Use of electronic noses for detection of odour from animal production facilities: a review

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Abstract In the field of controlling livestock and poultry odours in the internal and external environment and in derived food products, one main obstacle is how to measure the odour in a suitable way. Olfactometry and a human panel have been used in most studies of farm odour until now. Alternatives like electronic noses are interesting considering disadvantages for olfactometry regarding cost and labour requirement. An electronic device can produce an almost instant response which is useful in many applications. Studies have shown detection of farm odour for some electronic noses and also response to odour concentrations. Other studies have shown very high odour threshold values compared to human noses. Electronic noses with a large number of sensors have been developed since a base was formed in the 1950s. The fast progress in data processing and sensor development in the latest years have made the electronic noses interesting for a large number of industrial applications in the food processing industry, as well as in other areas. Materials like manure produce a complex mixture of odorous compounds and the interaction between these creates a unique odour where no specific dominating and characterising compound seems to exist. Related to swine farms almost 200 different odorous compounds have been reported. The electronic noses can, depending on the sensitivity of its sensors, detect some compounds at lower levels than the human nose, while other compounds offensive to a human nose cannot be detected. Proper function of the electronic noses with sensitivity for the odorous gases in the application must be followed by satisfying properties regarding ageing, temperature stability, humidity and other environmental factors.

Keywords Agriculture; animals; electronic nose; farming; measurement; odour

Introduction

One main obstacle in controlling farmstead odour is finding a suitable method for measurement. Most studies of farmstead odours until now have used olfactometry and the human nose measuring concentration, intensity and offensiveness. Disadvantages are expense of operation and difficulty of collecting representative samples (Hamilton and Arogo, 1999). Scentometers (simple hand-held dilution devices) deal with the person measuring, his/her bias and adaption to odour. Traditional gas chromatography mass spectroscopy (GC-MS) gives information of the concentration of a lot of volatile compounds present, however, little is known about the relation between these concentrations in a mixture and the human-perceived odour. In a study (Laing et al., 1994) of four major odorants from sewage plants (hydrogen sulphide, isovaleric acid, butanethiol, and skatole), the perceived odour intensity from a mixture was less than the sum of their intensities but greater than the intensity of each individual constituent.

An electronic device can produce an instant and continuous measure signal useful in many applications. The aim of this study is to find out if electronic noses might be suitable for measuring farmstead odours at the present state of development. Commercial devices (Table 1) and marketing of small and cheaper models intended for environmental studies add focus to the question.

Identification of materials possessing sensitivity to chemicals (odorants) and research concerning semiconductor materials in the 1950s formed a base and a start of the...
<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Location of company</th>
<th>Name of the electronic nose</th>
<th>Production information presented</th>
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<tbody>
<tr>
<td>Nordic Sensor Technologies</td>
<td>Linköping, Sweden</td>
<td>NST 3320</td>
<td>Modified according to requirements. Sensor types: MOSFET (metal oxide semiconductor field effect transistors); MISIC sensors (similar to the MOSFET but based on silicon carbide (SiC) instead of silicon); MOS (metal oxide sensors)</td>
</tr>
<tr>
<td>Osmetech (Aromascan Inc)</td>
<td>Crewe, England Hollis, New Hampshire, USA</td>
<td>Multisampler SP</td>
<td>32 (up to 48) element conducting-polymer (CP) sensor array</td>
</tr>
<tr>
<td>Lennartz Electronic GmbH (MoTech)</td>
<td>Tübingen, Germany</td>
<td>MOSES II</td>
<td>OMR Module 8 quartz micro balance sensors coated with different polymers. ScO₂ Module 8 different semiconductor sensors. based on tin dioxide. Calorimetric Module. Under development</td>
</tr>
<tr>
<td>Cyrano Sciences</td>
<td>Pasadena, California, USA</td>
<td>Cyranose 320</td>
<td>32 thin-film carbon-black polymer composite chemiresistors configured into an array</td>
</tr>
<tr>
<td>Alpha-MOS</td>
<td>Toulouse, France Hillborough N.J., USA</td>
<td>PROMETHEUS</td>
<td>Multi sensor array system (SAS) with fingerprint mass spectrometry (FMS). Made of KRONOS (fingerprint mass spectrometer) and FOX 4000 (sensor array system)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FOX</td>
<td>Hybrid sensor technology with MOS, CP, QCM sensors (metal oxide, conducting polymer, quartz crystal microbalances). FOX 2000 – 6 sensors, FOX 3000 – 12 sensors, FOX 4000 – 18 sensors, FOX 5000 – 24 sensors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Centauri</td>
<td>Bench top volatile organic compound (VOC) analyser. 6 MOS sensors. Sensor array technology and pattern recognition software</td>
</tr>
<tr>
<td>Bloodhound Sensors Ltd</td>
<td>Leeds, England</td>
<td>BH114 Sensory array system</td>
<td>14 sensors and a range of sensors available based on two technologies. Conductive Polymers suited to the detection of polar species. Discotic Liquid Crystals suited to non-polar species</td>
</tr>
<tr>
<td>RST Rostock Raumfahrt und Umweltschutz GmbH</td>
<td>Warnemünde, Germany</td>
<td>SamDirect M3-1</td>
<td>QCM (quartz crystal microbalances), SAW (surface acoustic wave transducers) and MOS (metal oxide) sensors. Measurement system for detection and classification of gaseous compounds. Based on electronic nose. Supervision system based on electronic nose.</td>
</tr>
<tr>
<td>RST Rostock Raumfahrt und Umweltschutz GmbH</td>
<td>Warnemünde, Germany</td>
<td>SamDirect G2-1</td>
<td>Portable sensor system based on electronic nose.</td>
</tr>
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<td></td>
<td></td>
<td>SamSelect</td>
<td></td>
</tr>
<tr>
<td>S-Mart Nose, Laboratory Dr. Zesiger</td>
<td>Marin-Epagnier, Switzerland</td>
<td>SMart Nose 300</td>
<td>Mass spectrometry based artificial nose.</td>
</tr>
<tr>
<td>WMA Airsense Analytics GmbH</td>
<td>Schwerin, Germany</td>
<td>PEN</td>
<td>Portable instrument 10 MOS (metal oxide sensors).</td>
</tr>
</tbody>
</table>
development of artificial olfactory systems (Pearce, 1997). Electronic noses (the term used since the late 1980s), by definition, (Gardner and Bartlett, 1994) contain electronic-chemical sensors and a pattern recognition system. The fast progress in data processing and sensor development in recent years have made the electronic noses interesting for a large number of industrial applications in the food processing industry as well as in other areas.

In recent years, quite a lot of research has been done involving use and application of electronic noses in food analysis (Schaller et al., 1998) such as analysis of fungal volatiles from food, feed and grain spoilage (Schnürer et al., 1999; Magan and Evans, P., 2000; Olsson et al., 2000), meat quality (Annor-Frempong et al., 1998; Grigioni et al., 2000), pear ripening (Oshita, 2000), classification of orange juice (Shaw et al., 2000). An electronic nose and a human panel were used in an experiment analysing UHT milk and tomato paste (Di Natale et al., 1998). Other examples are analysis of olive oil, ale, wine and cheese. Ólafsdóttir et al. (2000) used an electronic nose (FreshSense, Iceland) with gas sensors (CO, H₂S, NO, NO₂, SO₂, NH₃) and was able to predict the quality of the fish capelin when compared to the fishmeal industry traditionally measured total volatile bases (TVB; mg of N per 100 g of muscle). Biological applications and medicine are other areas and even odour from human skin (Di Natale et al., 2000) has been investigated. Mielle and Marquis (2000) indicate that

<table>
<thead>
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<tbody>
<tr>
<td>Element Ltd (RKS Sensor Systems)</td>
<td>Sauðarkrókur, Iceland</td>
<td>FreshSense</td>
<td>MOS (metal oxide) sensors</td>
</tr>
<tr>
<td>Envionics Industry Oy</td>
<td>Mikkeki (Kuopio), Finland</td>
<td>MGD-1</td>
<td>IMCELL-technique (advanced form of traditional ion mobility spectrometry, IMS)</td>
</tr>
<tr>
<td>Electronic Sensor Technology</td>
<td>Newbury Park, CA, USA</td>
<td>4100 Vapour Detector, 7100 Vapour Detector</td>
<td>6–15 SAW sensors (surface acoustic wave transducers). Gas chromatograph based. Portable handheld instrument and bench top instrument</td>
</tr>
<tr>
<td>Microsensor Systems Inc</td>
<td>Orlando, USA</td>
<td>VaporLab</td>
<td>Array of polymer-coated SAW sensors (surface acoustic wave transducers). Handheld, battery powered. Up to 6 sensors (4 typical)</td>
</tr>
<tr>
<td>Marconi Applied Technologies (EEV, Neotronics)</td>
<td>Chelmsford, Essex, England, UK Elmford, NY, USA Brampton, Ontario, Canada Bievres, Cedex, France</td>
<td>eNOSE 5000</td>
<td>Array of non-specific chemical sensors. Three types of sensors available: Conducting Polymer (CP) Sensors, Metal Oxide Sensors, Bulk Acoustic Wave Sensors. A standard sensor module consists of 12 CP sensors. MOS modules contain 8 sensors. A standard sensor module contains 8 BAW sensors (piezoelectric devices based on quartz crystal oscillators, QCM) coated with a range of materials</td>
</tr>
<tr>
<td>HKR Sensorsysteme GmbH</td>
<td>München, Germany</td>
<td>QMB 6</td>
<td>Monolithic chemosensor array based on quartz crystals. The 6 sensor elements are coated with different custom-built gas sensitive materials</td>
</tr>
<tr>
<td>Hewlett Packard</td>
<td></td>
<td>Agilent 4440</td>
<td>Mass-spectrometer based</td>
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systems based on metal oxide gas sensors may have a cycle time of less than 10 minutes and performances similar to mass spectra systems. Manufacturers also speak about seconds (Staples, 1999).

The concentration of different odour compounds in and around animal houses is, to a major extent unknown even if a large number of volatile compounds have been identified. O’Neill and Phillips (1992) listed 168 compounds. Many compounds are present at very low concentrations. Work has been performed to correlate odour with concentrations of the single components ammonia and hydrogen sulphiide. However, no such correlation seems to exist (Livestock and Poultry Odor Workshop I, 2000). Different sensors have varying capability of detecting a specific compound as well as the human nose, and electronic noses can, depending on the sensitivity, detect some compounds at far lower levels than the human nose while other compounds which are offensive to the human nose cannot be detected (Strike et al., 1999; Kher, 2000).

**Farm odour studies and environmental studies involving electronic noses**

Different techniques for measuring odours from livestock wastes were evaluated by Hobbs et al. (1995). Techniques using an electronic nose, a photoionization detector (PID), olfactometry and GC-MS were compared. The electronic nose contained 20 polypyrrole sensors of five types and was manufactured by the University of Manchester. The photoionization detector (ELE International) was equipped with a lamp with ionising energy of 10.2 eV. At this energy level volatile organic compounds (VOCs) as well as ammonia and hydrogen sulphur were included in detection but water vapour, carbon dioxide and methane were excluded. Silica and carbon-based adsorbents were used to concentrate odour for GC-MS. The olfactometric analysis showed a large variation of odour concentration with an average of 994,000 OU/m³ for pig odour and 67,000 OU/m³ for chicken odour. The electronic nose responded and was able to distinguish between odours at concentrations of over 60,000 OU/m³. The response from the electronic nose was non-linear for undiluted pig odour compared to ten-fold diluted (with response defined as change in difference of resistance divided by base resistance). Identification was easier for the ten-fold diluted odour than for the undiluted and it was suggested that the higher content of water vapour (58% relative humidity compared to about 30%) might have caused this by competing for sites on the sensors. The PID gave a linear response down to 1000 OU/m³. Improvement of the electronic nose by improved selection and manufacture of sensors was suggested as a potential.

Persaud et al. (1996) found a signal proportional to the concentration of volatile compounds when using conducting polymer odour sensors and artificial pig slurry. During three months the response was reproducible and the authors concluded that the chemicals involved did not damage the sensors.

An electronic nose was compared to a human panel in a study of odours emanating from acetic acid and synthetic pig slurry (Classen et al., 1997). The synthetic pig slurry contained acetic acid, propanoic acid, 2-methyl propanoic acid, butanoic acid, 3-methylbutanoic acid, pentanoic acid, phenol, 4-methylphenol, indole, 3-methylindole. The electronic nose (AromaScan) contained an array of 32 conducting polymer sensors. Dilutions were made and placed in tedlar bags together with reference air (40% relative humidity). The panellists were presented to dilutions and blanks randomly and smelled the headspace after removing the air-tight clips from the bags. In the experiments, acetic acid in dilutions with mineral oil was determined at lower concentrations than in dilutions with water and this fact was taken as an indication of reduction of sensitivity of the electronic nose due to humidity. Regarding acetic acid, the detection thresholds for the human and the electronic nose were approximately the same. In the first experiment with the synthetic slurry the human panel determined odour thresholds, but the sensor array of the electronic
nose together with data compression, consisting of windowed time integration (32 sensors 45 seconds reduced to 32 sensors 4 windows) and Karhunen-Loève expansion, was not able to select a detection boundary. Modifications of the data compression were made with somewhat better, but still poor, results in detection and classification, and improvements in experimental set-up were suggested.

Misselbrook et al. (1997) used two types of electronic noses (the Aromascan commercially available and the Odourmapper developed at University of Manchester) and by dynamic dilution olfactometry to measure odour concentrations following application of slurry to grassland. The sensors in the electronic noses were made from conducting polymers, the Aromascan contained 32 polypyrrole sensors and the Odourmapper contained 20 polynindole sensors. The change in resistance was recorded. Air samples were collected in tedlar bags before application of slurry and at time intervals after application. The experiment included samples from outside air downwind and samples from a wind tunnel underneath in which cattle slurry was spread. The samples were analysed at a laboratory. The samples taken at different times after spreading showed decreasing values of odour concentration. In the measurements the electronic noses responded to odour concentrations of 50 OU/m³ suggesting ability in a range of agricultural applications. A single line was fitted for each electronic nose expressing relationship to odour concentration (with a variance of 59–62%). A probable factor decreasing the variance is a variation of gas mixture of the VOC of the different samples. The samples were taken at different times and differences in response patterns were suggested to depend on variations in gas mixture and water vapour content according to time. Variations were also suggested to depend on the environment (background odours). However the response patterns were not distinctly different and classification to one odour type using an electronic nose with pattern recognition was concluded.

Byun et al. (1997) examined different methods of reduction of complex multidimensional data to be presented in a form easily interpreted by the user. Linear methods, such as Karhunen-Loève expansion can be used as well as non-linear methods such as Sammon’s mapping and neural networks such as Kohonen’s map. It was found that the best method for visualising multidimensional data combined both principal component analysis and Sammon mapping and resulted in rapid clustering without assumptions of class belonging. Differences between odours emanating from slurry from pigs fed with two different diets were easy visualised.

In a study of breath odour from dairy cattle Elliott-Martin et al. (1997) suggested it was possible to discriminate between healthy cows and cows with ketosis. An electronic nose (Fox 2000) with six metal oxide gas sensors was used in the study together with GC-MS and FTIR. An acetone concentration of 1–10 ppm in the breath (confirmed by blood analysis) was indicative of ketosis. The response from the electronic nose gave a 89% success rate in classification of healthy and ketoic cows. It was suggested that the conducting polymer gas sensor might be advantageous because of its lower sensitivity to hydrocarbons such as methane. Methane was found in concentrations of 70–1000 ppm. Dimethyl sulphide was found in concentrations of 80–100 ppm and butan-2-one in 70–80 ppm. Further work in the area of predicting illnesses with an electronic nose by sensing the breath of a cow is in progress (Spencer, 1999).

Rieß et al. (2000) measured odours in livestock buildings with an electronic nose and by olfactometry. The electronic nose contained a total of 18 sensors in three chambers each with six metal oxide sensors (MOS). For valuation the measured resistance values were scaled to initial resistance \(R/R_0\) and FOX 4000 software was used in data valuation. Distinction between different cattle stables was investigated by samples taken in a beef bull and a dairy cattle stable. The electronic nose found a distinction between the two stables although the samples seemed very similar presented to the human nose. Four weeks later.
new samples were collected in the beef bull stable. These were now differed from the original samples. It was suggested that altered feed, increasing weight and meteorological fluctuations was the reason. Neural network (with backpropagation architecture) showed a recognition rate of 95% while other methods showed poorer result. Rieß et al. (2000) also made quantitative measurements in two departments for fattening pigs with different ventilation design. During a week, ten samples from each department were tested by olfactometry and each 40 minutes a measurement was performed by the electronic nose for each department. The electronic nose was calibrated according to odour concentration (OU/m³) and the sum of sensor signals (adding the sensor deflections). Weighting of individual sensors is thought to be necessary in the future. A diurnal change in odour concentration was observed by the electronic nose (increase in the morning and decrease during night). The mean value of odour concentration was measured to 130 by olfactometry compared to 129 by the electronic nose in one department and 204 compared to 165 in the other. The diurnal change caused a slightly lower average value measured by the electronic nose.

Odours from a range of places in ten sewage treatment works were measured by olfactometry and an electronic nose (Stuetz et al., 1998, 1999a). The electronic nose (Neotronics NOSE) incorporated 12 conducting polymer sensors. UNISTAT statistical package with canonical discriminant and canonical correlation analysis were used. The electronic nose responded to odour concentrations of 125–781,066 OU/m³. For a single treatment plant a robust correlation was found between threshold odour numbers (OU/m³) and response of the electronic nose. However, regarding samples from a range of locations within different plants no such correlation was found. Measurements indicating sources of odour at a specific treatment work as well as environmental impact and efficiency of abatement units were suggested as suitable applications of electronic noses assuming the stable nature of the odour in these applications. Measurement of wastewater liquors (Fenner and Stuetz, 1999) showed that an electronic nose could distinguish between different types and origins.

Nicolas et al. (1999) performed tests with arrays of tin oxide sensors (Figaro), 12 sensors in a laboratory system and eight and four sensors in two experimental field detectors. Classification was found to be very good (laboratory system) using discriminant analysis or artificial neural networks when recognising fresh refuse odour, biogas and clinker odour. Also the field detector with eight sensors showed good classification at five sites, however unstable in windy places because of an open design with static contact between sensors and ambient air. Thermal insulation and pumped air flow were suggested for avoiding the influence of temperature and air movement. Air humidity was thought not to have a dramatic effect on recognition if variation is included in a learning phase.

BOD₅ (Biochemical Oxygen Demand) in samples of wastewater was measured by an electronic nose (Neotronics NOSE) with a sensor array of 12 polypyrrole conducting polymers (Stuetz et al., 1999c). A linear relationship between sensor response and BOD was found for a single work in time periods of four weeks or less but not over five months. No generalised relationship was found (using canonical correlation) between the response of the electronic nose and BOD in samples of raw sewage, settled sewage and final effluent from three wastewater treatment plants (Stuetz et al., 1999b).

An electronic nose with 12 metal oxide sensors (Alpha MOS, Fox 3000) was used in measuring odours emanating from a composting plant (Bockreis and Jager, 1998; 1999). Samples with odour concentrations of 40–100,000 OU/m³ (Bockreis and Jager, 1999) were used to calibrate the sensor array and teach an artificial neural network (ANN) the correlation between gas mixture and odour concentration. Varying odour composition at a composting plant and changing ambient air was thought to be a reason for difficulties in correlation between signals of the sensor array and the odour concentration. It was possible to get characteristic patterns for different parts of the plant.
Tests with an electronic nose (eNOSE 4000) in bioprocesses have shown the possibility of detection of abnormalities in the process (Pradyumna et al., 1998).

Discussion
Proper function of the electronic noses with sensitivity for the odorous gases in the application must be followed by satisfying properties regarding ageing, stability for temperature, humidity and other environmental factors. Kalman et al. (2000) performed a study of emissions from leather, which may be a problem in cars. The sensor array in the electronic nose (NST 3210) consisted of ten gas-sensitive metal oxide semiconductor field effective sensors (MOSFET) of different types and five semiconducting metal oxide sensors (MOS) and the signals were processed using principal component analysis (PCA). The electronic nose easily found samples with unusual gas emissions. It was suggested that humidity as well as temperature of the sample should be kept as constant as possible in order to avoid sensor changes due to sensitivity of humidity and headspace concentration changes due to temperature change.

Beside odour related to animal houses another interesting agricultural application of electronic noses is the measurement of fruit ripening and vegetable quality. However, according to Sarig (2000), at present there are no universal artificial noses that can solve odour-sensing problems related to quality evaluation of fresh produce. Heining and Wiese (2000) state that the use of electronic noses in ambient air control lies in the immediate future and that recognition and quantification of smells from agriculture together with measurements in composting and sewage engineering are most important. Strike et al. (1999) state that the majority of the literature deals with bench-top instruments although electronic noses frequently are presented to make rapid “in the field” measurements. Furthermore Strike et al. (1999) declare: “It is unfortunate that the popular press, aided to some extent by both industry and academia alike, have done much to oversell the current technology”.

Some volatile compounds present in farm odour, for example, methane and carbon dioxide, are odourless. Another gas present in comparatively high concentration is ammonia for which the human nose is rather insensitive. A perfect electronic nose should disregard odourless compounds as well as humidity and temperature and be as sensitive to each compound present as the human nose. Furthermore, it should know the perception of the human nose for every combination of volatile compounds in a mixture of gases and the effect of dust particles in the air.

Eklöv and Lundström (1999) have shown the possibility of increasing the information of a gas mixture by combining a flow cell with a catalyst (accelerating the chemical reaction consuming and forming new molecules) and a number of sensors in the flow direction. Using Pd MOSFET sensors, a cell with a thick Pd layer, principal component analysis (PCA) and artificial neural network (ANN) hydrogen and ethanol in a (binary) gas mixture could be identified and quantified.

Conclusions
Further research and development are needed in order to get an electronic nose close to the perfect one for environmental odour measurements. From the experiments made until now the following conclusions can be drawn.
• Odour intensities of 40 OU/m³ or higher can be registered making practical use possible.
• An electronic nose can be calibrated to recognise a specific odour from animals. For environmental studies this capability sometimes seems too good, grouping odours similar to human noses in different categories.
• A relation between response of an electronic nose and odour concentration can be derived for odours from the same place during a specific time.
Response of an electronic nose to similar odours from different places or from different time periods seem to differ which result in problems when predicting odour intensity. This inconvenience may be a result of different gas mixtures.

References


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