantages of e nose and e tongue

- A disadvantage for the e-nose and e-tongue systems (as with humans) is that they are also affected by the environment including temperature for both e-nose and e-tongue and humidity for e-nose, which can cause sensor drift, although calibration systems and built-in algorithms help compensate for this.
- There are more or at least not less different types of sensing materials for e-tongue (liquid sensors) compared to e-nose systems, and liquid sensors often possess higher selectivity and significantly lower detection limits compared to the gas sensors (e-nose).

Introduction---electronic nose(e-nose)

- Electronic noses are engineered to mimic the mammalian olfactory system.
- Instrument designed to allow repeatable identifications and classifications of aroma mixtures.
- Determines the various characteristics properties of the odour while eliminating operator fatigue.

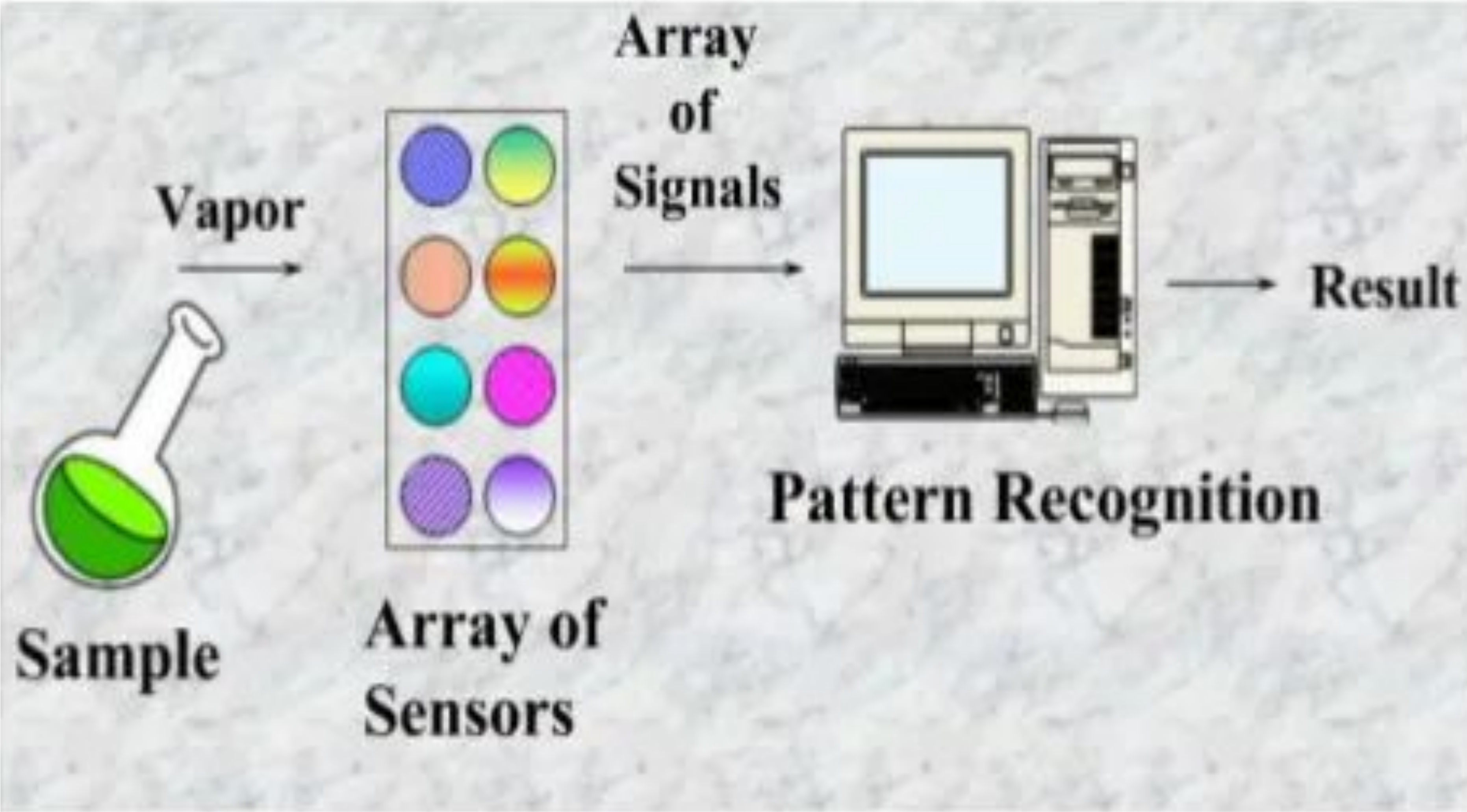


e-sensing

Refers to the capability of reproducing human senses using sensor arrays and pattern recognition systems.

❑ Definition: electronic nose(e-nose)

- Device intended to detect odors or flavors.
- Can be seen as arrays of sensors able to generate electrical signals in response to either simple or complex volatile compounds present in the gaseous sample.


Vapor
Array
of
Signals
Result
Pattern Recognition
Sample
Array of
Sensors

Comparison of e-nose with biological nose

- Each and every part of the electronic nose is similar to human nose.
- Comparison Table:

Biological Nose	E-Nose
Inhaling	Pump
Mucus	Filter
Olfactory epithelium	Sensors
Binding with proteins	Interaction
Enzymatic proteins	Reaction
Cell membrane depolarized	Signal
Nerve impulses	Circuitry and neural network

The need of an e-nose

- The human sniffers are costly when compared to electronic nose.
- Speedy, reliable new technology of the gas sensors are used in the electronic nose.
- Detection of hazardous or poisonous gas is not possible with a human sniffer.
- An e-nose also overcomes other problems associated with the human olfactory system.
- For the confirmation of the values obtained from a sniffer the result obtained from the sniffer has to be compared with some other sniffer's value.
- There lies a great chances of difference in the values got by each individual.

- An air sample is pulled by a vacuum pump.
- It is led through a tube into a small chamber consisting of electronic sensor array.
- A transient response is produced as the volatile organic compounds in the sample interact with the surface of the sensor's active material.
- A steady state response is reached within few minutes.
- This response is then sent to a signal processing unit.

- A washing gas such as an alcohol vapour is applied to the array for a few seconds to a minute.
- This is done to remove the odorant mixture from the surface and bulk of the sensor's active material.
- Finally, the reference gas is again applied to the array, to prepare it for a new measurement cycle.
- A variety of basic sensors can be used according to the nose strategy chosen.
- Each sensor in the array has different characteristics.
- The pattern of response across all the sensors in the array is used to identify and/or characterize the odour.

❑ Working principle of an e-nose

Electronic noses include three major parts:

I. a sample delivery system
II. a detection system
III. a computing system

I. Sample delivery system

- Enables the generation of the headspace (volatile compounds) of a sample.
- The system then injects this headspace into the detection system of the e-nose.

II. Detection system

- Consists of a sensor set, is the "reactive" part of the instrument.
- **Adsorption of volatile compounds on the sensor surface causes a physical change of the sensor;** they experience a change of electrical properties.
- A specific response is recorded by the electronic interface transforming the signal into a digital value.
- Recorded data are then computed based on statistical models.

III. Computing system

- Works to combine the responses of all of the sensors.

Sensor technology in e-nose

- The sensor array is clearly the key element. It forms the primary step in the detection or identification of an odorant.

- The most commonly used sensor s in electronic nose are:

(1) Conductivity sensors

Metal oxide sensors(MOS)   Conducting polymers

(2) Piezoelectric sensors

(3) MOSFET sensors

(4) Optical sensors

(1a) MOS (Metal oxide sensors) -

- **Adsorption of gas molecules provoke changes in conductivity** .
- This conductivity change is the measure of the amount of volatile organic compounds adsorbed.

(1b) Conducting polymers-

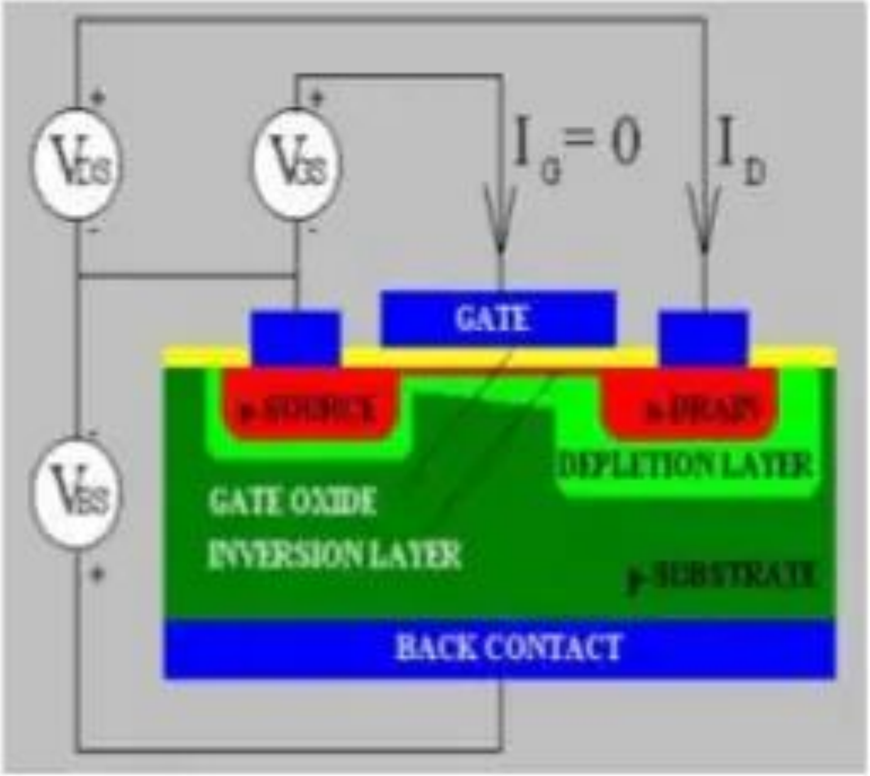
- Conducting or conductive polymer gas sensors operate based on **changes in electrical resistance caused by adsorption of gases onto the sensor surface**.

(2) Piezoelectric sensors-

- Adsorption of gas onto the surface of the polymer leads to change in mass on the sensor surface.
- This in turn produces a change in the resonant frequency of the crystal.
- This change in frequency is proportional to the concentration of the test material.

(3) MOSFET (Metal Oxide Silicon Field Effect Transistor)sensors-

- A volatile organic compound produces a reaction in the sensing layer(gate).
- This causes the physical property of the gate to change.
- Thereby the threshold voltage is changed and thus the channel conductivity.



(4) Optical sensors-

- Optical sensor systems are somewhat more complex than typical sensor-array systems having transduction mechanisms based on changes in electrical resistance.
- **Optical sensors work by means of light modulation measurements.**

Performing an analysis with an e-nose

- As a first step, an e-nose needs to be trained with qualified samples so as to build a database of reference.
- Then the instrument can recognize new samples by comparing volatile compounds fingerprint to those contained in its database.
- Thus they can perform the analysis.

APPLICATIONS OF ELECTRONIC NOSE

❑ Applications of E-nose

The applications(current) of an electronic nose include:

- Medical diagnosis and health monitoring

- Environmental monitoring

- Application in food industry
- Detection of explosives

- Space applications(NASA)
- In research and development industries
- In quality control laboratories
- In process and production department

The possible and future applications of an electronic nose include:

- in field of crime prevention and security
- detection of harmful bacteria
- detection of drug odours etc.

Applications of e-nose in food industry

Analysis of fruit ripening-

- Fruit ripening is associated with an accumulation of aromatic volatiles during ripening.
- Information from the noses can help in removal of rotten fruits at the appropriate time.
- This can help in avoiding storage losses due to rots and fruit diseases.

- **Beverages**

- For wine, an e-nose with semiconductor oxide sensors were trained in tandem with a sensory panel [29] and used to asses enologists and provide early detection of some chemical compounds with the purpose of preventing wine defects.

- A French manufacturer e-nose, AlphaMOS e-nose (FOX 4000), along with PCA and DFA analyses were used to discriminate beer and wines tainted with off-flavors (1-hexanol, ethyl acetate, 4-ethylphenol, octenol, and 2,3,4-trichloroanisole (TCA) after dehydration and dealcoholization of the samples.

- The e-nose was also useful for characterizing different fruit and grape wines produced based on their odor profiles including blackberry, cherry, raspberry, blackcurrant, elderberry, cranberry, apple and peach, as well as red, Chardonnay, Riesling and ice (grape) wines.

Tea

- Tea is 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) [36].
- The study also used the e-nose to determine the appropriate temperature and infusion time for emission of coumarin-like flavor.
- Using a newly developed “absolute value expression” (AVE) method, the authors were able to divide tea flavors into quality categories, expressed numerically, and the role of coumarin in tea flavor was determined.

- 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.
- Cup tests are subjective and not always reproducible, depending on the skills and training of tasters. Therefore, e-nose methods would help industry in QA-QC.
- An array of 12 tin oxide sensors was able to classify 90 samples of coffee consisting of two blends and two roasts with an 81.1 to 95.5% success rate and also could tell differences due to roasting time

Orange juice

- The Alpha MOS e-nose with 18 sensors, for ability to separate orange juice from fresh squeezed oranges, orange juice from a simulated commercial process (including pasteurization), orange juice from fruit harvested from healthy trees and the same commercially processed juice made from fruit harvested from Huanglongbing (HLB) infected trees and fresh squeezed tangerine juice (Figure 1). The e-nose separated all these juices using PCA, even the juice from HLB-infected trees, which were shown to have fruit that have off-aroma and a bitter-metallic flavor.

Grains

- An e-nose technique was optimized to classify wheat based on storage age using PCA and LDA and an Air sense analytics PEN2 nose with metal oxide semiconductors.
- Fungal volatiles of naturally infected and inoculated (*Fusarium culmorum) wheat and triticale grain were analyzed by* e-nose
- The e-nose was also used to detect key aromas that related to the different stages of the bread-baking process using a 4-sensor array (thin films based on titanium dioxide, mixed molybdenum and tungsten oxides and indium oxide).
- The Cyranose 320 with 32 polymer sensors was able to distinguish between varieties of long grain rice.

Cooking oils

- An e-nose with six metal oxide sensors was used to classify virgin olive oils with and without phenolic compounds for oxidative status.
- 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.
- Adulteration of virgin coconut oil with palm kernel olein (adulterant volatile methyl dodecanoate) was detectable using a *Z*-nose based on surface acoustic wave sensor technology.

Eggs and Dairy Products

- An e-nose could distinguish eggs stored for different amounts of time and at chilled or room temperature storage 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
- An Alpha Mos E-nose with metal oxide sensors was also used to determine shelf life of milk at ambient or refrigerated temperatures as well as bacteria growth in the milk.
- The Using PCA, the e-nose could distinguish the difference among all the milk flavorings as well as between the natural and enzyme-induced milk flavorings that were not that distinguishable in sensory tests. These discriminations were confirmed by SPME GC-MS.

Meat and fish

- 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 [19].
- For meats, sensory quality, shelf life spoilage, off-flavor, taints and authenticity are areas where volatile changes make e-nose screening of samples useful [19].
- A KAMINA e-nose with a MOS microarray and LDA was used to evaluate pork meat freshness when stored at 4 and 25 °C.
- An e-nose system with metal oxide sensors was used to detect changes in the headspace of stored beef strip loins inoculated with Salmonella typhimurium.
- An e-nose could distinguish broiler chicken in MAP packages with deteriorating quality from fresh in conjunction with sensory quality changes and was consistent with certain microbial counts [58].
- A MOS based e-nose was used to discriminate between human pathogens *E. coli and Listeria [59].*

- 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 using amperometric sensors, a heated catalyst and multivariate statistics (PCA and principal components regression or PCR).
- Formaldehyde is sometimes illegally used to prevent spoilage of seafood, which is a danger to consumer health. An e-nose with TGS (Japanese Taguchi gas sensor) was used to distinguish between water and formaldehyde-dipped octopus as a determination of spoilage.

Fresh, Fresh-Cut and Processed Fruits and Vegetables

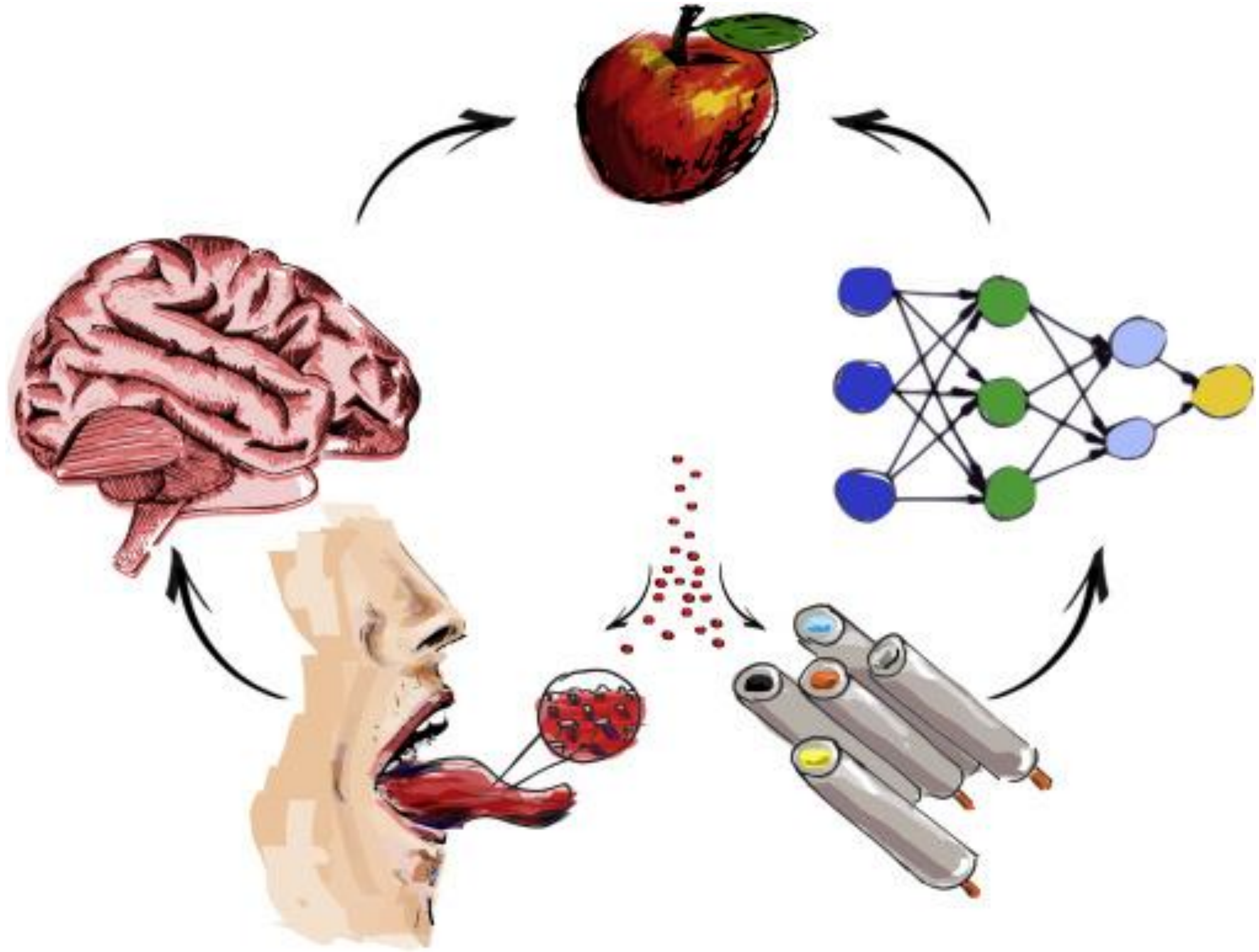
- For stone fruit, an Alpha-MOS E-nose was able to discriminate between different varieties of apricot using PCA and factorial discriminate analysis (FDA) and then was compared to a classification of the same varieties by measurement of aroma compounds by SPME GC-MS

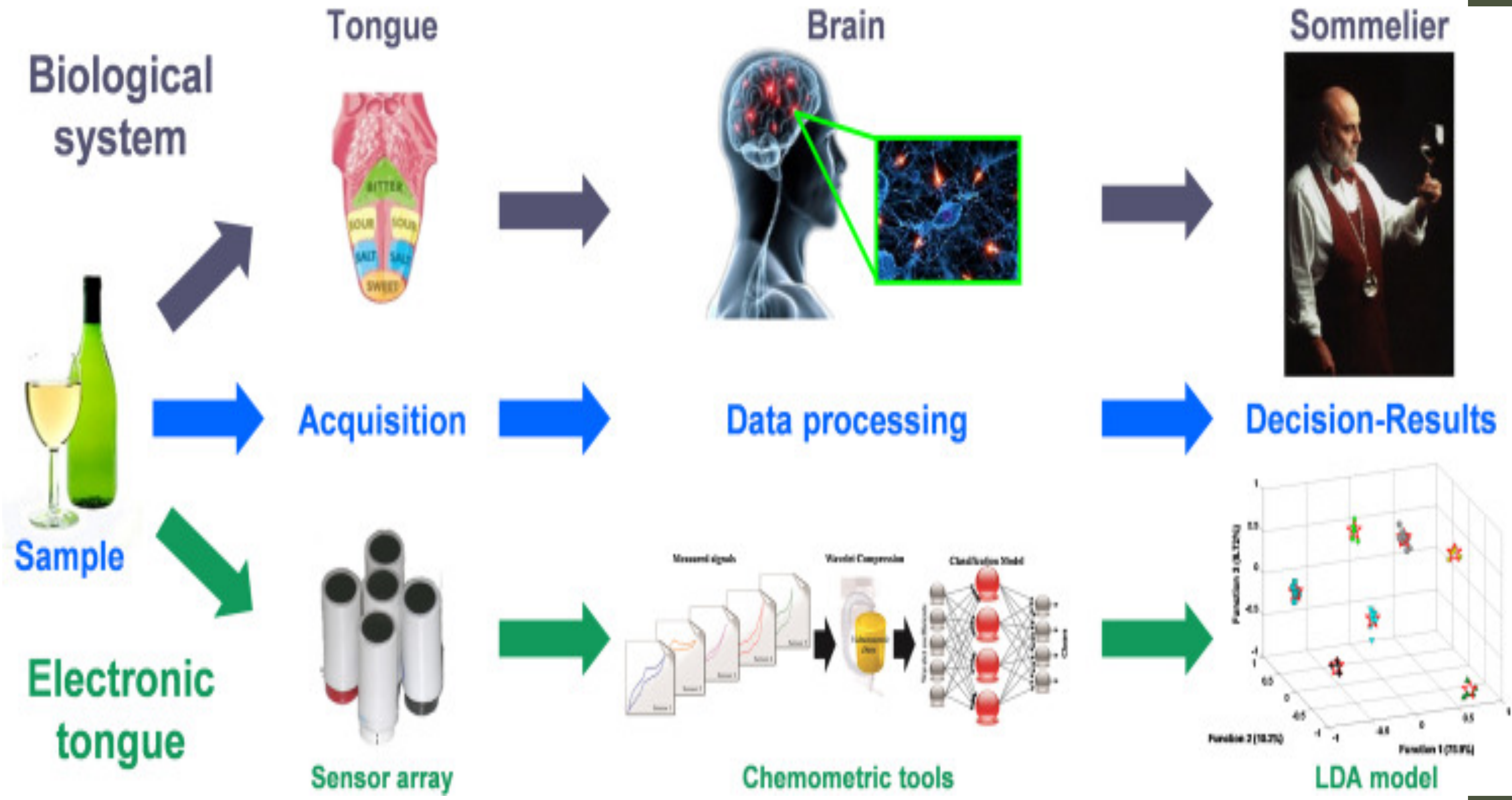
- For mangoes, classification and differentiation has been achieved with e-nose technology.

- For apples, a Cyranose with 32 composite polymer sensors was used in conjunction with a zNose™ to improve classification of damaged apples.

- For blueberries, a Cyranose was used to detect and classify diseased blueberry fruit inoculated with grey mold (*Botrytis cinerea), anthracnose (Colletotrichum gloeosporioides) and Alternaria rot* (*Alternaria sp.). Volatiles resulting from inoculations were resolved into four groups (including* non-inoculated control) using PCA.

e Tongue





Biological system
Tongue
Brain
Sommelier
Sample
Acquisition
Data processing
Decision-Results
Electronic tongue
Sensor array
Chemometric tools
LDA model

- E-tongues are used to obtain data for sourness, bitterness and astringency for foodstuffs such as beers, wines and teas
- This involved detecting polyphenols and predicting sensory attributes of bitter, sweet, sour, fruity, caramel, artificial, burnt, intensity and body using potentiometric/amperometric chemical sensors along with the same pattern recognition techniques described above for e-nose technology.
- Taste sensation is the result of physico-chemical interactions of food molecules with a complex system of hundreds of cell buds located randomly all over the tongue

- The principle for the e-tongue is to combine signals from specific, non-specific and overlapping sensors with pattern recognition as same as e-nose.
- For amperometric sensors there are four classes including metal, conducting polymer, phtalocyanine film and biosensors.
- Three different detection modes are fixed potential, step pulse potential and sweeping potential of which the last two are preferred in batch systems.

- Metal sensors - lack selectivity and are more useful for classification applications than for evaluation of taste, like predicting sensorial descriptors of Italian red dry wines of different origins
- Conducting polymers are used to evaluate bitterness, as well as sweet, bitter, acid, salty and astringent tastes
- E-tongues based on films of phthalocyanine sensors could discriminate between model solutions of sweet, bitter, salty, acid an umami basic tastes and bitterness in olive oils

Applications of e tongue

- Beverages - used for predicting wine age, used to characterize different types of beers including lager beers, ales and wheat beers. capable of predicting 20 sensory attributes of beer including bitter, sweet, sour, fruity, caramel, artificial and burnt. Bitterness in beer is an important quality parameter - e-tongue system proved capable of predicting real extract, alcohol and polyphenol content as well as bitterness.
- Tea - to determine contents of catechins and caffeine in green tea,
- A potentiometric e-tongue - able to classify milk based on producer and origin using an array of microelectrodes
- A potentiometric sensor array - used to monitor changes in probiotic fermented milk during storage

- Fruit-based soft drinks - used to test commercial fruit juices (orange, pineapple, mango and peach) from different brands
- Alpha MOS Astree e-tongue was able to separate between juices of processed orange juice from fruit harvested from healthy trees and those harvested from HLB-infected trees
- **Fruit and Vegetables –**
- **Cooking oils**
- **Meat and Fish**