Detection of Contraband and Drugs of Abuse Using An Ultrafast SAW/GC Vapor Analyzer

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Abstract

The first electronic nose using Ultrafast SAW/GC technology has been designed for security applications. Based upon ultra-high speed gas chromatography, it is a powerful new tool for detection of odors and chemical vapors produced by explosives, chemical and biological weapons, contraband of all kinds, hazardous industrial materials, improvised explosives, and even flammables. It is a true electronic nose, incorporating a new type of solid-state chemical sensor with part-per-trillion sensitivity and universal selectivity. In essence it misses nothing and can be trained to recognize and alert to any target odor signature.

Unlike trace detectors, electronic noses recognize odors and fragrances based upon their full chemical signature. An electronic nose is able to detect all compounds within an odor and provide a complete chemical profile. An expandable library of over 700 chemicals and odor signatures allows it to recognize virtually any target odor. Using ultra-high speed chromatography to separate chemicals within an odor in near real time, pattern recognition and trace detection using virtual chemical sensors can be performed at the same time. Trace detection combined with odor profiling can be an effective method for recognizing the presence of contraband material of all kinds. Electronic odor profiles are instrument independent allowing security users to distribute and share odor signatures.

Chemical sensor arrays have interested developers of security screening systems for some time, yet physical sensors have limited performance because of overlapping responses, physical instability, and low sensitivity. Using ultra-high speed gas chromatography, arrays of virtual chemical sensors with non-overlapping response are now possible. Long term stability coupled with picogram sensitivity allows the use of artificial intelligence, neural networks, and pattern recognition algorithms to detect and recognize an unlimited number of threat vapors.

Introduction – Security Screening

Inspection of cargo containers is just one example of security screening. The U.S. inspects 2-4 percent of the 7 million shipments that arrive at more than 100 ports. A wide variety of contraband materials such as explosives, chemical and biological weapons, drugs, contraband of all kinds, hazardous materials, improvised explosives, and flammable materials are targeted. Although not a widely publicized security problem, destructive odors from molds, mildew, and leaking barrels contaminate cargo and cause millions of dollars in damage each year.

Current sensor capabilities are fairly limited; in many cases, the best “technology” for practical use continues to be trained dogs. Manufactured sensors and trace detectors are often designed for use in specific environments and to detect only a limited number of chemicals. Yet because there is an ever-growing spectrum of possible threats, sensor systems are needed that can detect a large number of possible chemicals. In addition, sensor systems need different subsystems, including sample collection and processing, presentation of the chemicals to the sensor, and sensor arrays with molecular recognition.

Figure 1- Nearly 7 million cargo containers come into U.S. ports from overseas every year. Officials say it would be impossible to examine every one of them.

Electronic noses can compliment existing trace detectors and canines by chemically profiling odors in cargo containers. The ability to recognize odor signatures for explosives, hazardous substances, drugs of abuse, and even the cargo itself provides a dual-use screening tool for shippers and inspectors alike. In support of container security protocols, odor profiles can also be attached to an electronic manifest file and forwarded to authorities at the country of destination for comparison purposes.

Chemical Profiling and Security Screening

A portable chemical profiling system combining an ultra-high speed chromatograph column, a solid-state sensor, a programmable gate array microprocessor, a vapor preconcentrator, battery and disposable helium gas tank into a portable instrument is shown in Figure 2. It is able to speciate and quantifies vapor chemistry in near real time.

Figure 2- Portable SAW/GC chemical profiling system.

Vapors within closed spaces such as cargo containers can be sampled directly by inserting a sampling tube attached to the inlet of the instrument through a vent or a small opening in the container door (Figure 3). Containers can also be remotely sampled using a small handheld probe to first collect vapor samples. Remote sampling is more convenient than direct sampling and typically takes only 30-60 seconds to collect a 1-liter sample. Measurement sensitivity is substantially increased. Inserting the probe into the inlet of the SAW/GC and thermally desorbing the sampled vapors completes the analysis procedure.

Figure 3- Container vapors are sampled directly or remotely

Olfactory Images and Virtual Chemical Sensors

The SAW/GC uses a solid-state surface acoustic wave (SAW) crystal sensor, which is non-ionic and non-specific, to measure chemical concentration. It directly measures the total mass of each chemical compound as it condenses on the crystal surface, causing a change in the fundamental acoustic frequency of the crystal. Odor concentration is directly proportional to frequency with this integrating type of detector.

Plotting sensor frequency change (radial) vs elution time (angle) produces a high- resolution 2-dimensional olfactory image shown in Figure 4. These images display the odor signature or profile and enable recognition of complex odors and fragrances in the same way as the leaf of the marijuana plant forms a recognizable visual image.

A conventional chromatogram (top Figure 5) separates the individual compounds of an odor and is created by the derivative of the crystal frequency. Separating the compounds allows their concentrations to be measured (middle Figure 5). Different chemicals have different retention times and this enables creation of virtual chemical sensors and sensor arrays (bottom Figure 5) which are used for trace detection.

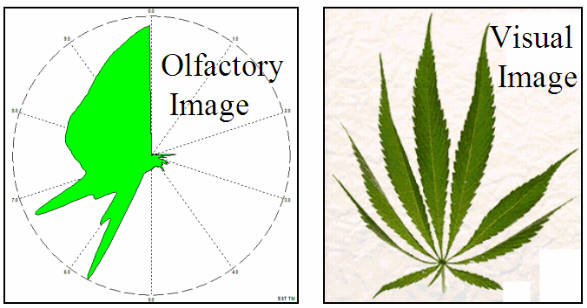
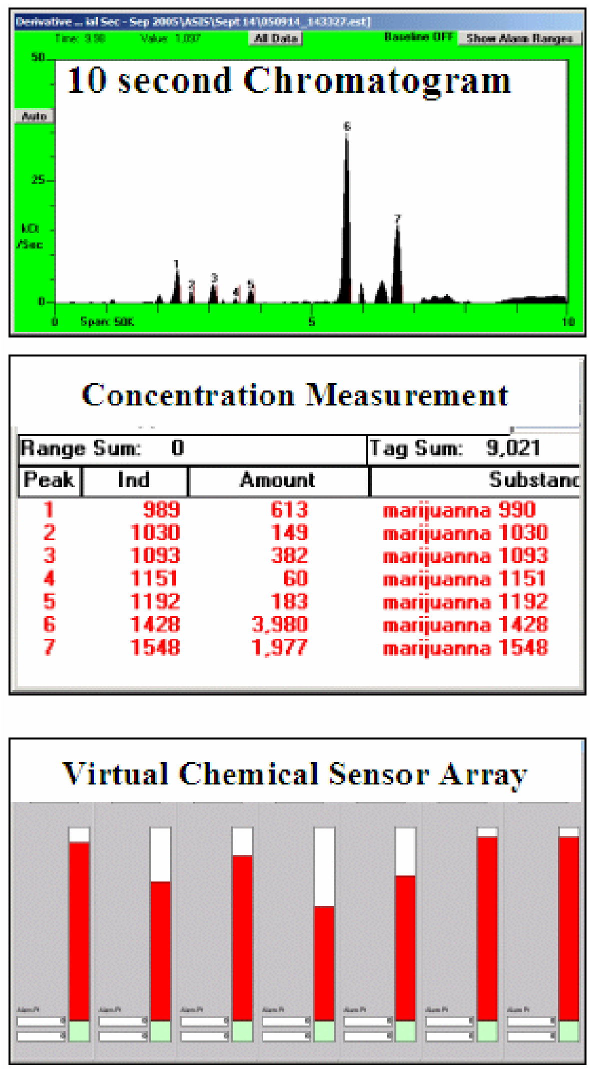


Figure 4- Olfactory image of marijuana odor forms easily recognizable visual image

Retention time indices (Kovats) of known chemicals relative to n-alkanes vapors allows the use of a chemical library and electronic odor profiles that can be shared by many users. Users can quickly distribute and share odor profiles of cargo, new threats, or contraband of any kind.



Peak	Ind	Amount	Substanc
1	989	613	marijuanna 990
2	1030	149	marijuanna 1030
3	1093	382	marijuanna 1093
4	1151	60	marijuanna 1151
5	1192	183	marijuanna 1192
6	1428	3,980	marijuanna 1428
7	1548	1,977	marijuanna 1548

Figure 5- Chromatography and virtual Sensors

Odors from Explosives

Because the SAW sensor is non-specific it is able to detect and quantify the vapor concentration of virtually any explosive independent of its chemical make-up e.g. nitro or non-nitro). The probability of detecting explosives from fugitive emissions (vapor phase) within a cargo container is strongly dependent upon the temperature of the cargo container, the vapor pressure of the explosive chemicals, and how they are packaged. For this reason odors of explosives such as Semtex and C4, which contain high molecular weight chemical explosives like PETN and RDX, are rarely detectable by vapor phase measurements. However, by international accord, all manufacturers of ‘plastic’ explosives now include a volatile taggant compound such as DMNB or MNT. This enables vapor detection systems and canines to detect these explosives. As an example, the complete chemical odor profile, olfactory image, and virtual sensor array response of C4 is shown in Figure 6. The RDX response (peak 7) is difficult to see however it is easy to detect the taggant (peak 1).

Not all explosives contain a nitrogen base and because of this they cannot be detected with conventional explosive trace detectors. One explosive of this type is triacetone triperoxide (TATP), which has 80% the explosive power of RDX, yet contains no nitrogen. This compound was used by the shoe-bomber Richard Reid and more recently by human bombers in the London subways. The chemical odor profile of TATP crystals is quite simple as shown in Figure 7. Like NG, DNT and TNT, TATP is very volatile and its odor can easily be detected by the SAW/GC at ppt levels.

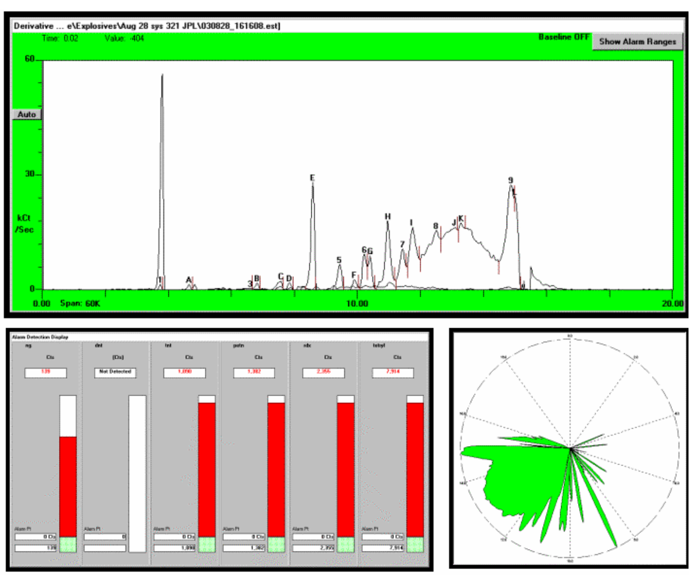


Figure 6- Chemical odor profile of C4 explosive.

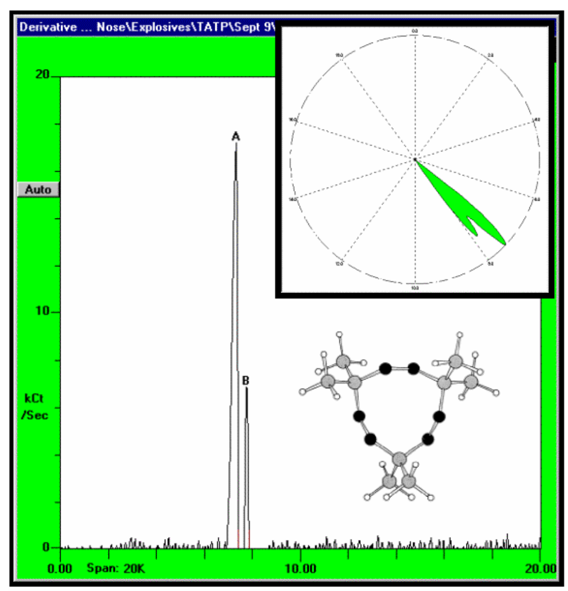


Figure 7- Chemical odor profile of TATP

Recognition of Target Odors

The SAW/GC is able to simultaneously perform chromatography, pattern recognition, and trace detection. Once the chemical profile and individual chemicals of the target odor are determined they are stored in memory and assigned to elements within a sensor array. The results of chemical profiling, pattern recognition, and trace detection are thus reduced to a simplified user display. Shown in Figure 8 are example detections using a virtual sensor array for DNT & TNT explosive, marijuana, US currency, and plastic explosive.

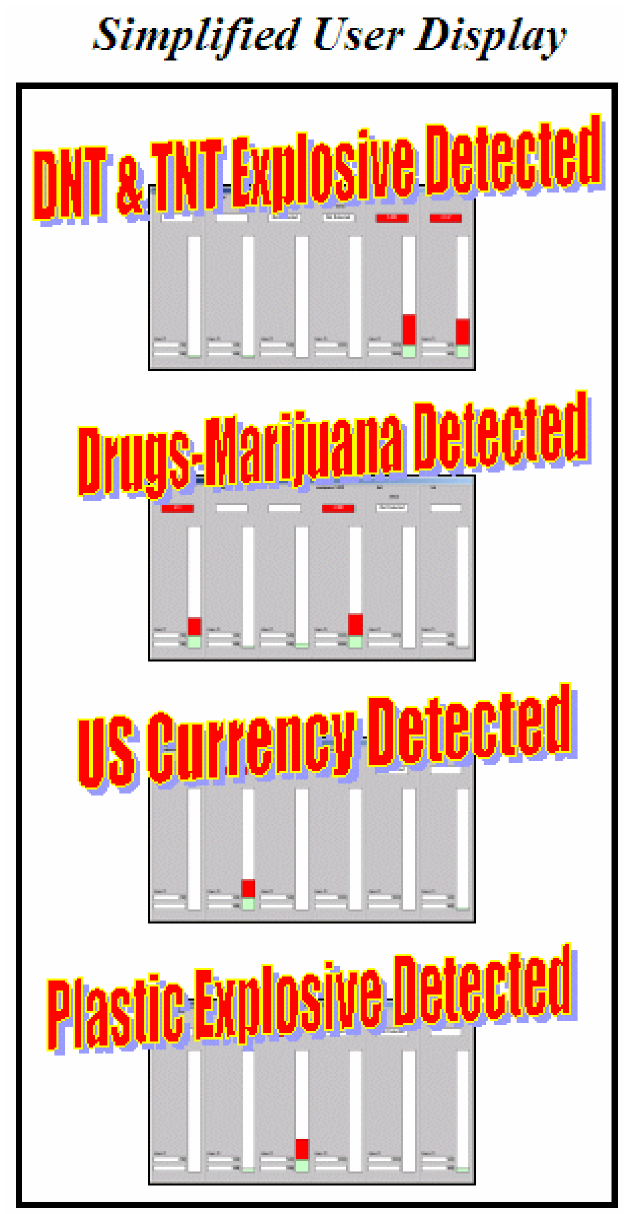


Figure 8- Example display results.

Environmental Monitoring Buildings, Subways, and Airplanes

Unlike trace detectors, the SAW/GC is able to detect all compounds within odors and this makes it a useful security tool for monitoring ambient air within buildings. In addition to recognizing known vapor threats it can also alert when suspicious odors are detected. Suspicious odors are not part of the buildings normal odor signature. All buildings have characteristic odor signatures and chemistry. One example is the odor signature of the rotunda of the Capitol building shown in Figure 9. More than twenty different chemical compounds were identified and their concentrations measured. Using a normal background odor signature, new or suspicious vapors can be quickly identified and security personnel alerted.

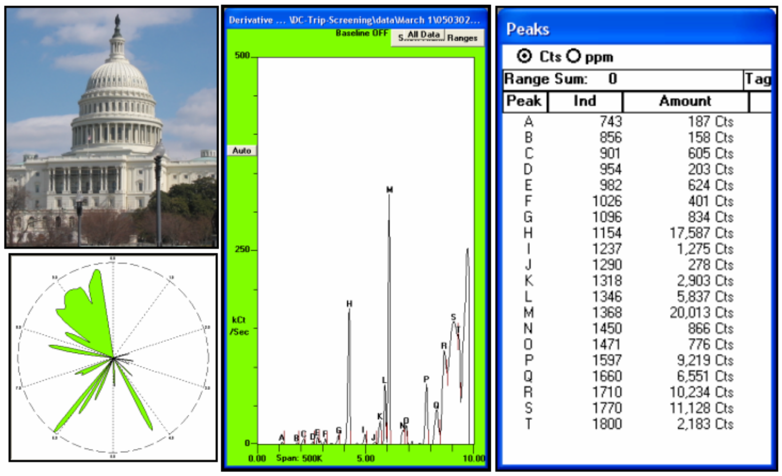


Figure 9- Odor signature of the Capitol Building

Because subways are underground with confined spaces they are vulnerable to chemical attack by terrorists. SAW/GC technology was designed to address vulnerabilities in closed spaces such as subways. In a recent demonstration air samples from the DC Metro were sampled and their chemical profile fingerprinted using olfactory imaging shown in Figure 10. By monitoring the air chemistry within the subway and comparing it with the normal background signature, new or suspicious vapors could be quickly identified and security personnel alerted. The SAW/GC is designed to recognize known vapor threats such as explosives and chemical agents. Improvised explosives such as TATP, which was used in the recent subway bombings in London, can easily be detected.

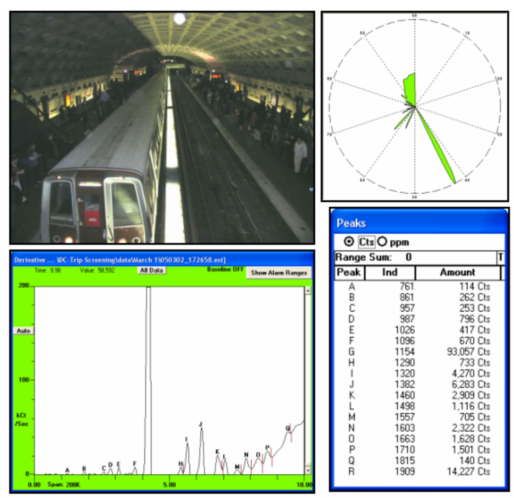


Figure 10- Odor signature of metro subway.

Commercial aircraft are an important part of the nations transportation system and of vital importance to homeland security. Traveling in an aircraft every passenger is exposed to a wide range of volatile organic compounds. As a result each aircraft produces a distinctive olfactory signature. The ambient air within a DC767 was sampled and its chemical profile fingerprinted using olfactory imaging as shown in Figure 11. The background chemical signature of the aircraft contained 25 distinct chemical compounds, which were indexed and tentatively identified using a database of known chemicals. Using the SAW/GC to monitor the ambient air chemistry, recognize odors of known threats, and to detect suspicious odors, which is not part of the airplane's normal vapor signature could enhance aircraft security.

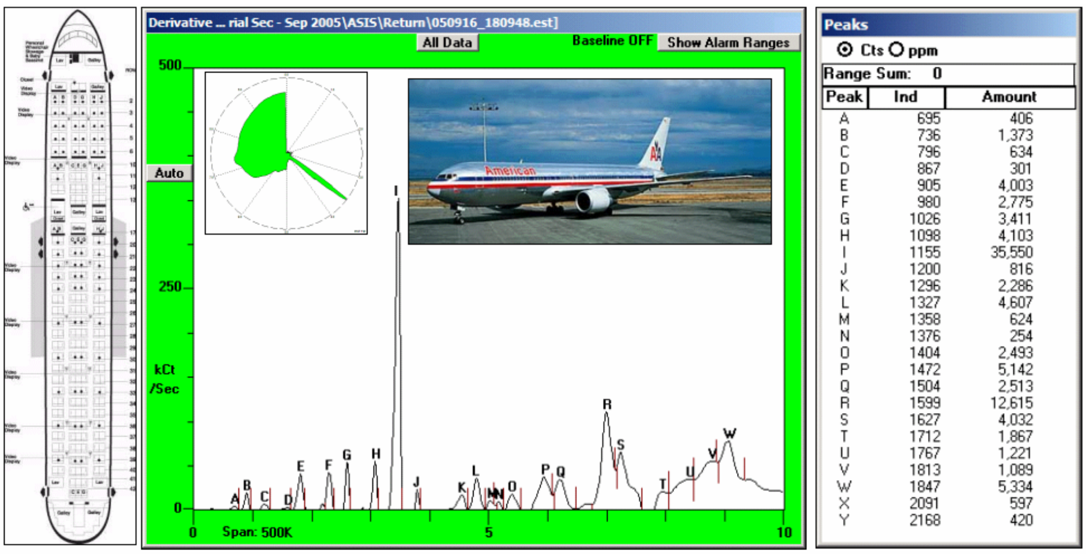


Figure 11- Background odor signature of a commercial aircraft.

Summary

A new electronic nose, using ultrafast chromatography and SAW sensor technology has been designed specifically for security. Unlike previous electronic nose technologies based upon sensor arrays, this electronic nose is based upon high-speed gas chromatography. The SAW/GC has demonstrated the ability to speciate and quantify the chemistry of virtually any vapor in just 10 seconds. The SAW/GC is a powerful new tool for detection of odors and chemical vapors produced by explosives, chemical and biological weapons, contraband of all kinds, hazardous industrial materials, improvised explosives, and even flammables. Because an electronic nose can detect all chemical odors it can be used to monitor the environment and spot unusual or suspicious odors.

The SAW/GC is complimentary to existing trace detectors such as IMS and does not replace them. Unlike trace detectors, the SAW/GC recognizes odors and fragrances based upon their full chemical signature. An electronic nose is able to detect all compounds within an odor and provide a complete chemical profile in near real time. An expandable library of over 700 chemicals and odor signatures allows the SAW/GC to recognize virtually any target odor. Because the SAW/GC uses chromatography to separate chemicals within an odor it also is able perform trace detection using virtual chemical sensors. Trace detection combined with odor profiling can be an effective method for recognizing the presence of contraband material of all kinds. Chemical libraries and electronic odor profiles are instrument independent and allow security users to quickly share odor libraries.

Cargo and port security are key components of the nation's homeland security strategy. More than seven million cargo containers arrive at U.S. seaports annually, according to the U.S. government and there is a need to develop screening methods, which will be quick and cost-effective. The nature of threat is such that there are an almost unlimited number of possible target chemicals so it is imperative that sensor technology be highly adaptive.

Electronic noses can play a major role in preventing catastrophic terrorism or, if attacks do occur, in minimizing their impacts. Adaptive virtual sensor arrays have the potential to thwart terrorist activities in the planning stage, before or during attempted attacks, and to help identify suspicious cargo. They may also be useful in forensic analysis to identify perpetrators after an attack. Sensors can also provide sensitive and rapid warning for the protection of fixed sites (subways, airports, government buildings, financial centers, high-value industries). For example, virtual chemical sensors for ventilation systems capable of detecting deviations from normal conditions and monitoring for chemical and biological agents could be coupled to rapid-shutdown procedures.