The nose knows

Initially developed as laboratory instruments, electronic noses are now used in a variety of industries, often replacing human smell- and taste-testers.

Lynn Crandall

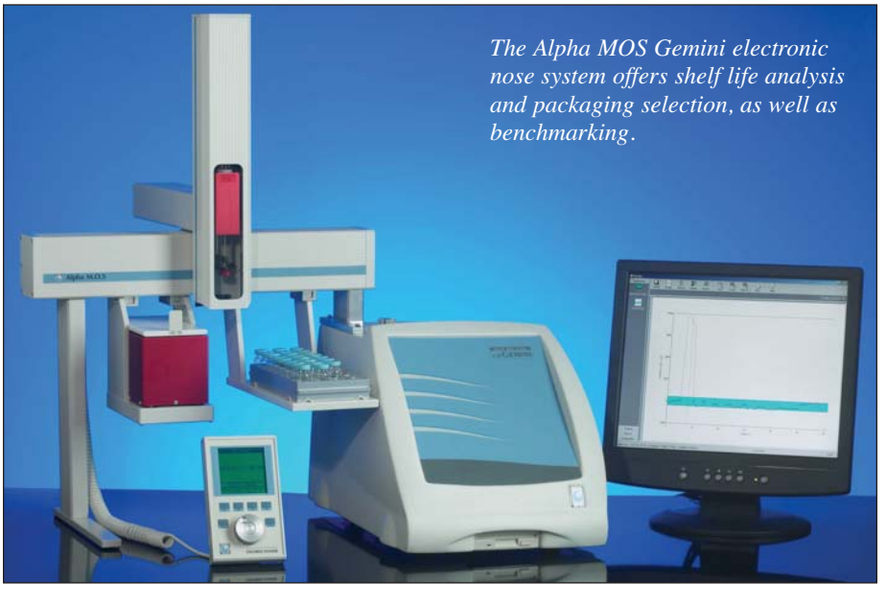
Instruments that mimic the human voice, ear, eye, and tactile sense have been in use for a number of years in a variety of industries. But in the late 1980s when Julian Gardner and researchers like him turned their attention to creating a device that would replicate the sense of smell, the complex human olfactory system was largely a mystery.

"At that time we could see that there were electronic counterparts for other senses, but there wasn't anything for smell or taste," Gardner said. Gardner is a professor of electronic engineering at Warwick University, Coventry, UK, where his research pioneered the field of electronic nose technology. "Smell is an important thing in food and drink and many other things, so the idea was to create machine olfaction and quantify smells. Very little was known about the sense of smell."

Research conducted in laboratories at universities around the globe during the late 1980s and early 1990s brought about the creation of machine olfaction devices, commonly referred to as electronic noses. Today the electronic nose has moved out of the research lab and into implementation in a number of commercial applications. Whether the research has translated into a practical device that offers satisfactory results is a point of disagreement among scientists. But most agree that machine olfaction is a developing technology that offers promising opportunities to improve human health, enhance security, and boost industrial economics.

The nose knows

While information collected from physical senses pertaining to acoustics, optics, temperature, and mechanics is fairly easy to measure, the human sense of smell and its chemical basis has proved more difficult to decode. In 1991, researchers Richard Axel at Columbia University, New York, USA, and Linda B. Buck at Fred Hutchinson Cancer Research Center, Seattle, Washington, USA, published their landmark discoveries clarifying the human olfactory system, for which they were awarded the 2004 Nobel Prize in Physiology or Medicine.



The Alpha MOS Gemini electronic nose system offers shelf life analysis and packaging selection, as well as benchmarking.

Capable of recognizing thousands of odorants, human olfaction is an important survival skill linked to flavor detection, memory, and emotion that allows an individual to perceive danger or delight. But it is this complex interaction of systems that has made human olfaction not only difficult to understand but also a challenge for industries across the board to satisfy. And while electronic noses were initially developed as laboratory instruments, researchers and manufacturers saw a need in various industries to augment and sometimes replace human sensory panels—professional smell- and taste-testers—with machine olfaction capable of sniffing even odors considered odorless to the human nose.

"Typically you would use expert tasters or smellers, but what happens when they have a cold or can't come in for a day or a week? And human sensory panels can become desensitized, so they need a break. They're expensive and not completely reliable," said AOCS member Lester Wilson, professor of food science and human nutrition at Iowa State University (ISU), Ames, Iowa, USA. "There could be a number of applications for sampling things that you don't know the quality until you smell or taste it."

Wilson and former AOCS president Pamela J. White, also a professor in food science and human nutrition at ISU, conducted research in the late 1990s on oxidative stability. Using an electronic nose from AromaScan, they analyzed corn oils with altered fatty acid content with satisfactory results.

"The principle behind electronic nose technology was to have an objective method to evaluate the impact of volatile compounds, particularly those that cause flavor and aroma and are related to food quality," White said. "The data we were able to derive was generally in agreement with the chemical methods we used."

Electronic nose 101

First introduced commercially in 1993 by France-based Alpha MOS, an electronic nose is a sensory device that produces a digital fingerprint of an odor and can send a signal to a computer, which monitors the process. Unlike traditional chemical analysis instruments, such as gas chromatography mass spectrometry (GCMS), the electronic nose consists of a chemical sensor system—a type of vapor-reactive sensor array—and a pattern-recog-

nition system, such as an artificial neural network (ANN).

When a sample of an odorant is presented to the sensor array, which typically consist of from eight to 60 non-selective sensors that detect different chemical compounds, the electronic nose system measures the complex odor present and compares its findings to patterns in its database.

A number of different sensors have been under development over the years, said Gardner.

"We tried to develop sensors which were nonspecific, only partially sensitive to different odors, and then apply different neural networking techniques," he said. "We looked at gas vapor sensors, semiconducting metal oxide materials, electric polymer materials, and also organic conducting polymer-based composite sensing materials. All of these technologies have been applied within the field of electronic noses."

Gardner said an enormous amount of work has gone into developing pattern recognition methods. Because an electronic nose doesn't analyze specific compounds in a sample—it detects patterns—it is only as good as its training. Commercial instruments currently on the market offer a host of linear and non-linear pattern recognition methods that can be tailored to different applications.

Sniffing out applications

The electronic nose has found acceptance most readily in the food industry, where applications can be relatively simple and focused. For example, other the nose can be programmed to react to rancidity. But researchers contend the instrument is still in the early-adoption phase of implementation. Gardner said the units are expensive and problems still exist with gaining acceptance with chemists, who often want to know the composition of samples, even though there is not any obvious relationship between the structure of the molecules and the smell. Also, ample time must be devoted to training the system, and applications need to be focused because sensors can misinterpret the sample and react to other factors such as humidity or an undisclosed chemical, which can result in faulty data.

Alpha MOS is the leading company in the field with locations in France, the United States, and Asia. Alpha MOS President and CEO Jean-Christophe Mifsud said his company currently holds about 70% the marketplace, with 30% of company sales coming out of the United States. Sales are also healthy in Asia.

Alpha MOS offers primarily two families of electronic noses, the Fox and Gemini systems. The systems offer shelf life analysis and packaging selection, as well as benchmarking, and range in price from around US$35,000 for the Gemini to more than $100,000 for the Fox.

The company's units utilize sophisticated data processing software and two different types of sensors, either metal oxide sensors, which measure a change in electrical resistance, or piezo-electric, which measure a change in frequency.

Mifsud said the company's electronic noses are best suited to research and development and quality control, and have been most popular in the food industry, especially in the fields of edible oils and animal fats.

"The system is able to predict pull-off date, shelf life, and aging," he said. "Another application is determining what type of packaging is going to react best and protect the best. And a third application is where the machine can help a company monitor the competitor's blends."

Eyeing growing segments

Researchers have taken a long look at capitalizing on vapor analysis as a means to expand applications for electronic nose technology and, in doing so, improve effectiveness of health care and homeland security measures.

Research at the University of Illinois (Urbana-Champaign, Illinois, USA) by Kenneth Suslick, a professor in the chemistry department, has led to commercialization of new technology aimed at replacing GCMS with sensors that change color in response to chemicals. Matthew Placek, CEO of Chemsensing (Champaign, Illinois, USA) said the technology, which he prefers to call a microarray, is expected to debut in 2006. The microarray features sensors that are impervious to humidity, making it especially adapted to use in the fields of industrial chemicals and medical diagnostics.

"The analysis of volatile organics and industrial chemicals is a $1 billion-a-year market and growing," Placek said. "Our focus is on saving lives, so a means to identify toxic chemicals is a clear choice for initial applications. … The home-run is the rapid identification of bacterial markers that indicate the presence of illness or types of cancers. That's a $35 billion-a-year market. To deliver satisfactory results in the market requires an electronic nose that's sensitive enough and selective enough to the biomarkers to identify those particular diseases, and some of the electronic noses in the past have been limited in those capacities. Our technology is performing well."

Another type of array-based sensing system, developed at the California Institute of Technology, is being commercialized at Next Dimension Technologies in Pasadena, California, USA. William Royea, company president, said Next Dimension Technologies is designing a prototype detection device using nanotechnology-enabled materials to provide solutions for complex sensing tasks. He agreed that electronic noses have previously failed to provide reliable solutions, but his company is addressing the issues by moving the technology toward tailored detection systems.

"Early generations of array-based detection systems weren't sufficiently sensitive and weren't adequately developed to address the specific needs of particular applications. A one-size-fits-all approach just didn't work," Royea said. "Next Dimension Technologies is addressing these issues by introducing advanced sensor array systems with higher sensitivities and by developing detection products that are geared toward specific sensing applications. This requires a lot of testing and customization, but ultimately provides robust, reliable solutions."

Royea said the company expects to target the security and defense market, as well as medical diagnostics applications.

Expectations

Electronic nose technology has offered potential for lowering operating costs, eliminating human subjectivity, and providing faster, more accurate testing results. But Mifsud said chiseling a market for electronic nose technology has been a struggle for a number of reasons. Competition is strong from traditional chemical analysis instruments. Countries with very traditional cultural heritages, such as Italy and France, have resisted implementing the technology for fear of losing control over product development and of reducing jobs. Additionally, the technology has needed to overcome a negative bias due to early introductions of devices from transient companies failing to provide reliable data. But persistence and technological improvements have helped companies such as Alpha MOS make headway.

"People are beginning to understand that the technology is not going to steal jobs; it's not going to develop new perfume, it's going to check it out; it's not going to develop new pizza, it's going to control the process," Mifsud said. "It is more important to use the electronic nose machine as a quality control tool and the human machine is important to use for product development."

Gardner also believes electronic nose technology may best be considered a complementary tool to other analysis instruments, but said the sky's the limit when it comes to ways it may impact on life.

Lynn Crandall is a freelance writer based in Ludlow, Illinois, USA. ■