Update:
Electronic Noses vs
Bomb Detectors

The Electronic Nose--A New Law Enforcement Tool

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abstract

A commercially available Electronic Nose may provide law enforcement officers with a new investigative tool. An Electronic Nose provides a recognizable visual image of specific vapor mixtures (fragrances) containing possibly hundreds of different chemical species. Conventional drug and bomb detectors use specific detectors designed to filter out interfering substances and achieve YES or NO detection of specific chemicals under very diverse conditions. However an electronic nose is different because it is designed to quantify and characterize all types of smells universally, including those from bombs and drugs of abuse. It is this universality which leads to a wide diversity of applications.

The new electronic nose is fast (10 seconds), operates over a wide range of vapor concentrations, has picogram sensitivity, and is simple to use and calibrate. The Electronic Nose has the ability to recognize as well as quantify many different and sometimes complex fragrances. This is achieved using pattern recognition and a visual fragrance pattern, called a VaporPrint™ derived from an integrating solid-state detector. Each smell or fragrance contains multiple analytes with a distinct relationship to each other. A VaporPrint™ image allows a complex ambient environment to be viewed and recognized as part of a previously learned image set. Using the ability of the law enforcement officer to recognize visual patterns allows quick assessment of unknown smell or vapor.

The speed and sensitivity of the Electronic Nose and has been validated for environmental monitoring by the USEPA and for drugs of abuse by the ONDCP. In addition, the new Electronic Nose is GSA listed and is approved for State and Local Law Enforcement use under the ONDCP/GSA “1122” program. Because the Electronic Nose can adapt and learn to recognize new vapors, it is a useful new tool for US customs inspections, forensic laboratories, and many other Federal and State law enforcement agencies.

Electronic Noses and Sensor Arrays

A type of vapor analyzer using an array of dissimilar sensors simulating the human olfactory response has become known as an Electronic Nose [Ref. 1]. An Electronic Nose provides a recognizable visual image of specific vapor mixtures (fragrances) containing possibly hundreds of different chemical species. An electronic nose is designed to quantify and characterize all types of smells universally. Sensors are selected for their chemical affinities and chemisorbing polymer films are commonly used for this purpose. Many sensors can be used and a serial polling of each sensor reading produces a histogram of sensor outputs as indicated in Figure 1. The responses are uncorrelated and sometimes multiple sensors respond to the same vapor e.g. overlap. Because of this, it is almost impossible to calibrate this type of Electronic Nose with test vapors containing more than one compound. A further issue is sensitivity because the vapor sample being tested by the array must be shared among each sensor in the array.

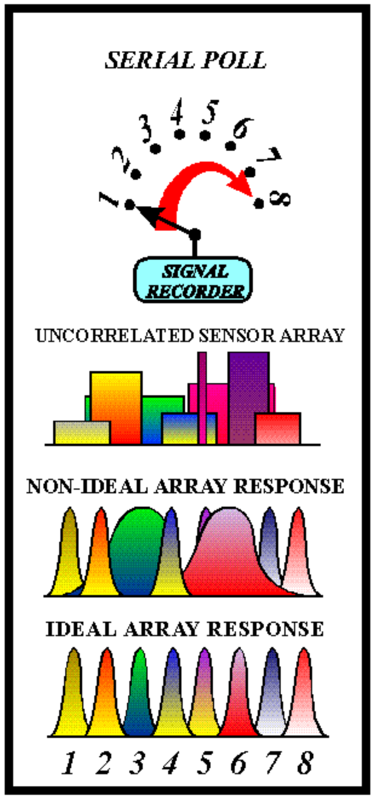
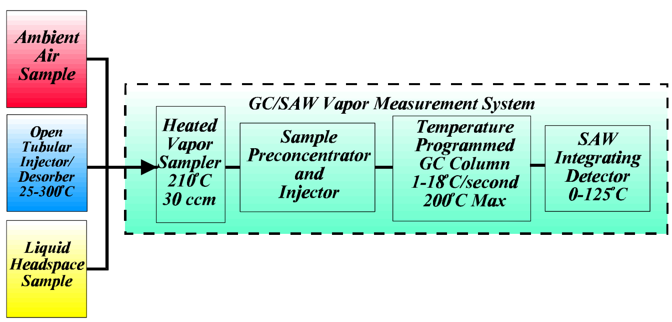


Figure 1- Histogram produced by serially polling sensor arrays.

In this paper a new type of electronic nose based upon fast chromatography is introduced. Sensor space is defined mathematically according to retention time slots. Separation of different compounds is greatly improved. In the optimal or ideal response there is no overlap of sensor outputs and each sensor output corresponds to only one analyte or chemical compound. Different chemical species have different retention times and hence these vectors can be given names like carbon tetrachloride' or 'cocaine'. With an Electronic Nose based upon chromatography, orthogonality of retention time vectors is a function of the column chemical phase and temperature profile.

Fast Gas Chromatography as an Electronic Nose

A new fast gas chromatography system using a Surface Acoustic Wave (SAW) detector [Ref. 2] is depicted in Figure 2. The system includes a heated inlet, vapor preconcentrator, temperature ramped and direct heated GC column, and a SAW detector. Sensitivity is excellent because the SAW detector has picogram sensitivity and there is no dilution of vapor sample. The system inlet can sample ambient air, desorbed vapor samples, or headspace vapors from liquid samples.



The SAW detector produces a variable frequency in response to analytes condensing and evaporating on the surface of a quartz crystal. The lower trace in Figure 3 displays the frequency histogram while the upper trace displays the derivative of frequency (column flux) and produces the familiar peaks of chromatography. Because the SAW detector measures the integral of the chromatogram peaks it is called an integrating detector.

In fast chromatography the chromatogram duration is 10 seconds, peak widths are in milliseconds, and retention time is resolved to within 20 milliseconds. Thus, potentially 500 sensors in 10 seconds can be polled serially. The 'sensor' responses are nearly orthogonal with minimum overlap. This feature allows for easy minimum detection level determination using a standard chemical mixture.

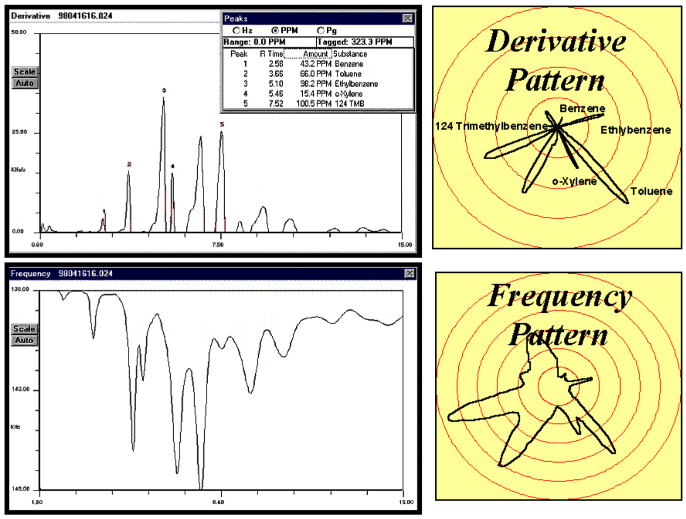


Figure 3- Gas Chromatograms used to create VaporPrint™ images.

In Figure 3 are also shown VaporPrints™ images [Ref. 3] of both the detector frequency and derivative of frequency. These images are formed by transforming the time variable to a radial angle with the beginning and end of the analysis occurring at 0^{o} or vertical.

VaporPrint™ Images and Pattern Recognition

A polar plot of chromatogram time with the radial direction being the sensor signal or the derivative of sensor signal provides an important graphical feature well suited Electronic Nose pattern recognition algorithms [Reg. 4,5]. The SAW sensor detects the amount of analyte condensing (and evaporating) on a quartz surface and the SAW frequency corresponds to the total (integral) amount of analyte condensed. The SAW crystal is the only integrating GC detector, all others detect the flux of column flow. The derivative of the detector output is only used to determine retention time. The amount of analyte detected is determined by sensor frequency.

The process of vapor identification and recognition for the GC/SAW Electronic Nose is depicted in Figure 4 using mushroom vapors as an example. After 5 seconds of sampling the vapor is analyzed

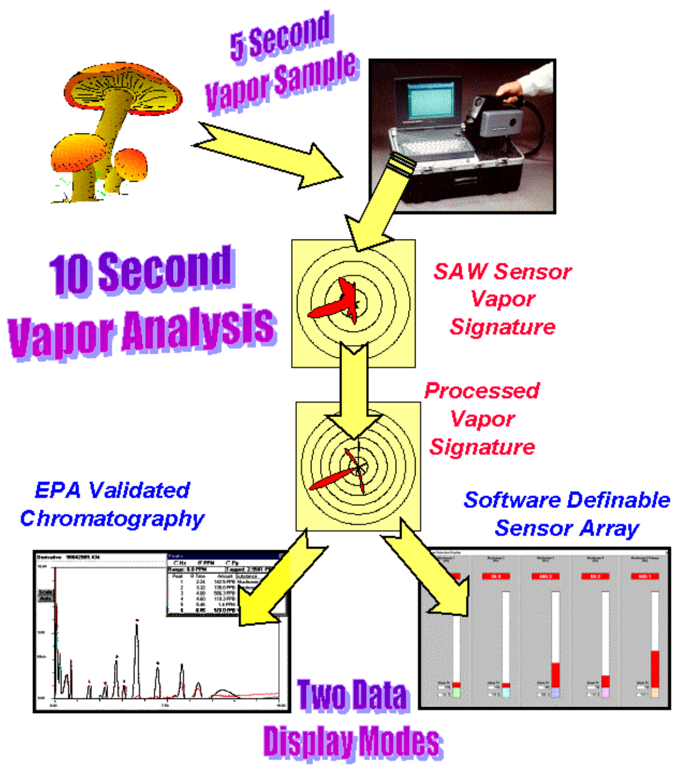


Figure 4- Pattern Recognition Process including the setting of alarms on individual sensor elements.

to form VaporPrint™ images, chemical chromatograms, and post the status of selected sensor alarms within 10 seconds.

The ability to form a sensor array with alarms enables the system to monitor only those analytes of interest, e.g. drugs of abuse or explosives. For the mushroom example there are five sulfur compounds which we simply select as the five sensor vectors we wish to monitor. A simple array of sensor meters then is displayed and this represents a mushroom nose. It only takes a software click to load another set of sensors and we have a marijuana nose.

Several electronic nose pattern recognition algorithms based upon sliding sets of correlation's using known compound patterns associated with complex fragrances were evaluated The objective was to find the best "pattern recognition algorithm". Thus far nothing approaching the performance of a human operator has been found. The situation is demonstrated in the pictures of plant leafs shown in Figure 5. For a human, identification of the marijuana leaf is simple and immediate, while for computation algorithms the task can be daunting, long, and tedious. For a similar reason screeners at airport security checkpoints remain as trained humans.

Figure 5- The human is an optimal pattern recognizer.

Humans must be trained to recognize VaporPrint™ patterns, however they excel when properly trained. VaporPrint™ images became richer with more complex and volatile compounds as found in food and perfumes. Some example images from infectious bacteria, drugs of abuse, and flammable fuels are shown in Figure 6. Experience has shown that human operators are able to recognize certain images or food smells because they looked like common shapes.

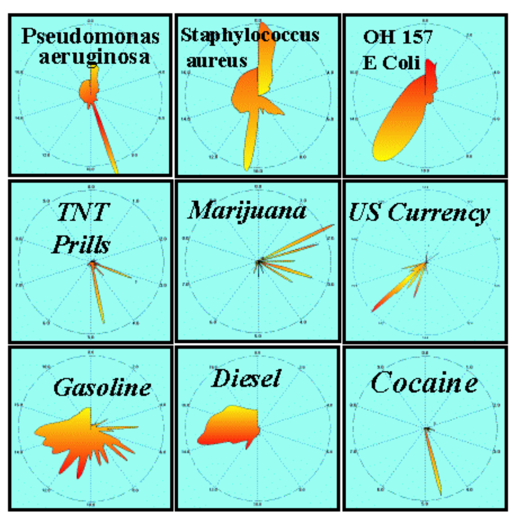


Figure 6- VaporPrints™ for common infectious diseases, explosives, drugs of abuse, and Flammable Fuels.

Law Enforcement Applications and Requirements

Conventional drug and bomb detectors use specific detectors designed to filter out interfering substances and achieve YES or NO detection of specific chemicals under very diverse conditions. However an electronic nose is different because it is designed to quantify and characterize all types of smells universally, including those from bombs and drugs of abuse. It is this universality which leads to the wide diversity of applications among law enforcement users. As an example of general drug enforcement, the following table downloaded from the Los Angeles police narcotics department web site [Ref. 6], illustrates the wide variety of compounds to be detected.

Table I -List of Illegal Drugs

Alcohol
Amphetamines
Designer Drugs
Cocaine/Crack
Ecstasy
Herbal Ecstasy
Ice
Inhaled Household Products
LSD
Marijuana
Mushrooms
Heroin
Methamphetamine Ice
PCP
Rohypnol
Special K
Steroids
Tobacco

Besides the needs of narcotics officers there are requirements for bomb squad officers, forensics, crime scene investigators, and general health and safety officers. In the US government there are also specialized agencies such as the US Customs and the Department of Defense. The number of items listed by the US Customs as contraband covers more than four pages and shows no sign of being shortened. For military services there are an unlimited number of uses for an Electronic Nose.

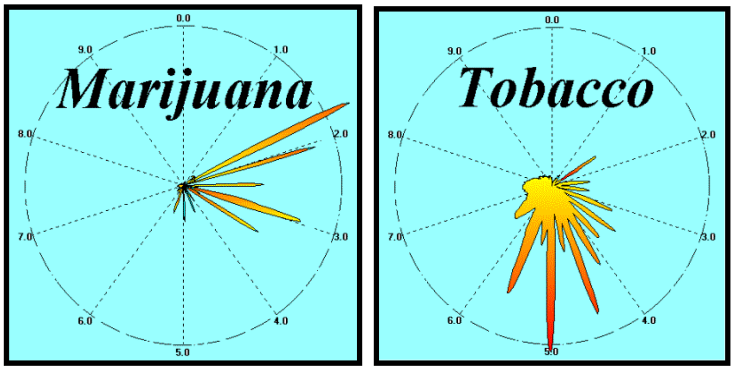


Figure 7- Identify and discriminate between different sources of smoke.

Law enforcement officers are taught situational awareness and the Electronic Nose improves the officer's ability in this regard. As an example, consider the usefulness of recognizing cigarette smoke compared to that of the illegal drug marijuana. Both odors are complex, yet their VaporPrint™ images are strikingly different and easy to recognize. The ability to quickly assess the odors present in a given situation could give officers other information such as that a weapon had recently been fired or that open alcoholic substances were being consumed.

To date the main barrier in the use of an electronic nose has been performance and cost. Law enforcement officers do not want to contend with complex instruments and even more complicated software. To be useful the cost must be within the budgetary constraints of these agencies. Early sensor array systems were not specific, had insufficient sensitivity, were slow, frequently unstable over time, and were expensive. In contrast, the GC/SAW nose operates in 10 seconds with a high degree of specificity and sensitivity, is stable and retains calibration over time, and utilizes a low-cost solid-state sensor technology.

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Commercial Availability of Electronic Nose

In 1997 Electronic Sensor Technology, Newbury Park, CA, began the first commercial production of a GC/SAW electronic nose or chemical vapor analyzer that performed flash chromatography, VaporPrint™ imaging, and sensor arrays with user defined alarm levels. With single-handed ease, this instrument delivered 10 second chro-

Figure 8- Commercially available Electronic Nose.

matograms using a patented Surface Acoustic Wave (SAW) sensor. The electronic nose is designed to operate in the field as well as in the laboratory. The instrument is stable over time, robust in construction, and operates over a temperature range of $0^{o}C$-$40^{o}C$. The system includes a Pentium computer with pre-installed Office97® and PCAnywhere® software for remote operation. Options also include a low-cost GPS receiver for accurately recording the location of each measurement.

The GC/SAW electronic nose is the first to receive validation from the US EPA for environmental monitoring of VOCs in water and PCBs in soil. Also, the White House Office of National Drug Control Policy (ONDCP) has validated the performance of this electronic nose for detecting cocaine and heroin vapors. For US government and law enforcement efforts involving drug interdiction, the electronic nose can be purchased under Section 1122 from the Government Services Administration (GSA).

In 1998, EST introduced a portable benchtop GC/SAW system designed for forensic laboratory users. Part per billion (ppb) sensitivity is achieved with volatile compounds and part per trillion (ppt) sensitivity for semi-volatile compounds. Because the GC/SAW uses a variable sample time preconcentrator with electronically variable sensitivity in the SAW sensor, the electronic nose is able to operate over a 1,000,000 to 1 dynamic range of vapor concentrations.

Figure 9- Laboratory style Fast GC/SAW.

Summary and Conclusions

A commercially available Electronic Nose can provide law enforcement officers with a new investigative tool. The Electronic Nose provides a recognizable visual image of specific vapor mixtures (fragrances) containing possibly hundreds of different chemical species. The new electronic nose is fast (10 seconds), operates over a wide range of vapor concentrations, has picogram sensitivity, and is simple to use and calibrate. The Electronic Nose has the ability to recognize as well as quantify many different and sometimes complex fragrances. This is achieved using pattern recognition and a visual fragrance pattern, called a VaporPrint™ derived from an integrating solid-state detector. A VaporPrint™ image allows a complex ambient environment to be viewed and recognized as part of a previously learned image set. Using the ability of the law enforcement officer to recognize visual patterns allows quick assessment of unknown smell or vapor.

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