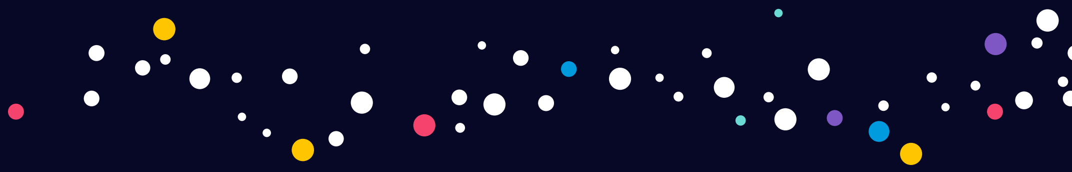
aryballe™



WHITEPAPER

Digital Olfaction for Odor Sensing

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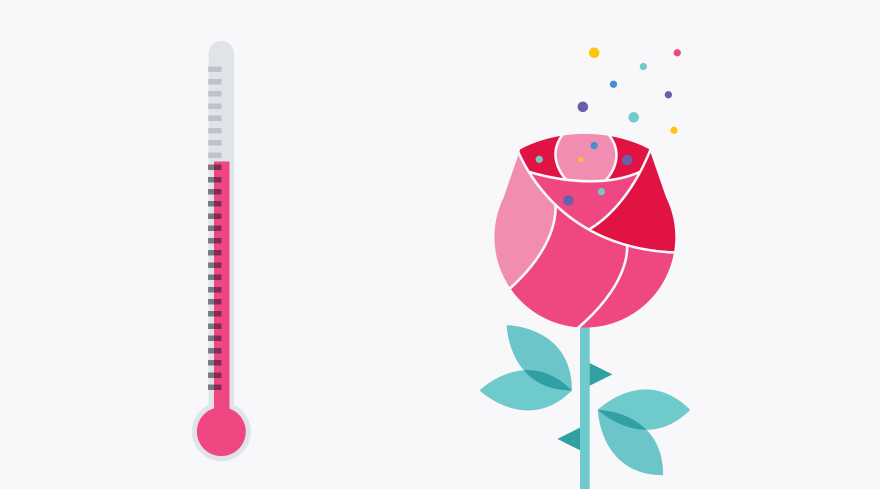
The technology behind electronic noses, digital olfaction, is generally defined as the digital capture and production of aromas, and its applications are broad and far-reaching. Similar to our sense of smell, digital olfaction mimics the process by which our brains identify and differentiate between odors. But to understand how it works, we must first define odor.

What Is An Odor?

Objects release odor molecules in response to energy variation. When energy increases (temperature, agitation, pressure), evaporation of odor occurs, and it then becomes possible for humans to absorb this odor through their nasal cavities (Figure 1). This stimulates the neural system of the olfactory bulb, and using other information, such as memory, the olfactory cortex produces the final result: the smell of the object.

Digital olfaction involves both a sensor—acting as the nose or receptor for odor molecules – and associated software which interprets information from the sensor based on a database of previously collected and analyzed odors. Think of this almost as our memory bank, which our brains rely on to correlate individual smells to life experiences and learnings and classifies the odor accordingly.

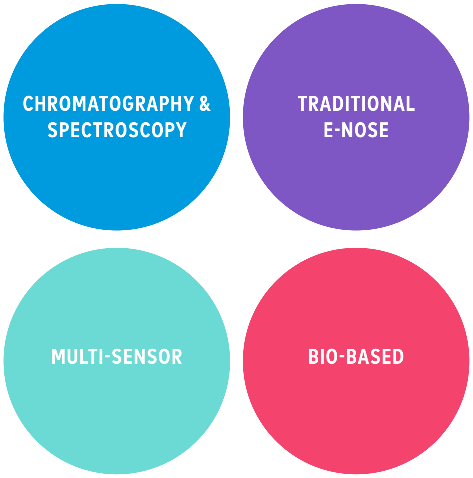
FIGURE 1



Odor Sensing Technologies

Current instrument-based techniques to analyze odors include chromatography/spectroscopy, multi-sensor devices, traditional e-noses and bio-based solutions (Figure 2).

FIGURE 2



- Separates and analyzes components of a mixture
- Bulky equipment often restricted to laboratory settings

- Based on polymer or metal oxide sensors
- Global odor analysis
- Requires Training phase

- Integrates multiple individual sensors
- Associated with advanced integration and automated decision making

- Functionalized sensor using biomaterials ranging from olfactory receptors to living cells
- Very specific and customizable

CHROMATOGRAPHY & SPECTROSCOPY

Gas Chromatography coupled with Mass Spectrometry (GC-MS) remains the golden VOC measurement method used in the many industries such as cosmetics. With its high sensitivity, it allows us to analyze the molecular composition of a sample, separating the molecules composing it and highlighting the presence of potential contaminants polluting it. Although it's very accurate, GC-MS is a costly piece of equipment and requires time to perform analyses. It also allows us to detail the chemical composition of a mixture, but this data is still sometimes far from the global sensorial experience of a human nose.

MULTI-SENSOR DEVICES

Multi-sensor devices rely on a number of sensors to measure a wide range of parameters at a given time. They typically integrate off-the-shelf sensors specific for a range of variables, like humidity, temperature, specific gases like ammonia or hydrogen sulfide and particulate matter. Information obtained through this data fusion approach give a general, broad overview of the global state of a system (e.g. vehicles, industrial settings).

TRADITIONAL E-NOSES

Electronic noses based on metal oxides (MOS) have also been used, although not widely and with limited success. Their main limitation is their lower number of sensitive sensors – typically less than 16. They are also known to be prone to drift and highly sensitive to humidity.

BIO-BASED

Bio-based technologies are the latest flavor of odor detection devices. They are based on biomimicry and result from an in-depth understanding of the olfaction mechanism. In these devices, sensors are biological molecules similar to the olfactory receptors (ORs) covering the nasal epithelium. These can range from short peptides derived from ORs, to bona fide full-size ORs, to olfactory neurons.

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Despite these various instrument methods, trained human noses remain highly valuable for most industries, allowing quick assessment of materials and delivering sensory results close to what the consumer will eventually experience.

A considerable part of quality control and odor assessment still relies on human noses. However, the human nose, even when highly trained, is sensitive to saturation; after testing a certain number of odors, the mucosa gets saturated, making it unable to further perceive and discriminate odors.

Human panels, where a larger number of testers are asked to assess and grade formulations, are susceptible to inter-individual variability, sometimes making the interpretation of results cumbersome due to the large dispersion of data recorded. The logistics behind organizing a panel can also take a significant amount of time before, during and after the testing session.

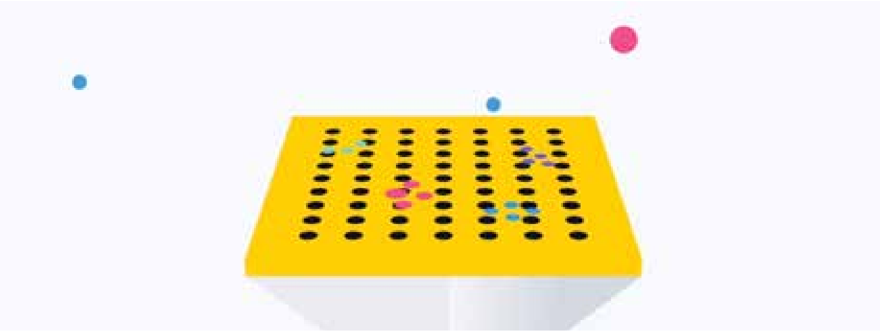
In addition to these challenges, there are also many situations where human testing isn’t feasible due to the toxicity of specific compounds—in particular when heated up and assessed frequently—creating safety and liability issues.

Aryballe's Approach

Aryballe's approach is based on biomimicry combined with a thorough understanding of human olfaction and how this can be mimicked in an opto-electronical device.

The core part of the technology is an optical prism printed with over 60 biosensors (Figure 3). These sensors are peptides inspired by the olfactive receptors of the human nose. Each sensor possesses different physico-chemical properties that impacts how the volatile organic compounds (VOCs) that make up an odor bind with the sensor.

FIGURE 3



Odors present in a headspace are pumped into the device measuring chamber, where VOCs come into contact with the biosensors. These interactions are transient, but strong enough to be detected by an optical system: an LED light that illuminates the prism from below, making it possible to take a picture of the interactions taking place in real time on the prism surface, with each dot representing a biosensor (Figure 4).

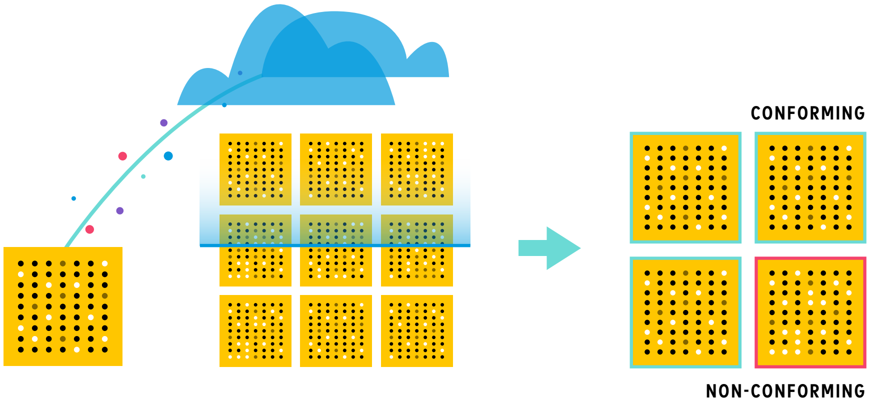
FIGURE 4

Based on an optical mechanism called surface plasmon resonance, the system in fact works like a molecular balance: the more VOCs bind, the whiter the dots. When the odor source is removed, the surface of the prism gets rejuvenated by pumping 'clean' neutral air into the device, thereby removing the interacting VOCs. This does not affect the biosensors so they can be rapidly re-used for the next analysis—in less than five minutes.

A key concept of the technology is that, similar to human olfaction, it combines results of the biosensors—and is not the output of a single receptor. This combination forms a pattern specific to each odor. Each pattern is recorded in the odor database and with machine learning it can be used to identify different odors and provide further analysis.

The full digital olfaction solution works in two steps: (1) a learning phase, during which odors are recorded by the device and annotated in the database; (2) a recognition phase, during which unknown odors are identified based on records within the database (Figure 5).

FIGURE 5



Just as a human would not be able to name an odor they never encountered before, the solution cannot identify odors it has never been 'taught' before.

COMPARATIVE METROLOGY

This solution allows for comparison of odors based on two basic types of analysis – low resolution and high resolution.

Low Resolution

Low resolution is where products from different chemical families can be distinguished (identification of incoming products and raw materials). This analysis can typically identify one compound out of five very different ones.

High Resolution

High resolution looks at the analysis of more subtle differences—typically used in quality control. This typically would require the use of simple ancillary valves to standardize measurements as much as possible. Because resolution is finer, more compounds can be distinguished, typically one out of ten, or one sample among different batches of raw materials.

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ANALYZING ODOR DATA

The device sensitivity lies typically in the range of 1-1,000 ppm, while virtually all chemical families can be successfully detected, provided the concentration tested lies within the sensitivity range. More than 5,000 different compounds have been measured to date – and this number continues to grow.

Two parameters are followed in the analyses: (1) odor intensity and (2) the olfactive signature of each compound, which represents the pattern defined by the interaction between the biosensors and the VOCs.

Intensity

Intensity is expressed in arbitrary units and allows for comparison of the intensity of one compound over time, or of similar compounds at the same time.

Olfactive Signatures

Olfactive signatures are represented as radar charts, on which each ray corresponds to the normalized intensity of stimulation of each biosensor. This acts as the "fingerprint" for the odor.

Odors can also be compared using principal component analysis (PCA), on which each dot represents a single measurement. The distances between the intensity reached by each biosensor are calculated and summed up for all measurements, giving rise to a distance matrix.

This matrix is converted into a two-dimensional graph, in which the relative distance between two dots represents the proximity of two records. The closer the dots are, the closer the odors (and conversely). The comparison of the database is also represented in a confusion matrix which shows the likelihood of a misclassification of a sample across the different odors.

TYPICAL USE CASE

The Food & Beverage Industry

One of the top use cases for digital olfaction involves quality assurance or quality control to either maintain controlled conditions or ensure consistency in manufacturing. For example, as consumer demand for sparkling water beverages grows, manufacturers must ensure the flavor, a combination of taste and smell, can be replicated time and again to ensure customer satisfaction.

FIGURE 6

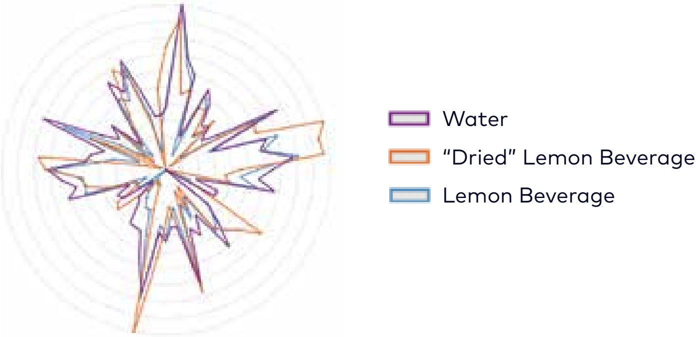


Figure 6 demonstrates how the scent of lemon would appear digitally—both in its raw diluted form in water and also with advanced humidity analysis ("Dried" Lemon Beverage). By using the software analytics component of digital olfaction, the solution takes into account the odor impact of water and isolates the lemon odor from it.

Manufacturers would want to consistently see the same lemon olfaction pattern over and over again to ensure the same odor and thus flavor of the lemon beverage.

At the same time, flavor contamination from food packaging is a recurring issue. Digital olfaction can help to prevent this "flavor scalping" by monitoring when food starts to absorb aromas from packaging, or even help manufacturers add the scent of the food item to packaging materials.

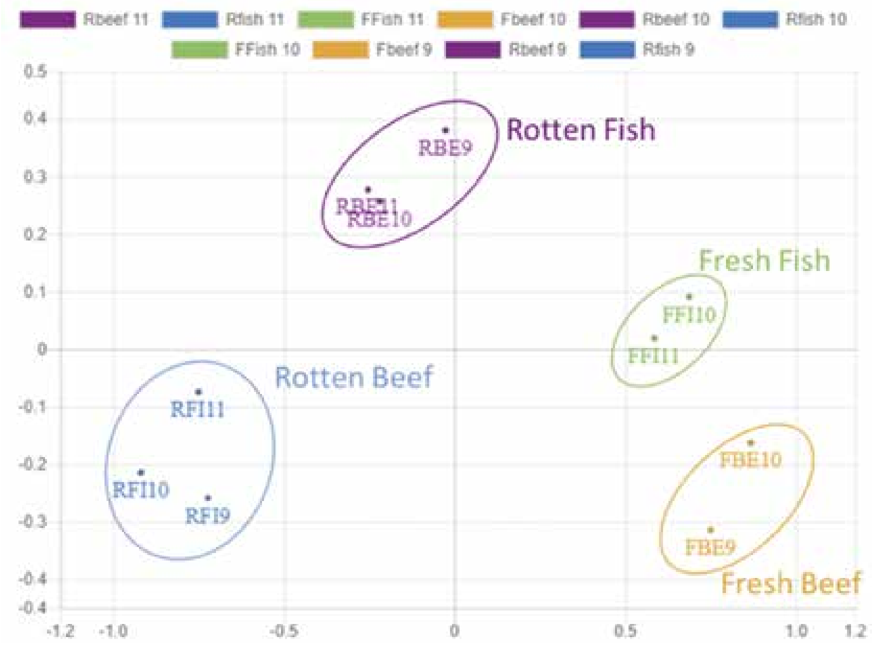
TYPICAL USE CASE

Inside Home Appliances

Homes today are stocked with numerous smart appliances, from temperature control, to security systems, to entertainment. So, it shouldn't come as a surprise that appliance manufacturers are also interested in devices that can smell.

The more common use cases take place in the kitchen, with refrigerators outfitted with odor sensing technologies that can alert consumers when food is about to go to waste. In fact, we've examined this exact scenario using a digital olfaction sensor device, which we used to determine whether a piece of fish had begun to spoil (Figure 7).

FIGURE 7



As suggested by the graph below, digital olfaction helps to categorize food using pattern recognition, comparing the food item's current odor signature to previously collected odor data to identify whether it is fresh or rotten.

The same process could apply to other appliances, such as an oven that would automatically stop when food is cooked or has reached its preferred level of doneness. We've seen digital olfaction devices distinguish between cookie dough and a baked cookie, all by relying on the odor data collected.

TYPICAL USE CASE

The Automotive World

Odor sensing technology in vehicles offers numerous use cases to address industry trends attributed to new mobility services and the evolution of self-driving cars. These cases involve everything from detecting nuisance smells and component malfunctions, which could include everything from stale food to a fuel leak, to helping refresh the smell of vehicles involved in peer-to-peer car-sharing.

FIGURE 8

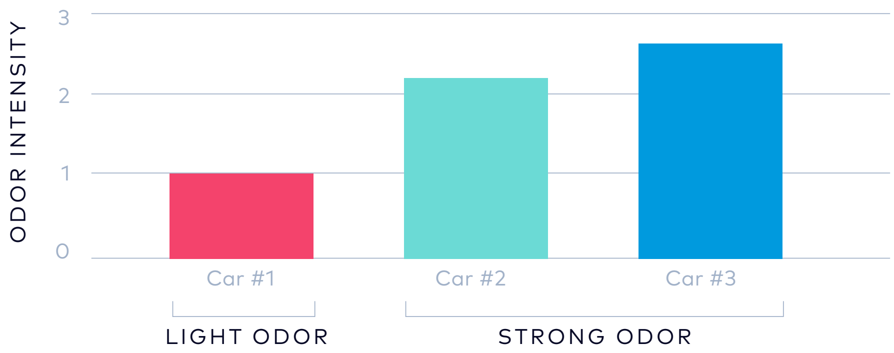


Figure 8 highlight's how a ride-hailing or car-sharing company might be able to determine when a car needs to be serviced. The figure clearly shows that cars #2 and #3 have a much stronger odor profile than car #1, indicating it is time for them to be cleaned before being put back into rotation.

FIGURE 9

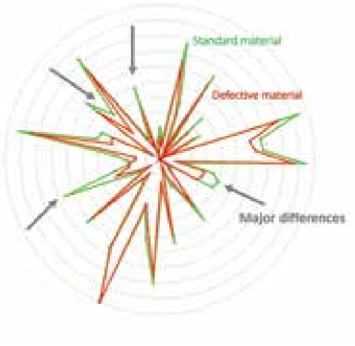


Figure 9 demonstrates the odor signature of standard materials versus that defective materials. If a digital olfaction sensor in a vehicle produced a defective odor signature, the indication is that there is something wrong with the vehicle.

Continued advances in digital olfaction will produce many more applicable use cases beyond what we've highlighted here. Digital olfaction not only provides consistency in the definition and use of smell, but enables companies to use odor data collected to inform key business decisions, from rejecting or approving a raw material supply, to ensuring positive customer experiences with ridesharing fleets.

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