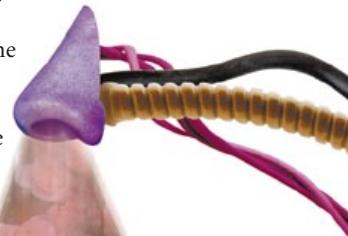# E-noses nose out traditional odor-detection equipment

SPECIALIZED SENSOR ARRAYS ARE REPLACING OLDER "ONE-TRICK-PONY" OLFACTORY SENSORS FOR BROAD-RANGE ODOR DETECTION. THESE UNIQUE ELECTRONIC NOSES, OR E-NOSES, BREATHE NEW LIFE INTO CONSUMER, INDUSTRIAL, AND MEDICAL SCENT-SENSING APPLICATIONS.

ALTHOUGH ELECTRONIC SYSTEMS for odor detection have been around for a few years, traditional systems suffer from a number of problems. Readily available, small, inexpensive sensors, such as a home carbon-monoxide detector, can detect only one gaseous substance. Systems capable of sensing multiple airborne substances, such as gas-chromatography/mass-spectroscopy (GC/MS) systems, are large and expensive and produce data that is difficult to correlate with sensory information. GC/MS systems can separate and identify individual volatile substances, but they cannot truly identify odors. Enter the electronic olfactory sensor, or "e-nose."

Universities and companies are developing e-nose technology built around an array of very small sensors. These sensors are sensitive to particular gaseous molecules, different combinations for each sensor, so that the entire sensor array can "fingerprint" a complex odor. Add some signal processing and μP-based electronics, and you have an electron-

ic nose that can give Fido a run for his money.

HOW WE DETECT ODORS

The human nose is a complex piece of equipment, containing around 10 million smell receptors. (Dogs have about 10 times that number.) Upon entering the nose, airborne molecules are captured and dissolve in the nose's mucous membranes (**Figure 1**). When dissolved, the molecules stimulate cilia, the hairlike ends of receptor cells. Stimulation causes the receptors to generate nerve impulses that go to the olfactory bulb on the brain's anterior lobe and backward to the brain's limbic region. The brain's cortex region then recognizes nerve impulses in the limbic region. The human brain cannot "recognize" smells; instead, the brain associates certain olfactory patterns with specific odors—sort of an odor-pattern recognition. This pattern-recognition function allows us to pick up odor patterns even for substances we've never before experienced.

The connection complexity between olfactory receptors and the brain, coupled with neural processing, makes smell an adaptive sense for humans and other animals. Most people can discriminate among around 2000 odors; trained personnel, such as wine makers and perfume evaluators, can discriminate among 10,000 or so. However, odor-detection situations exist in which it is inconvenient or even dangerous to have humans sensing odors. These situations need an electronic means of simulating the odor-sensing capabilities of a nose.

BUILDING A BETTER NOSE

Electronic-nose sensors come in many flavors, including metal oxide, quartz microbalance, SAW, and conductive polymer (**Reference 1**). Metal-oxide sensors work by performing surface oxidation/reduction of gaseous compounds. Manufacturers may coat some sensors with polymers to en-

AT A GLANCE
▷ Electronic-olfaction systems (e-noses) replace humans in dangerous or inconvenient applications.

▷ E-noses can "learn" odors for later odor-matching use, much like humans can sense scents.

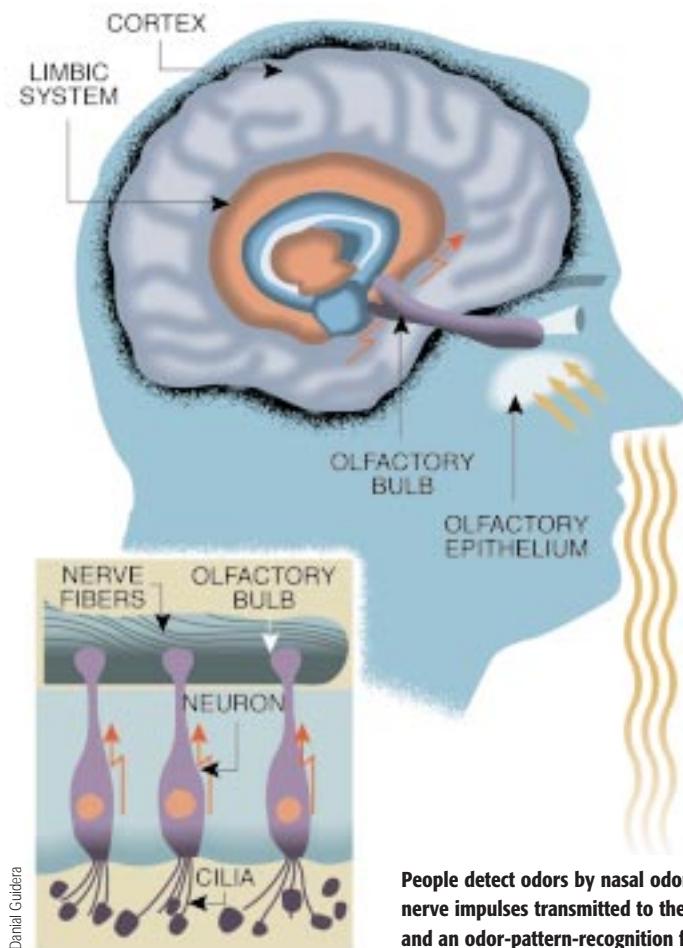▷ New e-nose-sensor technology will lead to smaller and cheaper odor-sensing and -recognition systems.

hance their sensitivity to some gases. Although water-sensitive, these sensors are less susceptible to "poisoning," and sensor vendors can manufacture them with less variance than that of conductive-polymer sensors. Quartz microbalances have an oscillation frequency that depends on the mass of a piezoelectric crystal. The crystal's mass increases when it absorbs gaseous molecules; coating the crystal with selectively absorbing materials enhances this absorption. SAW devices also have a frequency depending on mass, which varies with gas absorption. One manufacturer, Bloodhound Sensors, has developed a novel e-nose sensor using discotic (disklike)-liquid-crystal (DLC) technology. Disk-shaped molecules stacked like coins cover the sensor's surface. Sensor-surface interaction with gas molecules disrupts the molecular stacks, resulting in a measurable change in sensor resistance.

E-nose sensor arrays composed of metal-oxide elements, quartz microbalances, or SAW resonators with polymer layers suffer from problems such as nonreproducible results or excessively complex supporting electronics (**Reference 2**). To overcome these problems, many e-nose developers and manufacturers have turned to electrically conductive organic-polymer arrays. One pioneering e-nose company, Alpha MOS, bases its Fox e-nose on a combination of metal-oxide, SAW, and conductive-polymer sensors. Other e-nose vendors, including AromaScan, Neotronics, and the new Cyrano Sciences, base their products and research solely on conductive-polymer sensor arrays.

The more recent polymer-based e-nose

Figure 1

People detect odors by nasal odor capture, nerve impulses transmitted to the brain, and an odor-pattern-recognition function.

Danial Guidera

sensor arrays act more like a human nose than do some other sensor types. Each thin-film sensor is like an odor sponge that absorbs gaseous molecules. Absorbed molecules cause the sensor-element to swell, changing its resistance. You can easily measure this resistance-change parameter. Some vendors see conductive-polymer sensors as the e-nose of the future because they allow the vendors to potentially make arrays with hundreds of sensor elements on a silicon chip. This technology may someday lead to inexpensive handheld e-noses. E-nose-sensor vendors dope array sensors with different substances to make sensors more sensitive to a particular gaseous substance or group of substances (**Figure 2**). The resultant change in array electrical resistance, sensor by sensor, is an electronic fingerprint of the detected odor (**Figure 3**). You can compare detected array-resistance profiles with stored profiles to match odors. E-nose sensitivity depends on a number of ambient factors, including temperature, humidity, and airflow, and on properties of the detected gas. For example, less volatile substances are easier to detect, because the molecules on the sensor's surface tend to remain there in liquid form longer before they evaporate. Cyrano Sciences offers a sensor that employs a technology with an estimated lower limit of odor detection of around 10 parts per billion (**Reference 3**). Jet Propulsion Laboratories (Pasadena, CA) and the California Institute of Technology (Pasadena, CA) developed the technology for Cyrano Sciences' product.

Along with the sensor array, an e-nose needs some other equipment. Around the sensor is a control chamber into which vendors can pump a reference gas, such as pure nitrogen, to "zero" the sensor's response. E-nose users can then use the same chamber to introduce a controlled flow of a gaseous substance they want to identify and to flush out the system, preparing it for a new gas sample. By using the control chamber to minimize undesired ambient changes during detection, the e-nose sensor then changes resistance based on the aroma it is detecting. With the sensor and controlled environment, you can
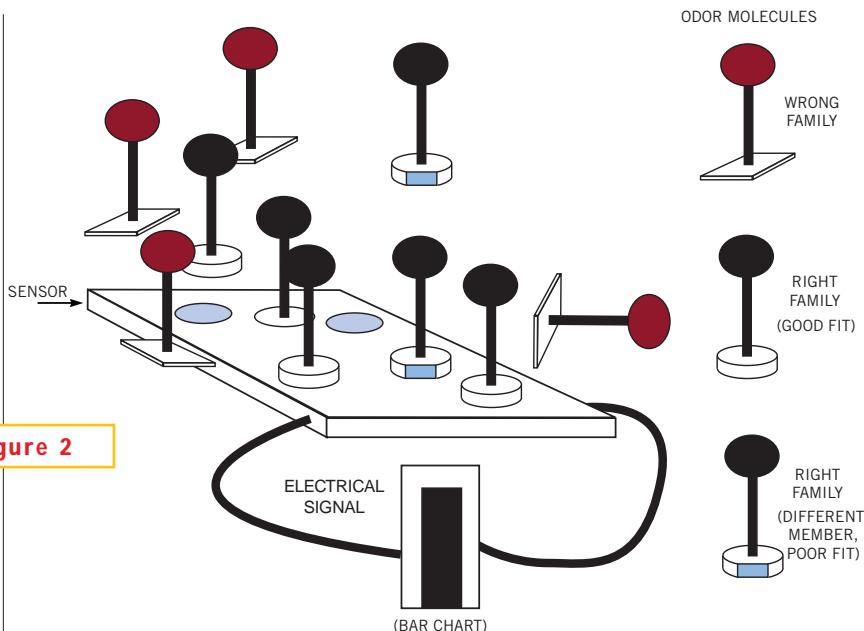

Figure 2

When sensitized to gas molecules, a conductive-polymer sensor absorbs those molecules, resulting in a reversible resistance change (courtesy AromaScan).

check an odor sample in about one to 10 minutes. You need most of this time to adjust the sensor environment; the actual odor-detection time is a small fraction of the total sample-checking period.

MAKING SENSE OF SCENTS

Having a sensor array that can differentiate between odors is nice but not a solution to mimicking the human nose and associated brain odor-recognition functions. Once an e-nose sensor detects an odor, you still have to process the data and use pattern recognition to get meaningful results from the sensor's output. E-nose companies often use artificial neural networks (ANNs) for pattern recognition. ANN systems have many interconnect processing elements, much like neurons in the brain. You can teach an ANN to solve a problem, such as recognizing odors when comparing them with "learned" odors that have previously been analyzed and stored (**Reference 4**). When you combine an ANN with an e-nose sensor array, you can detect more odors than there are sensors in the array (**Figure 4**). With the processed data from an ANN or other type of pattern-recognition system, there are many ways to "look at" a smell. ANNs work well for pattern-recognition tasks, and, unlike their human counterparts, ANN-based e-nose systems are unaffected by fatigue, emotional states, and uncomfortable ambient conditions.

With a multisensor array, you can look at the simultaneous individual-sensor-element responses to an odor as a bar chart. Because each sensor element has a unique odor sensitivity, the combined response of the elements is a unique profile, or fingerprint, of an odor. However, you need not rely on 1-D graphs of detected odors.

Figure 3
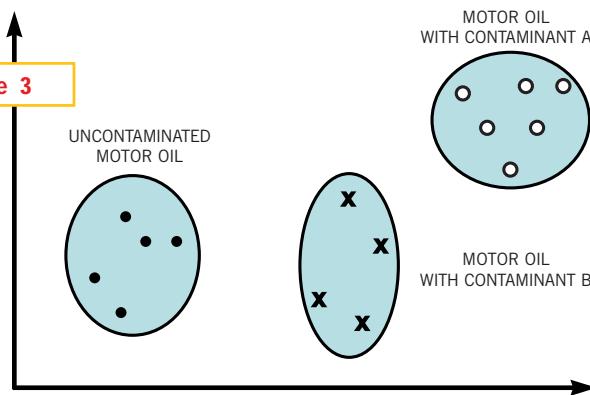
Each sensor in an odor-detecting array has different sensitivity to various odor components. The response of the entire array represents the fingerprint of a complex aroma.

E-nose vendors use data-processing software to manipulate sensor responses to display data as 2- or 3-D graphs. On these graphs, samples of a substance form clusters. The cluster groups then represent minute variations of the same substance, as well as show the more readily apparent variations between substances (**Figure 5**). E-nose vendors use statistical-analysis software, including principal-component analysis (PCA) and discriminant-factor analysis (DFA), to transform e-nose data into more readable charts and graphs (**Reference 5**).

You most often use PCA, an unsupervised pattern-recognition technique, for exploratory odor analysis. This technique is useful when you have no data on samples of an odor or when you may have unknown relationships between odor samples. DFA, a supervised pattern-recognition technique, is useful for classifying an odor by developing a model of that odor. You use DFA to compute a discriminative function representing variance between odors. Modeling software uses a sample group—nothing more than multiple detection-and-analysis runs of the same gas sample—to define a function describing differences between that sample and other odor samples. This data analysis reduces the multivariate (multidimensional) data of odor-detection runs into a 2- or 3-D data space that you can see in a plot. On these plots, sample groups appear as data-point clusters, with the difference between samples representing the similarity or difference between clusters. (The longer the distance between clusters, the more differ-
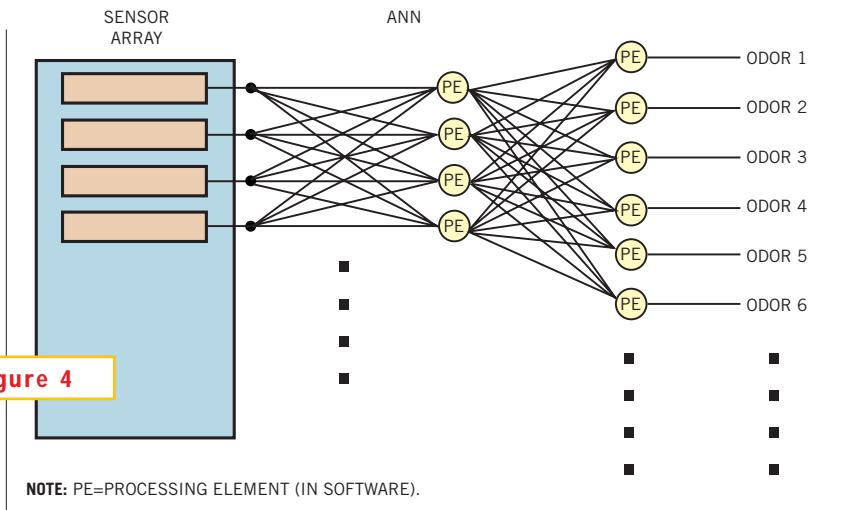

NOTE: PE=PROCESSING ELEMENT (IN SOFTWARE).

Combining an e-nose sensor array with a "trained" artificial neural network (ANN) provides a system that can recognize many more odors than the number of array sensors.

ence there is between the odor groups that make up each cluster.)

E-NOSE APPLICATIONS

The uses for an electronic nose, both in established and new arenas, are broad. Some apparent applications are in the food industry for detecting spoilage and product-quality control, in the cosmetic and perfume industries for aroma-quality control, and in industrial areas in which early toxic-odor detection can save lives. However, the availability of sensitive olfactory equipment leads to a variety of new and expanded industrial and—particularly interesting—medical applications.

A promising e-nose medical use is early wound-infection detection, which an e-nose accomplishes by recognizing the odor

that a form of streptococcus produces. AromaScan is investigating embedding small polymer-sensor arrays into wound dressings for simple wound monitoring. Another e-nose medical application is monitoring a patient's breath; certain mouth odors are precursors of types of disease or infection, such as pneumonia (**Reference 6**).

Current e-nose systems are bulky and expensive: $30,000 to $150,000. Conductive-polymer-sensor technology is promising but still has to overcome long-term stability, humidity-sensitivity, and contamination problems. However, sensor improvements coupled with chip-based pattern-recognition advancements will eventually lead to the e-nose Holy Grail—a handheld unit with rapid odor-response times and a price tag of a few hundred dollars or less.

As e-nose equipment gets smaller and cheaper, the following scenario is not too far-fetched: The new consumer e-nose Model OdorGard 5000 sits on a shelf in your refrigerator. Upon sensing that your milk has soured, OdorGard dials your local supermarket via a wireless modem and places an order for delivery tomorrow of one-half gallon of 2% milk, billed to your account. The e-nose knows! □
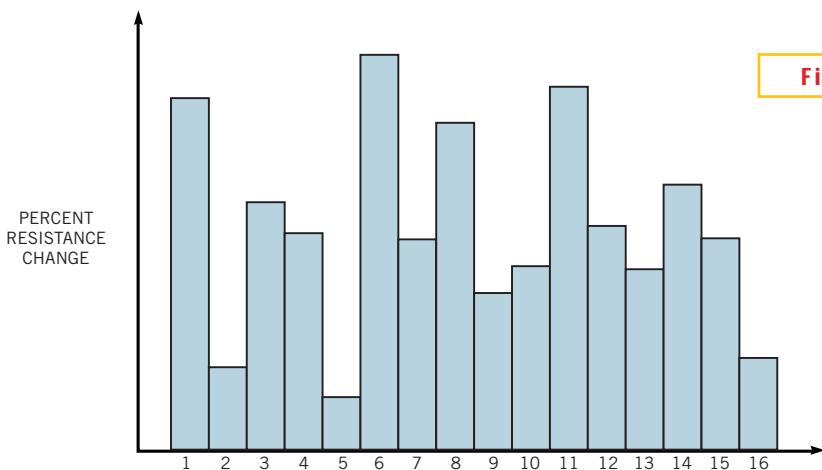
Data reduction of sensor-array responses to odors lets you plot data as 2- or 3-D scatter plots. The clustering of samples can show small differences in the same substance, such as food spoilage or the presence of impurities.

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FOR MORE INFORMATION...

For more information on representative companies offering electronic-nose products, circle the appropriate numbers on the Information Retrieval Service card or use *EDN*'s InfoAccess service. When you contact any of the following manufacturers directly, please let them know you read about their products in *EDN*.

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