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Handbook of Machine Olfaction

Electronic Nose Technology

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Contents

17 Environmental Monitoring *419*

Preface

In the past decade, electronic nose instrumentation has generated much interest internationally for its potential to solve a wide variety of problems in fragrance and cosmetics production, food and beverages manufacturing, chemical engineering, environmental monitoring, and more recently, medical diagnostics and bioprocesses. Several dozen companies are now designing and selling electronic nose units globally for a wide variety of expanding markets. An electronic nose is a machine that is designed to detect and discriminate among complex odors using a sensor array. The sensor array consists of broadly tuned (non-specific) sensors that are treated with a variety of odor-sensitive biological or chemical materials. An odor stimulus generates a characteristic fingerprint (or smellprint) from the sensor array. Patterns or fingerprints from known odors are used to construct a database and train a pattern recognition system so that unknown odors can subsequently be classified and identified. Thus, electronic nose instruments are comprised of hardware components to collect and transport odors to the sensor array – as well as electronic circuitry to digitize and store the sensor responses for signal processing.

This book provides a comprehensive and timely overview of our current state of knowledge of the use of electronic sensors for detection and identification of odorous compounds and mixtures. The handbook covers the scientific principles and technologies that are necessary to implement the use of an electronic nose. A comprehensive and definitive coverage of this emerging field is provided for both academic and practicing scientists. The handbook is intended to enable readers with a specific background, e.g. sensor technology, to become acquainted with other specialist aspects of this very multidisciplinary field.

Following this Preface, Part A covers the fundamentals of the key aspects related to electronic nose technology, from the biological olfactory system that has inspired the development of electronic nose technology, through to sensor materials and pattern analysis methods for use with chemical sensor arrays. This section provides a valuable tutorial for those readers who are new to the field before delving into the more specialist material in later chapters.

More advanced aspects of the technology are dealt with in Parts B and C, which provide an up-to-date survey of current research directions in the areas of instrumentation (Part B) and pattern analysis (Part C). Advanced instrumentation issues include novel sensing materials through to handheld chemical sensing devices and distributed chemosensory systems.

Recent topics in pattern analysis include on-line learning methods to extend calibration life-span, dynamic signal processing methods that exploit sensor transient behavior and optimization strategies for chemical sensor arrays.

An important element of the handbook is the inclusion of case studies of various applications of the electronic nose (Part D). Leading manufacturers of electronic nose equipment and key end-users have provided most of the chapters covering several interesting application areas.

Part A Overview: Fundamentals of Odor Sensing

Part A of the book is an overview of the fundamental key aspects of biological and machine olfaction. The section begins with two chapters that review the field of biological olfaction. The next four chapters cover the basic functional components of electronic noses including the sample handling system, gas sensor arrays and types, and signal processing systems for classification and identification of odorous compounds. The first chapter by Schiffman and Pearce describes how the biological sense of smell utilizes a remarkable sensor array of neurons that detects and discriminates among a vast number of volatile compounds (and mixtures of compounds) present in minute concentrations. This exquisite sensitivity is the reason why scientists and engineers have developed and begun to market machines that mimic this biological apparatus to detect and discriminate among volatile chemicals. The initial chapter provides an overview of the physicochemical and molecular properties of odorous molecules (called odorants) along with a description of odor classification and its limitations. It also provides an introduction to the biological olfactory pathway including descriptions of the olfactory epithelium, olfactory sensory neurons, seven-membrane-spanning receptors, the olfactory bulb, and the olfactory cortex. The chapter emphasizes that as few as 40 molecules of some compounds (e.g. mercaptans) are sufficient for humans to perceive an odor. Second, the range of distinctive odor sensations is vast, and a skilled perfume chemist can recognize and distinguish 8000 to 10 000 different substances on the basis of their odor quality. The remarkable discriminability is achieved by a coding scheme in which different odor stimuli are recognized by different combinations of olfactory receptors. That is, the biological olfactory system uses a combinatorial receptor coding scheme such that the specific patterns of activation across many neurons induced by an odor stimulus makes it possible to discriminate among the vast number of distinct smells.

The second chapter of Part A by Cometto-Muniz expands on the first chapter with additional details of human olfactory perception and an overview of the topic of chemesthesis (the common chemical sense). Olfactory perception is achieved by stimulation of the olfactory nerve (cranial nerve I), which allows us to discriminate between odor stimuli such as chocolate and coffee. Chemesthetic sensations, on the other hand, include piquancy, prickling, stinging, burning, freshness, tingling, and irritation, which are grouped under the term pungency and are mediated by a different nerve called the trigeminal nerve (cranial nerve V). Airborne compounds elicit odor sensations at concentrations below those that induce pungency. Methods for quantifying odor and pungency in humans are described including the determination of thresholds, the relationship between concentration and perceived intensity, and the sensory consequences of adding multiple compounds together in a mixture. Approaches for quantifying odor with static olfactometry, dynamic olfactometry, and environmental chambers are explained. In static olfactometry the vapor stimulus is drawn from an enclosed container in which the liquid and odorous vapor of the chemical(s) are in equilibrium with one another. In dynamic olfactometry, the vapor flows continuously in a carrier-gas stream, typically odorless air or nitrogen. A mathematical model is presented that can be used to predict odor and pungency threshold concentrations from physicochemical determinants. Instrumentation currently used by the flavor industry to analyze odorous mixtures including gas chromatography and mass spectrometry (GC/MS) is described. Overall, the sense of smell outperforms conventional analytic instruments (specifically GC/MS) in detecting and identifying odorous substances.

The third chapter by Nakamoto covers basic principals of odor handling and delivery of samples to electronic noses with two main types of systems (flow and static) described. In flow systems, the sensors are placed in the vapor flow of the sampling system so that the vapor around the sensors is constantly exchanged. Several flow systems are described, including headspace sampling, diffusion and permeation methods, a bubbler, and sampling bags. In static systems there is no vapor flow around the sensors but rather the sensors are exposed to vapor with a constant concentration. For static systems, the steady-state response of the sensors is measured. An open system is also illustrated in which a sensor is directly exposed to a vapor without a sensor chamber. Because different types of sensors vary widely in their sensitivity, methods for increasing the sensitivity are described using a preconcentrator tube. The physics of evaporation are also covered because most samples submitted to electronic noses are liquids from which odorants are evaporated. Issues of removal of humidity from samples are also described.

The fourth chapter by Nanto and Stetter is an overview of chemosensors that can be used in electronic nose systems to convert chemical information into an electrical signal. The chapter describes conductometric chemosensors (metal-oxide semiconductors (MOS) and conducting polymers (CPs)), chemocapacitors, potentiometric chemosensors (e.g. MOS field-effect transistors (MOSFETs)), gravimetric chemosensors (quartz crystal microbalance (QCM), surface acoustic wave (SAW)), optical chemosensors (surface plasmon resonance (SPR), fluorescent sensors), calorimetric sensors, and amperometric sensors. The underlying principle of conductometric sensors (also called chemoresistors) is the conductivity change that occurs when gaseous molecules react chemically with MOS or organic CPs. These are the simplest of type of gas sensors and are widely used to make arrays for gas and odor measurements. In chemocapacitor (CAP) devices, a polymer adsorbs the gaseous analyte, which alters the electrical (e.g. dielectric constant e) and physical properties (e.g. volume V) of the polymer relative to the baseline capacitance of the polymer when no gaseous analyte molecules are present. Potentiometric chemosensors of the MOSFET type utilize a gate that is made of a gas sensitive metal as a catalyst for gas sensing. Gravimetric odor sensors detect the effect of sorbed molecules on propagation of acoustic waves. The two main types of gravimetric sensors include QCM and SAW devices that are configured as mass-change sensing devices in the electronic nose. Optical chemosensors have several principals of operation. SPR is a physical process that can occur when plane-polarized light hits a metal film under total internal reflection conditions. In order to utilize this system as a gas sensor, a very thin film of methylmethacrylate, polyester resin or propylene ether as a sensing membrane can be deposited on gold metal thin film, and the angle of the reflected light is measured. Another type of chemosensor consists of optical fibers deposited with a fluorescent indicator dye in polymer matrices of varying polarity, hydrophobicity, pore size, elasticity, and swelling tendency to create unique sensing regions that interact differently with vapor molecules. Thermal sensors record the heat of solution of an analyte in the coating, with greater heat generated by larger amounts of absorbed analyte. The principle of amperometric gas sensors is the electrochemical oxidation or reduction of the analyte gas at a catalytic electrode surface that generates electrical current proportional to the concentration of the analyte.

The next chapter by Gutierrez-Osuna, Nagle, Kermani, and Schiffman covers interface circuits, signal conditioning electronics, and pre-processing algorithms; topics that serve as a bridge between the previous chapter on odor sensors (see Nanto and Stetter Chapter 4) and the following chapter on pattern analysis techniques (Hines and colleagues Chapter 6). The chapter presents a review of interface circuits for the most widely used odor sensors (chemoresistive, acoustic wave, and field effect), as well as an introduction to analog conditioning circuits for signal amplification, filtering, and compensation. Signal preprocessing algorithms commonly used prior to pattern analysis, including baseline manipulation, compression, and normalization, are also reviewed.

The final chapter in Section A by Hines, Boilot, Gardner, Gongora, Llobet deals with pattern analysis for electronic noses. There is an introduction into the nature of sensor array data and classification of analysis techniques including conventional statistical methods as well as biologically motivated technologies. This is followed by a more detailed discussion of statistical techniques such as principal components analysis (PCA), discriminant function analysis (DFA), partial least squares (PLS), multiple linear regression (MLR), and cluster analysis (CA) including nearest neighbor (NN). The discussion of biologically motivated technologies covers artificial neural networks (ANN), fuzzy inference systems (FIS), self-organizing map (SOM), radial basis function (RBF), genetic algorithms (GA), wavelets, neuro-fuzzy systems (NFS), and adaptive resonance theory (ART). Biologically motivated technologies for pattern analysis are especially attractive for use with electronic nose technology because they have the potential to perform incremental learning and offer self-organizing and self-stabilizing potential.

Part B Overview: Advanced Instrumentation

Part B of the book describes in some detail sensor technologies and instrumentation for electronic nose systems. The section begins with a chapter that reviews the field of electronic nose instruments that are currently available. These commercial instruments are predominantly large desktop-based systems that require an automated headspace sampler and a personal computer to operate the whole system. More recent instruments may be described as handheld but tend to have a limited battery life caused by either the need for the sensors to be held at a constant (elevated) temperature or high computing power.

The next chapter considers the development of optical rather than solid-state electronic noses. In this type of instrument, chemically sensitive materials are used as the sensing elements. For example, Dickinson et al. describe the operation of an optical 'smell camera' based upon the 2D raster scanning of the surface of a distributed capacitor, in order to read out the charge generated by a local catalytic reaction with the odor molecule. The composition and temperature of the catalyst, making up one electrode of the capacitor, is varied to generate a 2D image of the smell. In a different approach, Walt et al. coat a large number of small glass beads with a variety of fluorescent indicator dyes and these are used to create pixels in a composite image of an odor. This involves the fixing of the beads on to the end of optical fibers to complete the transducer. The process has been simplified more recently by Suslick et al. who have created a small rectangular array of porphyrin based sensing elements that change their chromatic properties when exposed to reactive gases. This colorimetric electronic nose can work from an ordinary light source and CCD array, and so is quite similar in technology to a commercial color flatbed scanner. The concept of an opto-electronic electronic nose is an attractive one and it remains to be seen how this technology stands against the alternatives.

The chapter by Baltes et al. explores the current research being undertaken in the development of small palm-top electronic noses. The approach focuses on the use of CMOS technology to fabricate a low-cost, low-power and miniature electronic nose. This necessitates the use of room-temperature gas-sensitive materials that can be deposited at a low temperature (compared with CMOS processes). Consequently, the chapter describes the development of capacitors, resistors, calorimeters, and cantilever beams predominantly coated with compounds used as the stationary phase in gas chromatography, i.e. rubbers and polymers. The fabrication of CMOS sensors permit the integration of CMOS or even BiCMOS circuitry next to the sensing elements and thus produce simple voltage read out. It is thus an attractive technology for the production of electronic noses at high volume, e.g. millions of units per year.

Gardner et al. expands upon the concept of a micro nose and investigates the possible development of an electronic nose that has integrated mechanical as well as electrical components. There has been rapid progress in the field of micro electro mechanical systems in recent years and this chapter considers related advances in the fabrication of micro valves, micro pumps and other micro-fluidic components. The challenges associated with making an analytical instrument on a chip are also presented with a description of work being carried out to make micro gas chromatographs and micro mass spectrometers. This approach poses a number of technological challenges because it has to deal with the transportation of the odor through the nose as well as the sensing elements. However these analytical micro noses may well compete with solid-state noses in terms of discriminating power.

The final chapter describes the advances taking place to create another sensory instrument, namely, the 'electronic tongue'. Clearly, an instrument that can mimic both the sense of smell and taste would provide valuable information on the nature of the flavor of a compound. In some ways the electronic tongue, as described, here behaves as an electronic nose under water – in other words the chemical sensors work in the liquid rather than gaseous phase. Thus the sensors are not specific to detecting the four primary tastes, salty, bitter, sweet, and sour (or putative additional taste primaries such as metallic and monosodium glutamate) but will provide signals that can be correlated with them. For example, the bitterness of a compound can be related to the acidity (i.e. pH value) while the sweetness will relate to the conductivity. The specificity of electrochemical sensors may be enhanced through the use of biological coatings of, for example, shear-horizontalmode SAW (SH-SAW) devices. Unfortunately, this type of biosensor tends to suffer (like all biosensors) from a short life when exposed to the environment. Nevertheless the development of electronic tongue technology could well lead to further advances in electronic nose technology.

Part C Overview: Advanced Signal Processing and Pattern Analysis

The foundations of signal processing strategies for chemical sensor array systems were provided in Chapter 6, which outlined the fundamentals of applying signal processing (predominantly pattern recognition based) techniques to chemical sensor arrays, for recognizing and discriminating specific 'fingerprints' of sensor array response that correspond to distinct categories of odor stimuli. This section of the handbook continues this theme by considering more advanced or, perhaps more accurately, specialized aspects of signal processing related to chemical sensor arrays – each chapter exploring fertile areas for future research in machine olfaction.

A key theme here is the technological advantage that can be achieved in these systems through the development of their integral signal/information processing system. The chapters in this section are representative of current trends in research in this area that appear to emphasize two distinct aspects. First, the improvement in system performance through advances in information processing strategies applied to chemical sensor arrays, for example by considering transient sensor response (as opposed to the single-valued steady-state response) to enhance discrimination or the detection threshold of these instruments. Second, widening the scope of applications of such systems and solving novel chemosensory detection problems, for example by correlating quantitative electronic nose data with qualitative human sensory panel information in an attempt to achieve automated sensory panel analysis through technological means.

The first of these themes looks more to the past, in terms of refining and improving on what has gone before, whereas the second theme is firmly looking to the future of this technology, in terms of opening up new domains in which the technology may be applied. For this reason this section of the handbook provides a taste (!) of some exciting prospects for the future of electronic nose technology as we move further into the 21st century, which will be driven by parallel developments in sensor technology and information processing capability.

The performance of electronic nose systems depends greatly on each of its components: from the odor delivery system; through to the choice and diversity of chemosensor materials; the interface circuitry; as well as the computational subsystem for discriminating between array responses.

The first three chapters relate to the first theme – that is, how to improve system performance by developing signal-processing strategies that may be applied to machine olfaction. Although perhaps at first sight not quite as groundbreaking in its ambition as the second theme, the topics covered in these chapters are vital to the future welfare of this field as a commercial, scientific, and technological endeavor. Key issues are covered here that are important for overcoming existing technological barriers to the take-up and deployment of the technology.

The first chapter in this section, by Llobet, covers aspects of dynamical model approaches for interpreting chemical sensor response information. Shifting the emphasis from steady-state sensor response information to transient sensor response promises less sensitivity to drift, the possibility of yielding additional discrimination of stimuli, and becomes essential when environmental conditions vary on a similar time scale as sensor response. An overview of a number of dynamical models and system identification techniques are provided alongside an example of how these might be applied to a specific sensing problem.

In many cases the practical performance of chemical sensor array systems is limited by changes in characteristics of sensor response over time or with chemical exposure. Commercial systems require frequent calibration against known standardized samples in order to minimize these effects and assure some minimum measurement accuracy. In many cases, recalibration may be required on a daily basis in order to maintain acceptable performance in the field. Therefore, the development of signal-processing strategies that counteract the affect of these shifts in sensor characteristics to repeated and identical stimuli are of considerable importance to the practitioner and researcher. A true understanding of temporal drift in sensor characteristics will only ultimately be found through a detailed physical understanding of interaction of chemicals with sensing materials. Even then, only if the mechanisms involved are purely deterministic will it be possible to eliminate their effects entirely. In the meantime, empirical methods for compensation can be developed and these are considered by Artursson and Holmberg in Chapter 13 as practical strategies for coping with this phenomenon in working instruments.

Due to the distributed nature of chemical sensor arrays it is not simple to define their sensing performance in terms of the properties of the underlying chemical sensors. However, this is vital if a rigorous approach to specification of sensor performance and future optimization of sensor arrays is ever going to be achieved. Pearce and Sanchez-Montanes (Chapter 14) describe recent work on quantifying sensor array performance for multidimensional stimuli such as odors that allows the system detection performance to be predicted given the tuning and noise properties of the underlying chemosensors. This allows the selection of chemosensors for specific detection tasks to be made, which until recently has been achieved by ad hoc means. In this chapter the theory of performance definition is applied to consider the practical issue of optimizing detection thresholds in artificial olfactory systems.

The final two chapters of this section describe new domains where artificial olfactory systems find application. New areas of application open up to this technology all the time but future challenges will also require new and refined signal-processing strategies. Here we consider two areas where the signal-processing subsystems play a key part in this development.

The first of these considers signal-processing strategies for correlating human-defined sensory panel information with chemical sensor-array responses. This has important consequences, particularly in the food and beverage industry where millions of dollars are spent each year on both instrumental analyses (mostly GC and MS-based methods) and sensory panel investigations. Neither of these approaches in isolation offers a complete picture of odor or flavor quality. By applying multivariate statistical analysis techniques to chemical sensor array data there is the possibility for artificial olfactory systems to provide the missing link between instrumental and sensory-based investigations. Some of these methods and an example of an environmental monitoring problem is provided by Sneath and Persaud in Chapter 15.

Finally a promising new area of research in machine olfaction is presented – applying chemical sensor systems to mobile robotic systems. Ishida and Moriizumi consider the possibilities for mobile chemosensory systems. Two possible modes of operation are considered here: relatively straightforward chemical trail following and the far more complex problem of chemical source localization in turbulent odor plumes. Insect models are used as the inspiration for the approach – the ant for trail following behavior and the moth for chemotaxis within airborne odor plumes. Although their experiments are preliminary and work in this area is at an early stage, there are many exciting research challenges that will need to be considered in the future.

Part D Overview: Applications and Case Studies

This final section of the Handbook presents a variety of areas in which electronic nose technology has been applied. In each application, the tools and techniques of Parts A, B, and C are selectively employed to achieve specific performance goals.

In the first chapter, Nagle, Gutierrez-Osuna, Kermani, and Schiffman examine environmental applications. Examples of water, land, and air monitoring experiments reported in the open literature are examined, followed by four case studies of work done by the authors. The first three demonstrate the ability of the AromaScan A32S electronic nose to classify odors from animal confinement facilities. In the first, the A32S was employed to classify the source of an odor emission as being from the lagoon, the confinement building exhaust fan, or a downwind ambient air. In the second, the A32S was used to determine the detection threshold concentration for acetic acid, a major individual constituent in swine slurry odor. In the third case study, the A32S was used to evaluate the performance of a biofilter of earth, wood chips, small twigs, and straw on the confinement building exhaust as an odor remediation measure. In the fourth case study, the NS State Electronic nose, a prototype unit with fifteen commercially available MOSs, demonstrated that an electronic nose can differentiate between five types of fungi that commonly lower indoor air quality in office buildings and industrial plants. These four case studies demonstrate that the electronic nose can perform well in various environmental monitoring applications.

The next chapter by Persaud, Pisanelli, and Evans gives a summary of medical diagnostics and health-monitoring applications. Many diseases and intoxications are accompanied by characteristic odors, and their recognition can provide diagnostic clues, guide the laboratory evaluation, and affect the choice of immediate therapy. After reviewing the history of electronic nose uses in this area, two case studies are introduced. In the first, metabolic changes due to myopathies are detected by urine odor. The electronic nose was able to differentiate the normal population from that with myopathies. In the second case study, an electronic nose was employed to detect bacterial vaginosis. Success in this area led Osmetech to seek federal drugs administration (FDA) approval of one of their instruments for this application.

Next, Deffenderfer, Feast, and Garneau provide a comprehensive overview of the electronic nose as an analytical tool for applications in natural products ranging from identifying solvents and the discrimination of spirits, to beverage and grain quality. Following this overview, they then illustrate two specific case studies. In the first, the Cyranose 320 is used to identify trees of different species for the pulp and paper industries in eastern Canada. In the second case study, the Cyranose 320 is employed to differentiate essential oil-bearing plants. Their results indicate that the electronic nose has great potential in these industries.

Process monitoring is the subject of the fourth applications chapter. Haugen and Bachinger give an overview of the fundamentals of non-invasive on-line monitoring of biological processes, followed by two case studies. The electronic nose in their studies used a set of 10 MOSFETs sensors, up to 19 MOS sensors and 1 CO_2-monitor based on infrared adsorption. The MOSFET sensors were produced in-house at Linköping University (Sweden) with different catalytic metal gates of Pd, Pt, and Ir. The MOS sensors used were commercially available sensors of Taguchi (TGS) or fuzzy inference systems (FIS) type. The electronic nose was used to monitor the aroma of cell cultures to gain insight into cell and process state changes as well as to identify process faults. In their first case study, ANN technology was used successfully to relate the gas sensor signal pattern to the cell biomass from *Escherichia coli* fermentations. The second case study focused on using an electronic nose to monitor the composition of the bioreactor headspace gas, and thus to track physiological state changes. Fast cell transition states were monitored in a semiquantitative approach appropriate for on-line and non-invasive control of industrial bioprocesses.

The next applications chapter focuses on food and beverage quality assurance. In this chapter, DiNatale states that ‘the analysis of foodstuff is one of the most promising and also the most traveled road towards industrial applications for this technology.’ After a review of the literature in this field, a case study in fish freshness is detailed. The study uses a prototype instrument called the LibraNose from the University of Rome ‘Tor Vergata’. The LibraNose is based on an array of QCM sensors whose chemical sensitivity is given by molecular films of metalloporphyrins and similar compounds. Spoilage in fish can be detected through the measure of the amount of amines, such as trimethylamine, in the headspace of storage containers. In the study, the LibraNose was able to track two important parameters indicating that the electronic nose is a good candidate for future use in food freshness applications.

The next chapter focuses on automotive and aerospace electronic nose applications. Automotive applications include monitoring the exhaust for combustion efficiency, monitoring the engine compartment for leaking oil or other fluids, and monitoring the cabin air for passenger safety (offgassing of fabrics and materials, leaks of coolant from the air-conditioning system, and intake of air from the roadway and the engine compartment). Aerospace applications vary from the addition of an electronic nose to study the variations in atmosphere over days or seasons on other planets, to monitoring air quality in human habitats. The electronic nose developed at the Jet Propulsion Laboratory (JPL) was designed to detect a suite of compounds in the crew habitat of a spacecraft, an enclosed space where air is recycled and it is unlikely that unknown and unexpected vapors will be released. In this chapter, Ryan and Zhou present a case study in which the JPL ENose in a flight experiment on the Space Shuttle flight STS-95 (October – November 1998) was tested as a continuous air quality monitor to distinguish among, identify and quantify 10 common contaminants which may be present as a spill or leak in the recirculated breathing air of the space shuttle or space station. The JPL ENose has an array of 32 sensors, coated with 16 polymers/carbon composite sensing films developed at Caltech. In the study, the JPL ENose was trained to 12 compounds, the 10 compounds most likely to leak or spill and the other two being humidity change and vapor from a medical swab (2-propanol and water) used daily to confirm that the device was operating properly. For all cases except one (formaldehyde), the JPL ENose was able to detect the compound at or below the expected levels.

Pamula investigates the use of the electronic nose for the detection of explosives. After reviewing the literature in this important application of electronic nose technology, the author reviews progress of the defense advanced research projects agency (DARPA) program to detect explosive mines by their chemical signatures. The chapter concludes with a case study of the Nomadics' Fido (Fluorescence Impersonating Dog Olfaction) device. The device uses fluorescent polymer beads to detect trace amounts of TNT emanating from landmines. This technology shows great promise for future deployment in demining applications.

In the final applications chapter, Rodriguez, Tan, and Gygax survey electronic nose applications in cosmetics and fragrances. Even though the use of electronic noses in the cosmetic and fragrance industry has been more limited than in many other areas, the published literature shows that, with optimization, many cosmetic and fragrance related analytical tasks can be solved. After the literature review, this chapter presents two case studies. In the first, eight fragrant samples with distinct odor characters but similar bulk composition were tested. Samples were analyzed by an HP 4440 Chemical Sensor and by capillary GC/FID. Both approaches were successful in classifying and differentiating the odorous samples. In the second study, an Alpha MOS Fox4000 electronic nose with 18 chemical sensors and a human panel were used to judge the odor quality of a sunscreen product. The product samples had already passed analytical tests prior to undergoing sensory evaluation. Expert panel evaluations were made on ~ 150 samples judged to fall in three categories: meets sensory standard, does not meet sensory standard but can be used as a 'diluent' when adjusting bulk quality, and does not meet sensory standard and is rejected. Over a six-month evaluation period, the Fox4000 demonstrated its ability to carry out sensory analyses by accurately classifying 'good' and 'bad' batches of the tested product.

We believe that the material presented in the Handbook of Electronic Noses should not only help readers to find out more about this new and challenging subject, but also act as a useful reference in the future.

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