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Malodor Detection Based on Electronic Nose

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1. Introduction

Recent decades have observed significantly increasing interest in the applications of electronic nose (E-nose) for qualitative analysis of odors. The first E-nose experiments were conducted in the early 1990s. (Shurmer et al., 1990; Shurmer & Gardner, 1992) Since then, E-nose has become a powerful tool to complement or even replace traditional chemical analysis in many applications ranging from quality control of foods (Barié et al., 2006; Panigrahi et al., 2006; Santonico et al., 2008; Tikk et al., 2008) and beverages (Ragazzo-Sanchez et al., 2008; Yu & Wang, 2007; Wongchoosuk et al., 2009b, 2010b), environment protection (Negri & Reich, 2001; Kuske et al., 2005), medical applications (Chan et al., 2009) to public safety (Scorsone et al., 2006; Zhang et al., 2007). Electronic nose employs an array of chemical gas sensors, numbering from 2 up to a few hundred sensors. Research on chemical gas sensors is mainly focused on improving two properties: selectivity (specificity to a molecule or a class of molecules) and sensitivity (strength of signal upon exposure to low concentration of molecules). Both selectivity and sensitivity leads to performance enhancement of an e-nose for specific applications such as bomb detection (Lubczyk et al., 2010), determination of food freshness based on amine detection (Lorwongtragool et al., 2011; Liao et al., 2010), quality control of alcoholic beverages (Wongchoosuk et al., 2009b, 2010b) and hydrogen gas sensing (Wongchoosuk et al., 2010a).

Chemical sensors can be classified into 4 types (James et al., 2005) based on their transduction, a mechanism that converts chemical interaction into a sensor signal: (1) Optical, (2) Thermal, (3) Electrochemical and (4) Gravimetric. Electrochemical transduction has so far dominated research activities on gas sensors, because its interface setup is more straightforward than other transduction methods. (Choopun et al., 2007; Lorwongtragool et al., 2011) Nevertheless, many research groups including us have been working on many transduction principles, i.e., optical (Uttiya et al, 2008) and gravimetric (Tuantranont et al, 2008), in parallel in order to take advantage of hybrid methodology that could dramatically enhance the performance of electronic nose. Due to the simplicity of the electronics involved, most commercial chemical gas sensors adopt electrical transduction technology in which the metal oxide semiconductors assume the most used sensor architecture according to their low-cost, high sensitivity and simplicity in function. (Korotcenkov, 2007) Thus, one
could easily integrate several functional elements such as sensitive layer, signal converter and control electronics within the same device of a size as required for most applications. Notwithstanding the simple working principles of metal oxide gas sensors, the gas-sensing mechanism at the microscopic level is quite complex and so far still insufficiently understood. (Korotcenkov, 2005; Surnev et al., 2003) As widely known, the gas sensors having the same metal oxide materials can have completely different gas-sensing properties depending on the preparation conditions. It is commonly believed that the chemo-resistive change of the metal oxides is caused by catalytic redox reactions at the sensing surface. Such reactions are controlled by electronic structure, chemical composition, crystal structure and relative orientation of the oxide surface to the analyte molecules, thereby allowing tuning their gas-sensing properties by modifying such parameters. Structural engineering by reducing grain size and modifying crystallite microstructure has been widely accepted as the best method to optimize the metal oxide gas sensors. It can be said that metal oxide gas sensors have nowadays been the most robust technology for gas detection in most applications. As will be seen in this chapter, most E-noses employ this type of gas sensors, except for section 2.1 where carbon nanotube/polymer gas sensors were developed for amine detection.

In this chapter, we have explored the applications of E-nose for malodor detection in three areas: (1) animal malodor, (2) human body odor and (3) indoor air quality.

2. Animal malodor

Among the numerous applications of an E-nose, detection of malodor involving with animal often refers to odor assessments of animal products and animal waste. The changes in the sensory properties of the both animal products and waste are mainly caused by the decomposition of organic matters. The major cause of these unpleasant and unacceptable odors is the growth and metabolism of microorganisms such as bacteria, yeasts and moulds leading to formation of the various toxic volatile organic compounds (VOCs) (Gram & Dalgaard, 2002; Huis in’t Veld, 1996). In this section, a review of E-nose applications for malodor detection as caused by animal products and animal waste is given.

2.1 Animal products

Quality of animal products is very important because they are protein sources for human and some animals. Mechanisms of food spoilage can be classified into four types, as follows (Berk, 2009; Ghaly et al., 2010):

i. Microbial spoilage: degradation of food components due to the activity and/or presence of microorganisms

ii. Enzymatic spoilage: undesirable changes due to the activity of enzyme in enzyme catalyzed reactions

iii. Chemical spoilage: irreversible changes such as discoloration due to non-enzymatic chemical reactions between intrinsic food components or the action of environment to the food components (e.g. Maillard browning and lipid oxidation)

iv. Physical spoilage: undesirable changes in the physical structure of the food (e.g. sugar crystallization in preserves, separation of emulsions and collapse of gels).

Early studies acknowledged that microorganism activity is a crucial cause of food spoilage because it can affect to both quality and safety. During propagation process of food spoilage, some physical properties may be observed such as changes in color, taste and smell, etc.
(Wilkes et al., 2000). Analytical techniques commonly used to determine quality of food are gas chromatography-mass spectrometry (GC-MS) technique, bacterial and sensory analysis (Zhang et al, 2010). Up to the present, many researchers have tried to push E-nose forward as one of the standard techniques in food industry to evaluate food quality (Berna, 2010). Because the results of an E-nose are normally reported in terms of aroma pattern yielded from the response of chemical sensor array, therefore several scientists tried to correlate E-nose data with the standard techniques. (Blixt & Borch, 1999; O’Sullivan et al., 2003). The E-nose has been applied in a wide range of animal products, including: animal flesh product (e.g. meat (Blixt & Borch, 1999; Panigrahi et al., 2006; Vernat-Rossi et al., 1996; Winquist et al., 1993)), fish and seafood (Alimelli et al., 2007; Huang et al., 2011; Kent et al., 2004; Lorwongtragool et al., 2011; Ólafsdóttir, et al., 1997, 2004; Rajamäki et al., 2006; Zhang et al., 2009), dairy product (e.g. cheese and milk) (Ampuero & Bosset, 2003; Drake et al., 2003; Seregély et al., 2006) and egg product (Suman et al., 2007; Yongwei et al., 2009)). Most applications are associated with using E-nose to determine the degree of microbial spoilage. In the literature, development of E-nose system for food monitoring has been conducted in the same direction. E-nose is expected to be usable for on-line analysis in quality control (Blixt & Borch, 1999; Vernat-Rossi et al., 1996). In 1996, E-nose with a limited number of semiconductor gas sensors (six sensors: TGS822, TGS812, TGS824, TGS825, TGS880 and TGS800) was demonstrated to discriminate cured meat products such as dry sausages of various origins or cured hams of different qualities. It was also used for analysis of the volatile compounds of bacterial strains (Vernat-Rossi et al., 1996). The experiment was done by pumping (10 ml min⁻¹) headspace generated by bacteria after 48 h to a gas sensor array. Fig. 1 shows analysis diagram of the volatile compounds of bacterial strains.

Fig. 1. Analysis of the volatile compounds of bacterial strains. (A) Preliminary analysis to train the gas sensor. Volatile compounds of a non-inoculated Petri dish are introduced for 40 s through the measurement chamber. (B) The two stages of the volatile-colapound analysis: (1) return to baseline for the gas-sensor signal; extraction of the headspace of an empty Petri dish for 10 min; (2) extraction of volatile compounds from an inoculated Petri dish and analysis for 40 s. (Vernat-Rossi et al., 1996)
The performance of E-nose has been demonstrated for quality estimation of ground beef and pork (Winquist et al., 1993). The studies were performed by using a sensory array composed of 10 metal oxide semiconductor field-effect transistors, four Tagushi type sensors and one CO$_2$-sensitive sensor. With the same sensor array, Blixt and Borch (Blixt & Borch, 1999) showed that the degree of spoilage of vacuum-packed beef could be determined quantitatively. They also developed mathematical model, describing the relationships between the degree of spoilage, as determined by a sensory panel, and the sensor signal magnitudes of the electronic nose. This relationship is given in equation (2.1)

$$Y = b_0 + b_1 \times S_1 + b_2 \times S_2 + \ldots + b_n \times S_n$$  \hspace{1cm} (2.1)

where $Y$ is the degree of spoilage, $b_i$ is the unweighted regression coefficient obtained from partial least-squares regression (PLS), and $S_i$ is the standardized sensor signal magnitude of the electronic nose. The factor $1/(\text{weight of meat (g)})^{1/2}$ was used as the standardized sensor signal.

It is noticed that most applications for evaluating food quality prefer metal oxide gas sensors as a sensor array (Berna, 2010). Metal oxide semiconductor gas sensors can respond highly and rapidly to volatile compounds. However, this type of gas sensors work at high temperature, thereby consuming higher electrical power than others (Fleischer & Meixner, 1997; Tomchenko et al., 2003) Gas sensors with lower power consumption are therefore in higher demand nowadays. Many research groups have developed alternative sensing materials that can be sensitive to volatile compounds at lower temperature. Hybrid metal oxide and multi-walled carbon nanotube (SnO$_2$/MWCNTs, WO$_3$/MWNTs films) was found to present excellent sensitivity towards NO$_2$ at room temperature (Espinosa et al., 2007; Su & Pan, 2011). Conducting polymer as well as polymer/conductive filler composite are new sensing materials that can be applied to indicate quality of food products. Conductive filler such as carbon black, carbon nanotube and graphite can be loaded into the polymer matrix at the level near the conduction percolation threshold to obtain high gain sensors. For example, four nanocomposite sensor materials based on conductive polymer loaded with carbon black were demonstrated for potential applications in real time analysis and quantification of the odor given off from a selection of food borne pathogens including *Salmonella spp.*, *Bacillus cereus* and *Vibrio parahaemolyticus*. (Arshak et al., 2007)

Applications of E-nose involving fish and seafood freshness monitoring were also widely interested. Freshness monitoring of such protein-based products is usually based on chemical contents decomposed by microbial and chemical spoiling process, generally known as total volatile basic nitrogen (TVB-N) such as trimethylamine (TMA), ammonia (NH$_3$) and dimethylamine (DMA). (Dapkevicius et al., 2000; Gram & Huss, 1996; Önal, 2006; Pacquit et al., 2006; Seo et al., 2011;) Because many fish species contain high content of free amino acid and trimethylamine oxide (TMAO), TMA is formed from the reduction of TMAO by bacterial activity (Howgate, 2010a, 2010b).

In order to apply the E-nose efficiently for a specific application, the gas sensor array containing in the E-system should be highly sensitive and selective to the volatile compounds presented in the samples. Lorwongtragool and co-workers have designed a new type of polymer/SWNT-COOH gas sensors that are highly sensitive to the presence of amine based volatile compounds (Lorwongtragool et al., 2011). Fig. 2 shows the sensor responses of polymer/SWNT-COOH nanocomposites to dimethylamine, dipropylamine,
pyridine, and ammonium hydroxide at the concentrations of 50-1000 ppm. This E-nose was shown to be an efficient device for fish freshness monitoring.

![Graphs showing data for different odors: dimethylamine, dipropylamine, pyridine, and ammonium hydroxide at various concentrations.](image)

Fig. 2. The average of percent change in resistance of each sensor in static condition when exposed to (a) dimethylamine (b) dipropylamine, (c) pyridine, and (d) ammonium hydroxide at the concentrations of 50-1000 ppm (Lorwongtragool et al., 2011)

### 2.2 Animal waste

This section illustrates the literature and our recent works on malodor measurement in farms. Problems of most livestock industries often concern with unpleasant odor generated by animal waste resulting in conflict between producers and the local public. In fact, many factors that cause air pollution are associated with farm management (Hamelin et al., 2010; Ivanova-Peneva et al., 2008; Melse & Timmerman, 2009; Sheridan et al., 2002; Van der Werf et al., 2005; Pan et al., 2006, 2007). Numerous animal farms has employed E-nose for odor monitoring such as pig (Brose et al., 2001; Lorwongtragool et al., 2010), poultry (Sohn et al., 2008), sheep (Cramp et al., 2009) and cattle farms (Lane & Wathes, 1998). With complexity of odor in the livestock farm, odor monitoring, reducing and controlling are required due to the impacts of health risks of human and quality of livestock production (Pan & Yang, 2007).

Over 400 compounds identified by GC-MS technique are normally generated from anaerobic process in pig farm area. The compounds identified include many acids, alcohols, aldehydes, amides, amines, aromatics, esters, ethers, fixed gases, halogenated hydrocarbons, hydrocarbons, ketones, nitriles, other nitrogen-containing compounds, phenols, sulfur-containing compounds, steroids, and other compounds (Schiffman et al., 2001). Although analytical instruments such as gas chromatography and mass spectrometry can identify
individual components in a complex odor, the data obtained are lacking the qualitative characteristics as perceived by the human nose (Hyung et al., 1997). Moreover, GC-MS technique as well as other traditional technique (e.g. human assessment) does not support the monitoring on site and at real time due to the method of sampling. Schiffman, et al. (Schiffman et al., 2001) collected the odor onto Tenax® cartridges and Tedlar® bags to be analyzed by GC-MS. Odor threshold and sensory assessments were carried out by human assessors. The flexibility of E-nose has shown its ability beyond the human panels with its long operating hours and good reproducibility. Since E-nose containing air flow unit in the system can suck the air directly into the sensing unit, it can be a better choice than taking air into a gas sample bag that posses many difficulties (Trabue et al., 2006). Fig. 3 shows schematic diagram of the portable E-nose system using for detection of unpleasant odor in pig farm (Lorwongtragool et al., 2010).

The odor measurement by using E-nose works under switching between the reference gas (purified air) and odorous gases (non-purified air) pumped into the sensor chamber from the point of sampling. The reference gas was obtained from purification of air with activated carbon. Direction and rate of flow are controlled by 3-way solenoid valve and a mass flow controller, respectively. The USB-DAQ card used as interface device sends analog signal for flow rate adjustment and receives a set of digital signal back for reading the real-time flow rate value. Odor can be directly sampled from interested point by pumping. Because it is well-known that the air inside a pig farm concerning usually consists of ammonia and hydrogen sulfide (Kim et al., 2008; Timmer et al., 2005), so the gas sensor array should be chosen appropriately to detect these gases. Polyethylene odor sampling duct may be constructed to provide well-mixed (homogenous) air samples. Sohn et al. (Sohn et al., 2008) used a temporary duct with a design of Australian Standard AS 4323.1 as shown in Fig. 4. The complex odour-generating mechanisms within
poultry housing were continuously monitored by E-nose based on 12 metal oxide semiconductor sensors.

Fig. 4. Tunnel ventilated broiler shed showing polyethylene sampling duct attached to an exhaust fan. (Sohn et al., 2008)

Actually, the E-nose used to monitor the odor in the farm area is useful for supporting farm management. Numerous published papers have used the E-nose to study the parameters relating to changes of malodorous odors and used as one of the equipment to find out the final solution for odor reduction. According to Lorwongtragool et al. (Lorwongtragool et al., 2010), the E-nose based on eight commercial metal oxide gas sensors used as assessment technique finally led to an optimized feed menu and cleaning schedule to control and reduce the odor in pig farm. Environmental conditions such as season, temperature, wind, and humidity, etc. that are difficult to control and manage bring the emitted odor to spread to neighbor areas have been evaluated by E-nose (Pan et al., 2006, 2007). In addition, E-nose with applying analysis software can highly improve the accuracy and precision of livestock farm odor evaluation.

Recently, the non-specific conducting polymer was used as chemical gas sensing materials in E-nose system for monitoring odor emissions from a biofiltration system in a piggery building (Sohn et al., 2009). Based on PCA analysis the odor samples collected at the outlet of the biofilter and those from the inlet and post-humidifier were discriminated. Data pre-processing techniques including normalising and outlier handling could also enhance the odor discrimination performance.

E-nose can also be used to detect illness of animals (Cramp et al., 2009; Lane & Wathes, 1998). There are only a few published papers reported about using E-nose to diagnose or detect unusualness of animal; for examples, detection of perineal odors associated with oestrus in the cow (Lane & Wathes, 1998) and detection of cutaneous myiasis in sheep (Cramp et al., 2009). In early stage, the flystrike (Cutaneous myiasis) is difficult to detect,
therefore cutaneous myiasis causes the death of millions of sheep each year due to the larvae of flies burrowing into and feeding on body tissues (Krajewski et al., 2009; Lane & Wathes, 1998; McGraw & Turiansky, 2008). Since a characteristic unpleasant odor is generated from flystrike, this leads to a potential application of E-nose technology to detect the flystrike in advance.

The E-nose combined with non-linear signal measurement techniques and linear discriminant analysis (LDA) extracts signal features and process those features for classification of odor groups. Schematic diagram of the experimental system is given in Fig. 5 (Lane & Wathes, 1998). The E-nose system composed of six metal oxide gas sensors chosen on the basis of GC-MS profile of flystrike odor. Each of the odor sample and clean air is drawn through the E-nose chamber by using diaphragm vacuum pump. The direction of air flow is controlled by two solenoid valves to switch between sample odor and clean air. This experiment can accurately distinguish flystrike odor on days 1, 2 and 3 of development from that of dry wool in all experiments (P < 0.05).

Fig. 5. Schematic diagram of the experimental system, which included the odor or clean air source, the sensor array enclosed in an airtight chamber, an odor delivery system, moisture trap and computer for data logging and recording (Cramp et al., 2009)

3. Human body odor

3.1 Historical background

Human body odor refers to unpleasant and pleasant scents that can be emitted from many parts of the body such as skin, armpit, mouth, feet, etc. In fact, most of body odors were considered socially unpleasant while there are only a few of them that are believed to serve as attractants. The human body odor was first investigated systematically in 1936 (Yaglou et al., 1936). They studied the perceived air quality on different numbers of persons who were seated in an experiment-controlled room. They found the relationship of ventilation rates per person required to provide a certain acceptable odor intensity as emitted from the human body in a definite space. Their work has then become the basis of European guidelines for ventilation rates in buildings for more than 50 years.
However, during that time, no scientific instrument existed to measure perceived air quality or human body odor directly. Thus, human panel test, assisted by statistical analysis, had been the only mean to evaluate perceived air quality. The perceived air quality (AQ) in decipols can be written down as (Fanger, 2001):

\[
AQ = 112 \left[ \ln \left( \frac{\exp(-0.18 - 5.28 \bar{AA})}{1 + \exp(-0.18 - 5.28 \bar{AA})} \times 100 \right) - 5.98 \right]^4
\]  

(3.1)

Where \( \bar{AA} \) is the mean vote of air acceptability (from -1 to +1) measured from untrained panel of impartial subjects who enter the space and judge the acceptability of the air quality.

Nowadays, analytical instruments such as gas chromatograph–mass spectrometry (GC-MS) and electronic nose (E-nose) have become available for detection and analysis of human body odor with both qualitative and quantitative capabilities. Human body odor consists of various volatile organic compounds (VOC). By using stir bar sorptive extraction in connection with thermal desorption, Penn and co-workers (Penn et al., 2007) found on average 241 peaks in the GC–MS of armpit sweat, 179 in saliva and 163 in urine per individual. The list of 152 identified VOCs in the GC–MS profiles from armpit sweat is displayed in Table 1.

| RT (min) | Identification |
|---------|----------------|
| 9.98    | 2-phenylethanol |
| 12.3    | a-terpineol |
| 12.47   | y-terpineol |
| 12.9    | 2-phenoxyethanol |
| 13.34   | citronellol |
| 13.82   | geraniol |
| 16.48   | eugenol |
| 18.93   | isoeugenol |
| 21.93   | 1-tridecanol |
| 26.83   | pentadecanol |
| 27.75   | a hexadecadienol |
| 29.51   | hexadecanol |
| 12.74   | decanal |
| 13.93   | p-anisaldehyde |
| 14.38   | geranial |
| 15.46   | undecanal |
| 18.1    | dodecanal |
| 20.61   | tridecanal |
| 20.83   | lilial |
| 23      | tetradecanal |
| 23.58   | pentylcinnamaldehyde |
| 26.04   | E-2-hexylcinnamaldehyde |
| 28.09   | hexadecanal |
| RT (min) | Identification |
|---------|----------------|
| 8.98    | acetophenone   |
| 9.49    | 2-nonanone     |
| 14.99   | 2-undecanone   |
| 15.42   | an isopropylacetophenone |
| 17.47   | jasmone        |
| 17.69   | 2-dodecanone   |
| 19.45   | γ-irone        |
| 19.66   | β-ionone       |
| 20.22   | 2-tridecanone  |
| 20.54   | Z-α-irone      |
| 22.52   | 2-tetradecanone|
| 18.27   | α-ionone       |
| 23.09   | benzophenone   |
| 24.08   | 1-ethyl-3-methyl-β-ionone |
| 24.92   | 2-pentadecanone|
| 27.54   | 2-hexadecanone |
| 28.7    | 2-acetyl-3,5,5,6,8,8-hexa-methyl-5,6,7,8- tetrahydronaphthalene |
| 29.22   | 7-acetyl-6-ethyl-1,1,4,4-tetramethyl tetralin (Musk 36A) |

**Esters**

| RT (min) | Identification                              |
|---------|---------------------------------------------|
| 11.4    | benzyl acetate                             |
| 12.07   | 2-phenylethyl acetate                      |
| 12.73   | dihydromyrcenol acetate                    |
| 14.82   | cis-2-tert-butylcyclohexyl acetate         |
| 16.37   | a-terpinyl acetate                         |
| 16.43   | citronellol acetate                        |
| 16.62   | neryl acetate                              |
| 17.16   | geranyl acetate                            |
| 17.86   | methyl-N-methylantranilate                 |
| 18.28   | 2-hexyl-2-pentenoate                       |
| 18.79   | E-cinnamyl acetate                         |
| 21.24   | a-trichloromethylbenzyl acetate            |
| 21.95   | pentyl salicylate                          |
| 22.21   | isoctanedioldibutyrate                     |
| 22.69   | isoeugenol acetate                         |
| 23.3    | isopropyl dodecanoate                      |
| 23.73   | methyl-cis-dihydrojasmonate                |
| 24.15   | 3Z-1-hexenyl salicylate                    |
| 24.46   | 1-hexyl salicylate                         |
| 25.01   | methyl trans-jasmonate                     |
| 25.73   | a hexenyl salicylate                       |
| 26.65   | benzyl benzoate                            |
| 27.38   | ethyl tetradecanoate                       |
| 27.53   | 2-ethylhexyl salicylate                    |
| 28.23   | a branched isopropyl hexadecanoate         |
| RT (min) | Identification                                      |
|---------|-----------------------------------------------------|
| 30.06   | ethyl pentadecanoate                                 |
| 30.32   | 2-phenylethyl phenylacetate                         |
| 30.93   | methyl palmitate                                    |
| 32.29   | decyl octanoate                                     |
| 32.36   | dodecyl hexanoate                                   |
| 32.4    | hexyl dodecanoate                                   |
| 32.99   | ethyl hexadecanoate                                 |
| 33.7    | isopropyl hexadecanoate                             |
| 35.64   | ethyl heptadecanoate                                |
| 36.47   | a branched dodecyl benzoate                         |
| 37.35   | 2-ethyl-hexyl 4-methoxycinnamate                    |
| 38      | dodecyl octanoate                                   |
| 38.72   | dodecyl benzoate                                    |
| 43.19   | tridecyl benzoate                                   |
| 47.56   | tetradecyl octanoate                                |
| 49.15   | tetradecyl benzoate                                 |

*Hydrocarbons*

| RT (min) | Identification                                      |
|---------|-----------------------------------------------------|
| 7.67    | p-cymene                                            |
| 12.26   | 1-dodecene                                          |
| 12.5    | dodecane                                            |
| 15.15   | tridecane                                           |
| 17.55   | 1-tetradecene                                       |
| 17.77   | tetradecane                                         |
| 18.22   | β-caryophyllene                                     |
| 19.72   | trans-muurola-4(14),5-diene                         |
| 19.96   | a methyl biphenyl                                   |
| 20.36   | α-farnesene                                         |
| 20.38   | pentadecane                                         |
| 21.77   | 4-methylpentadecane                                 |
| 22.56   | hexadecane                                          |
| 23.28   | 5-phenylundecane                                    |
| 23.53   | 4-phenylundecane                                    |
| 23.99   | 3-phenylundecane                                    |
| 24.94   | 2-phenylundecane                                    |
| 25.04   | heptadecane                                         |
| 25.49   | 6-phenylundecane                                    |
| 25.66   | a sesquiterpene                                     |
| 25.77   | 5-phenylundecane                                    |
| 26.96   | a propyl-substituted dodecane                       |
| 27.48   | octadecane                                          |
| 27.57   | 2-phenylundecane                                    |
| 28.09   | 6-phenylundecane                                    |
| 28.64   | 4-phenylundecane                                    |
| 29.4    | 3-phenylundecane                                    |
| 29.54   | 3-methylundecane                                    |
| RT (min) | Identification |
|----------|----------------|
| 30.13    | 1-nonadecene   |
| 30.22    | nonadecane     |
| 30.38    | 2-phenyltridecane |
| 32.19    | 3-methylnonadecane |
| 32.93    | eicosane (C-20 linear hydrocarbon) |
| 35.79    | heneicosane (C-21 linear hydrocarbon) |
| 38.79    | docosane (C-22 linear hydrocarbon) |
| 41.49    | tricosane (C-23 linear hydrocarbon) |
| 43.44    | tetracosane (C-24 linear hydrocarbon) |
|          | **Amines**    |
| 12.65    | 2-pentylpyrrole |
| 13.28    | 2-phenoxyethylmethylamine |
| 15.19    | an aliphatic amine |
| 16.34    | nicotine       |
| 16.81    | 4-sec-butylaniline |
| 20.37    | N,N-dimethyl-1-dodecylamine |
| 30.24    | N,N-dimethyl-1-hexadecylamine |
| 35.88    | N,N-dimethyl-1-octadecylamine |
|          | **Amides**     |
| 17.18    | methyl N,N-diethylthiocarbamate |
| 18.04    | a hydroxy acetonilide |
| 21.98    | n-propylbenzamide |
|          | **Carboxylic acids** |
| 12.24    | octanoic acid |
| 14.76    | nonanoic acid |
| 21.03    | 8-methylundecanoic acid |
| 21.9     | dodecanoic acid |
| 22.8     | a methyl dodecanoic acid |
| 23.18    | 9-methylundecanoic acid |
| 25.74    | 10-methyltridecanoic acid |
| 26.8     | myristic acid (tetradecanoic acid) |
| 28.36    | a methyltetradecanoic acid |
| 28.65    | a methyltetradecanoic acid |
| 28.84    | 9-pentadecenoic acid |
| 29.31    | pentadecanoic acid |
| 30.76    | a methylpentadecanoic acid |
| 31.7     | 9-hexadecenoic acid |
| 32.49-33.00 | palmitic acid (hexadecanoic acid) |
| 34.37    | 9-heptadecenoic acid |
| 37.31    | oleic acid |
| 38.03    | stearic acid (octadecanoic acid) |
|          | **Lactones**   |
| 12.27    | γ-heptanolactone |
| 16.7     | γ-nonanolactone |
| 18.6     | coumarin       |

Table 1. Compounds identified from armpit samples (Penn et al., 2007).
The changes in body odor associated with aging were investigated by Haze and co-workers (Haze et al., 2001). They found that 2-Nonenal compound only presents in the odor of individuals over the age of 40 years. The 2-Nonenal compound and other aldehydes were produced from oxidative degradation of monosaturated fatty acids such as palmitoleic acid and vaccenic acid. Some VOCs associated with aging that were detected by GC/MS are displayed in Table 2.

| Compounds       | Detection rate (%) |
|-----------------|--------------------|
|                 | <40 y (n=9) | >40 y (n=13) |
| **Hydrocarbons**|                |               |
| 1-Octene        | 11          | 8             |
| Decane          | 11          | 23            |
| Undecane        | 22          | 23            |
| Dodecane        | 67          | 69            |
| **Alcohols**    |                |               |
| 1-Butanol       | 11          | 8             |
| 1-Hexanol       | 11          | 15            |
| 2-Ethylhexanol  | 89          | 85            |
| Octanol         | 11          | 8             |
| 1-Decanol       | 11          | 15            |
| Amyl alcohol    | 11          | 8             |
| Hexadecanol     | 11          | 8             |
| Octadecanol     | 11          | 8             |
| **Acids**       |                |               |
| Acetic acid     | 22          | 23            |
| Butyric acid    | 22          | 15            |
| **Ketones**     |                |               |
| 4-Methyl-2-pentanone | 11         | 8             |
| 6-Methyl-5-heptenone | 89    | 77            |
| **Aldehydes**   |                |               |
| Hexanal         | 33          | 23            |
| Heptanal        | 11          | 15            |
| Octanal         | 89          | 85            |
| Nonanal         | 89          | 85            |
| Decanal         | 89          | 69            |
| 2-Nonenal       | 0           | 69            |

Table 2. Some compounds detected from body odor by GC/MS (Haze et al., 2001).

Comparison of compounds extracted from the samplings of male and female was also studied by Curran and co-workers (Curran et al. 2005a). Some compounds such as dodecanoic acid, propanedioic acid-methyl ester, octanal, and tetradecanoic acid could be extracted from the male subjects only and they were not present in any of the female profiles. Overall, the individual human body odors can be determined by several factors, which are either stable over time (genetic factors) or vary with environmental or internal conditions. The human body odor can thus be classified into three types (Curran et al. 2005b): i. “Primary odor” of a person contains constituents that are stable over time regardless of diet or environmental factors.
ii. “Secondary odor” contains constituents that are present due to diet and environmental factors.

iii. “Tertiary odor” contains constituents that are present because of the influence of outside sources (i.e., lotions, soaps, perfumes).

For identification of an individual using the human body odor, detection of the primary odor class should be used because they are stable over time and diverse across people.

### 3.2 Evaluation of body odor strength

There are more refined and less subjective ways to measure odor strength in a direct way. For instance, the concept of dilution-to-threshold principle can be used quite accurately to reduce uncertainties associated with subjective impressions (Nicell, 2003; Henshaw et al., 2006; Kim & Park, 2008). In the cosmetic industry, human olfaction has been commonly employed to evaluate the odor strength of armpit for the development of deodorants. The armpit odor comprises a complex set of chemicals as shown in section 3.1. However, to simplify the odor strength of armpit, only a single component such as isovaleric acid can be used for training the sensory panel (Hooper et al., 1982). Isovaleric acid (3-Methylbutanoic acid) is a natural fatty acid that can represent the sweaty primary odor (Amoore, 1967, Leyden et al., 1981) which contributes mainly to the armpit malodor. Molecular structure of isovaleric acid is shown in Fig. 6.

![Isovaleric acid structure](image)

**Fig. 6. Isovaleric acid ((CH₃)₂CHCH₂COOH)**

Hooper and co-workers (Hooper et al., 1981, 1982) assigned the concentrations of isovaleric acid levels on a scale 0 to 5 corresponding to subjective impression by human nose, as shown in Table 3.3. Their test was carried out by a team of three female assessors of ages ranging from 20 to 40 years. They were selected for olfactory evaluation on the basis that each person is able to rank correctly the odor levels of the series of aqueous isovaleric acid solution listed in Table 3.

| Level | Concentration of aqueous isovaleric acid solution (mM) | Subjective impression |
|-------|------------------------------------------------------|-----------------------|
| 0     | 0                                                    | No odor               |
| 1     | 0.12                                                 | Slight                |
| 2     | 0.48                                                 | Definite              |
| 3     | 1.99                                                 | Moderate              |
| 4     | 7.88                                                 | Strong                |
| 5     | 32.33                                                | Very strong           |

Table 3. The concentration of the isovaleric acid levels that correspond to subjective impression using human nose.

Recently, evaluation of body odor strength based on isovaleric acid solutions as prepared according to the intensity scale can also be performed using gas sensor array in stead of the
Malodor Detection Based on Electronic Nose

human nose (Wongchoosuk et al., 2009a). The response of a gas sensor array to the isovaleric acid is displayed in Fig. 7.

![Fig. 7. Logarithmic plot of the sensor response to isovaleric acid at different intensity level (Wongchoosuk et al., 2009a).](image)

3.3 Instrument and method for real-time human odor detection

Even though GC-MS method can be used to detect VOCs emitted from human body odor, they are quite time-consuming, complicated and so costly. Therefore, it is impractical to use it in real-time or at point of use, especially where quick screening for detecting human body odor is the case. One of the most state-of-the-art technologies that can be used for real-time human odor detection is electronic nose (E-nose). Recently, there have been increasing interests in the application of E-nose for measurement of human body odors. If successful, many new applications await in such area as healthcare monitoring, biometrics, homeland security and cosmetics. The first success in distinguishing between two different people by detecting human odor from the armpit region using E-nose was reported by Wongchoosuk and co-workers (Wongchoosuk et al., 2009a). Schematic diagram of the E-nose system for real-time human odor detection is exhibited in Fig. 8.

To allow an identification of human odors, principal component analysis (PCA) was employed to perform pattern recognition and discrimination. PCA is a popular statistical technique usually used to visualize in two or three uncorrelated dimensions transformed from all correlated information. In principles, PCA process contains five following steps (Wongchoosuk et al., 2009a):

i. Get data from matrix, $X_{M \times N}$. The row $M$ represents different repetition of the experiment and the column $N$ represents the number of independent sensors.

ii. Normalize the data matrix, $\text{Norm}(X_{M \times N})$, by the mean subtraction. The mean of each $N$ column is calculated and subtracted from the data set. Hence, the new data set produces the mean equal to zero.

iii. Calculate the covariance matrix, $\text{Cov}(X_{M \times N})$, and calculate eigenvectors and eigenvalues of the covariance matrix. The calculated eigenvectors must be unit eigenvectors.
iv. Rearrange the eigenvectors and eigenvalues. The eigenvectors are ordered by eigenvalues from highest to lowest, \( \text{max} \rightarrow \text{min} \).

v. Obtain the PCA result by matrix multiplication and transpose,

\[
(Cov(X_{M \times N}))_{\text{max} \rightarrow \text{min}} \otimes \text{Norm}(X_{M \times N})^T.
\]

The obtained new dataset with orthogonal linear transformation have been plotted in two or three dimensions containing the most relevant of the data set.

Fig. 8. Schematic diagram of the E-nose system (Wongchoosuk et al., 2009a).

By using typical E-nose with PCA, Wongchoosuk and co-workers showed obviously discrimination between person A and person B and the use of deodorant may not change the odor fingerprint (Fig. 9). To recognize and discriminate more persons, the method for sensor signal correction should be developed. It is well-known that sensor drift effect is a serious impairment of chemical sensors. The sensor signals alter over time. Therefore, they will produce different responses for the same odor. To correct the sensor drift effect, a mathematical model has been applied to the raw sensor signal via the following formulation:
\[ S'(t) = S(t) - F(t) + \overline{F(t)} \]  \hspace{1cm} (3.2)

Where \( S'(t) \) represents the corrected sensor signal. \( S(t) \) is the smoothed raw sensor signal. \( F(t) \) is defined as spline interpolation calculated from relationship between the averaged values of their 10 neighboring data points that switch from reference to sample of each loop. \( \overline{F(t)} \) is a mean value of \( F(t) \). The Eq. 2 can be demonstrated in Fig. 10.

Fig. 10. Correction of sensor drift.

The real armpit measurement by E-nose is shown in Fig. 11. It clearly shows the sensor drift effect that makes the difference of the baseline shift, especially the signal from sensor 1 and

Fig. 11. Raw sensor signals (L-hand side) and corrected sensor signals by using mathematical model (R-hand side).
sensor 2. The drift effect of sensor signal may arise from the temperature variation under long time measurement and humidity generated from armpits (sweat) during the measurement. After correction by using the mathematical model, the sensor signal becomes more homogeneity. It will be useful for reorganization and discrimination of many persons because it helps to reduce the humidity and temperature effects.

To add 95% confidence ellipse for an XY scatter plot in PCA results, the equation of an ellipse is given by the following equation:

\[
\frac{(X - X_0)^2}{a^2} + \frac{(Y - Y_0)^2}{b^2} = 1
\]  

(3.3)

Where 

\[
a = \sqrt{\frac{\sum_{i=1}^{N} x_i^2}{N}} \quad \text{and} \quad b = \sqrt{\frac{\sum_{i=1}^{N} y_i^2}{N}}
\]  

(3.4)

The \(X_0\) and \(Y_0\) can be calculated from the center of mass of XY scatter plot. The ellipse is rotated from the horizontal by the following angle:

\[
\theta = 0.5 \tan^{-1} \left( \frac{2 \sum_{i=1}^{N} (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{N} (y_i - \bar{y})^2 - \sum_{i=1}^{N} (x_i - \bar{x})^2} \right)
\]  

(3.5)

The PCA result shows clear classification of four persons within 95% confidence ellipses as shown in Fig. 12. The results confirm that each human body has a unique odor pattern. Even though odor of each person can be changed under diverse living conditions such as eating, drinking, sexual activities, health or hormonal status, the E-Nose is still able to identify the people from armpit odor region.

Fig. 12. Discrimination of four persons.
Based on the results as shown above, it is expected that E-nose has potential for helping identify terrorists from a distance in the near future.

4. Indoor air monitoring

Most people spend more than 80% (90% in industrial countries) of their time indoors (Austin et al., 1992), i.e., in offices, houses, stores, restaurants, public or private transportation vehicles, movie theatre, etc. Typically, several hundreds of indoor chemical contaminants including by-products of the combustion (CO₂, CO), cigarette smoke, particulate matter, mineral fibers etc. can be found. A list of typical indoor air pollutants is displayed in Table 4. In spite of the very low concentrations, some of these compounds are extremely toxic such as CO, NO₂ or formaldehyde. Only as low as 667 ppm of CO may cause up to 50% of the body's hemoglobin to convert to carboxyhemoglobin (Tikuisis et al., 1992) that is ineffective for delivering oxygen to bodily tissues. Exposure to 100 ppm of NO₂ can produce pulmonary edema that may be fatal or may lead to bronchiolitis obliterans while formaldehyde was proved to be carcinogenic. Concisely, indoor air quality can greatly affect morale, emotion, productivity, and health status of people. Therefore, development of technical devices for indoor air monitoring has become an important issue of public interest. In 1988, Fanger (Fanger, 1988) proposed a method for assessing the air quality and introduced that discomfort as caused by indoor air quality based on human sensory panels. However, his method is too time consuming and cannot be used for continuous measurements in long time monitoring and control.

| Inorganic Pollutants | Organic Pollutants | Physical Pollutants | Biological Pollutants |
|----------------------|--------------------|---------------------|----------------------|
| Carbon dioxide       | Volatile Organic Compounds | Particulate matter | House dust mites |
| Carbon monoxide      | Formaldehyde       | Asbestos            | Dander from furred animals |
| Nitrogen dioxide     | Pesticides         | Radon               | Fungi |
| Sulphur dioxide      | Aromatic hydrocarbons | Polychlorinated biphenyls | Bacteria |
| Ozone                |                     |                     |                      |

Table 4. Typical indoor air quality contaminants

In the last decades, gas sensor systems (E-nose) have been developed for monitoring air quality instead of human sensory panels. In an E-nose system, the gas sensors may be considered the most important component. For developing individual gas sensor, there is a great deal of effort on improving the sensitivity and selectivity using nanotechnology. A list of nanostructure gas sensors for indoor chemical contaminant monitoring is given in Table 5. In many cases, individual gas sensor, that provides only one output signal, is not sufficient for monitoring a wide range of gases. The combination of several gas sensors yielding an E-nose is therefore necessary to measure, maintain and control indoor air quality in real-world applications. Unfortunately, typical commercial E-nose architectures are not suitable for such usage. Most of them are usually designed for fixed location that relies on wired connectivity. Moreover, they are power consuming and very limited in local data processing.
capabilities (Vito et al., 2008). Therefore, design of new E-nose architectures such as
networked or wireless E-nose is a current interesting topic of E-nose development for indoor
air monitoring.

| Pollutants | Detection range | Sensing material | Ref. |
|------------|-----------------|------------------|-----|
| CO         | 5–1200 ppm      | CuO Nanowires    | (Liao et al., 2009) |
| CO₂        | 500-2500 ppm    | La-SnO₂          | (Marsal et al., 2003) |
| NO₂        | 5-500 ppb       | In₂O₃ Nanowires  | (Zhang et al., 2004) |
| SO₂        | 2-32 ppm        | SnO₂–NiO         | (Hidalgo et al., 2005) |
| O₃         | 0.2-0.4 ppm     | WO₃              | (Vallejos et al., 2007) |
| VOCs       | 100-1000 ppm    | Au-ZnO           | (Wongchosuk et al., 2009b) |
| CH₂O       | 0.8-12 ppm      | NiO              | (Lee et al., 2007) |
| Pesticide  | 0.1-1.0 ppm     | SnO₂             | (Huang et al., 2003) |

Table 5. List of nanostructure gas sensor responding to some indoor air quality contaminants.

4.1 Typical E-nose

In principles, an E-nose consists of three main parts: (i) air flow system, (ii) detection system,
and (iii) control and data analysis system. The air flow system refers to the way to deliver
aroma molecules into the detection system. There are two main types of flow systems,
including static and dynamic flow systems. The static system has no vapor flow around the
gas sensors and the gas sensors are exposed to vapor at a constant concentration. In the
dynamic system, E-nose is subjected to continuous flow of vapor with controllable flow rate
during measurement. The simple gas sensor chambers for static and dynamic systems are
displayed in Fig. 13.

![Fig. 13. Static (L-side) and dynamic (R-side) sensor chambers for static and dynamic
systems, respectively.](image)

The air flow rate in a dynamic E-nose system is usually controlled by a mass flow controller.
Mass flow rate \( \dot{m} \) can be calculated from the density of the gas or liquid \( \rho \), its velocity
\( v \), and the cross sectional area \( A \) of the flow by the following equation;

\[ \dot{m} = \rho \cdot A \cdot v \]
\[ \dot{m} = \rho v A \] (4.1)

For an ideal compressible gas, the equation of mass flow rate (Benson, 2008) can be written down as;

\[ \dot{m} = \frac{pA}{\sqrt{T}} \sqrt{\gamma R (1 + \frac{\gamma - 1}{2} \frac{M^2}{\gamma})^{\frac{\gamma + 1}{2(\gamma - 1)}}} \] (4.2)

Where \( p \) is total pressure, \( T \) is total temperature, \( R \) is gas constant, \( \gamma \) is specific heat ration and \( M \) is mach number.

A detection system consists of a gas sensor array embedded in a sensor chamber. There are many types of gas sensors used in E-nose such as metal oxide semiconductors (MOS), conducting polymers (CP), quartz crystal microbalance (QCM), surface acoustic wave (SAW), etc. Each type has specific gas detection principle. The MOS and CP rely on the change in electrical conductivity of the sensing materials for detecting aroma molecules. MOS is usually operated under high temperature. When it is heated, oxygen will be adsorbed onto the sensing surface with a negative charge. Then, donor electrons in the crystal surface are transferred to the adsorbed oxygen, resulting in leaving positive charges in a space charge layer. Thus, the surface potential is formed to serve as a potential barrier against electron flow. Electrical conductivity of MOS is low when it presents in pure air. In the presence of a deoxidizing gas or malodor, the surface density of the negatively charged oxygen decreases, so the barrier height in the grain boundary is reduced. The reduced barrier height results in increasing conductivity of MOS. In a CP gas sensor, swelling of vapor molecules into the polymer film is the basis of sensing mechanism. The swelling decreases the number of connected pathways of the conducting component of the composite material leading to an increase in the electrical resistance of the film. For a pure CP, insertion of analyte molecule into polymer matrix generically increases interchain distance that affects the electron hopping between different polymer chains (Bai & Shi, 2007). The interchain electron transfer can be described by the following relationship (Vercelli et al., 2002):

\[ \left( \ln \frac{\sigma}{\sigma_0} \right)^{-1} = \left( \frac{\varepsilon_0 - \varepsilon}{\varepsilon} \right) \dot{B}^{-1} \] (4.3)

Where \( \sigma \) and \( \sigma_0 \) are the conductivity before and after exposure to solvent vapor, respectively. \( \varepsilon_0 \) and \( \varepsilon \) are the relative permittivity of the solvent and the polymer, respectively. \( B \) is a constant and \( X \) is the molar fraction of absorbed vapor for sensing polymer. A simple linear circuit, called as voltage divider (see Fig. 14), can be used for basic measuring of the resistance of MOS or CP gas sensor array.

Fig. 14. Basic measuring circuit for MOS or CP gas sensor.
Sensor resistance \((R_s)\) can be calculated by the following equation:

\[
R_s = \left(\frac{V_{cl}}{V_{RL}} - 1\right) \times R_L
\]  \hspace{1cm} (4.4)

For QCM and SAW gas sensors, a change in the mass of the piezoelectric sensor coating due to gas absorption results in a change in the resonant frequency on exposure to a vapor (Arshak et al., 2004). The QCM utilizes bulk acoustic wave traveling through the entire bulk of the crystal while the SAW uses surface acoustic wave that propagates along the surface of the crystal at a depth of one wavelength at operating frequencies between 100 and 400MHz (Pearce et al., 2003). The resonant frequency of the QCM sensor is related to the change of the mass of QCM loading by the following equation (Sauerbrey, 1959):

\[
\Delta f = \frac{-2 f_0^2 \Delta m}{A \sqrt{\rho_q \mu_q}}
\]  \hspace{1cm} (4.5)

Where \(\Delta f\) is the change in resonant frequency, \(f_0\) is resonant frequency, \(\Delta m\) is mass change due to adsorption of vapor, \(A\) is the piezoelectrical active crystal area, \(\rho_q\) is density of quartz and \(\mu_q\) shear modulus of quartz.

In case of the SAW sensor, the change in frequency with sorption of a vapor is given by (Pearce et al., 2003):

\[
\Delta f_{\text{SAW}} = \frac{\Delta f_p c_v K_p}{\rho_p}
\]  \hspace{1cm} (4.6)

Where \(\Delta f_p\) is the change in frequency caused by the membrane, \(c_v\) is the vapor concentration, \(K_p\) is the partition coefficient and \(\rho_p\) is the density of polymer membrane.

Both air flow system and detection system are normally controlled by computer via USB, RS-232 or parallel port. Pattern recognition and machine learning such as artificial neural networks (ANN), linear discriminant analysis (LDA), support vector machine (SVM), and principal components analysis (PCA) are typically used in data analysis on a computer.

### 4.2 Networked E-nose

Networked E-nose can be developed based on a typical E-nose by modifying only one main part (control and data analysis system). If an E-nose can work and analyze the results over a network system such as LAN, WiFi or ZigBee, the E-nose can be defined as networked E-nose. Development of a networked E-nose for indoor air monitoring is demonstrated below:

#### 4.2.1 Air flow system

Schematic diagram of an air flow system for networked E-nose is displayed in Fig. 15. The measurement works under switching between the reference gas (clean air) and indoor air (malodor) pumped into the network E-nose from the point of sampling. The reference gas was generated by purifying the sucked-in air with activated carbon. The flow was controlled by a mass flow controller and 3-way solenoid valve. Switching between the clean air and the indoor air was used to obtain the baseline and signal, respectively.
4.2.2 Detection system

The commercial MOS gas sensors widely known as TGS (Tagushi) gas sensors can be used for the sensing part. The resistance measurement is performed as shown in Fig. 16 by applying a constant excitation current of $I_C=10\mu\text{A}$ to each sensor element and measure the voltage drop $U_1$ via $V_1$.

\[ R = \frac{U_1}{I_C} \]  

(4.7)

An 8-Channel multiplexer was used to address each gas sensor. The voltage $U_1$ was measured between the input to all sensors and the output of the multiplexer (MUX). The
differential voltage $U_1$ was measured using the first channel of a 24-Bit Delta-Sigma ADC defined as $V_1$. The second channel measures the voltage drop $U_2$ defined as $V_2$ over a fixed resistor $R_C=100\,\text{k}\Omega$ that is in series with the multiplexers and the sensor matrix. Therefore, it is possible to measure the constant current and calculate corrections if the current changes due to temperature effects or external noise.

### 4.2.3 Control and data analysis system

From section 4.2.2, the ADC, MUX and excitation current source are part of a measurement system controlled by a Microchip PIC24HJ microcontroller. Additionally, a digital-analog converter (DAC) was used to set the flow rate of a mass flow controller and one ADC input of the microcontroller was used to measure the flow rate feedback. Also the 3-way solenoid valves were controlled by the microcontroller. The microcontroller is interfaced to an Ethernet controller, so the measurement system can make an Ethernet connection to a personal computer (PC) on board the measurement software written in LabView. By connecting the measurement system to a small WiFi-Router, this E-nose could become a flexible solution for use in a wireless sensor network. It is possible to use encrypted communications to the PC that can make the system to be secure. The PCB board that contains the metal oxide gas sensors and a temperature/humidity sensor was plugged onto the measurement system PCB board. This creates a flexible setup with interchangeable sensors. A photograph of a networked E-nose is displayed in Fig. 17.

![Fig. 17. Photograph of a networked E-nose (15 cm x 10 cm) developed by Center of Nanoscience and Nanotechnology, Faculty of Science, Mahidol University.](image)

### 4.2.4 Other networked E-nose

A wireless E-nose based on IEEE 802.15.4 (ZigBee wireless network) has been developed for environment quality classification as shown in Fig. 18 (Pogfay et al., 2010).
The advantage of this ZigBee wireless network lies in its ability to offer low power consumption (50 mW) and extend the line of sight distance up to 1 mile. By combined with PCA analysis, the wireless E-nose can clearly classify the air environment from different rooms as shown in Fig. 19.

A smart wireless E-nose (Pan & Yang, 2009) has been designed to be compact in size, energy efficient, and low cost as shown in Fig. 20. This E-nose has been applied for online monitoring of livestock farm odors. Based on field applications like livestock farm monitoring, the circuit and environmental factor noises can strongly affect the output signals. To overcome the problems, a modified Kalman filtering technique has been developed for improving the sensor sensitivity and precision of odor strength measurement for livestock farm odors (Qu et al., 2009). The new odor strength measurement equation based on the noise analysis of MOS gas sensors can be modeled by (Qu et al., 2009):
\[ y_k = Cx_k + d_k + s_k \]  \hspace{1cm} (4.8)

where \( C \) is a measurement matrix, \( x_k \) is the system state vector, \( d_k \) is the direct current noise component with the same frequency as the signal and \( s_k \) is the white noise.

Fig. 20. The smart wireless E-nose (Qu et al., Pan & Yang, 2009).

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6. References

Alimelli, A.; Pennazza, G.; Santonico, M.; Paolesse, R.; Filippini, D.; D’Amico, A.; Lundström, I. & C. Di Natale. (2007). Fish freshness detection by a computer screen photoassisted based gas sensor array. *Analytica Chimica Acta*, Vol. 582, No. 2, pp. 320-328.

Amoore, J.E. (1967). Specific Anosmia: A Clue to the Olfactory Code. *Nature*, Vol. 214, pp. 1095–1098.

Ampuero, S. & Bosset J.O. (2003). The electronic nose applied to dairy products: a review. *Sensors and Actuators B*, Vol. 94, pp. 1–12.

Arshak, K.; Adley, C.; Moore, E.; Cunniffe, C.; Campion, M. & Harris, J. (2007). Characterisation of polymer nanocomposite sensors for quantification of bacterial cultures. *Sensors and Actuators B*, Vol. 126, pp. 226–231.

Arshak, K.; Moore, E.; Lyons, G.M.; Harris, J. & Clifford, S. (2004). A review of gas sensors employed in electronic nose applications, *Sensor Review*, Vol. 24, pp. 181–198.

Austin, B.S.; Greenfield, S.M.; Weir, B.R.; Anderson, G.E. & Behar, J.V. (1992). Modeling the indoor environment. *Environmental Science & Technology*, Vol.26, pp. 851–858.

Bai, H. & Shi, G. (2007). Gas sensors based on conducting polymers. *Sensors*, Vol. 7, pp. 267-307.

Barié, N.; Bücking, M. & Rapp, M. (2006). A Novel Electronic Nose Based on Miniaturized SAW Sensor Arrays Coupled with SPME Enhanced Headspace-analysis and Its Use.
for Rapid Determination of Volatile Organic Compounds in Food Quality Monitoring. *Sensors and Actuators B*, Vol. 114, pp. 482–488

Benson, T. (2008). Mass Flow Rate Equations. http://www.grc.nasa.gov/WWW/k-12/airplane/mchkdrv.html

Berk, Z. (2009). Spoilage and Preservation of Foods. *Process Engineering and Technology*, pp. 351-354, ISBN: 978-0-12-373660-4

Berna, A. (2010). Metal Oxide Sensors for Electronic Noses and Their Application to Food Analysis. *Sensors*, Vol. 10, pp. 3882-3910, ISSN 1424-8220

Blixt, Y. & Borch, E. (1999). Using an electronic nose for determining the spoilage of vacuum-packaged beef. *International Journal of Food Microbiology*, Vol. 46, pp. 123–134

Brose, G.; Gallmann, E.; Hartung, E. & Jungbluth, T. (2001). Detection of the dynamics of odour emissions from pig farms using dynamic olfactometry and an electronic odour sensor. *Water Science and Technology*, Vol. 44, No. 9, pp. 59–64

Chan, H.P.; Lewis, C. & Thomas, P.S. (2009). Exhaled Breath Analysis: Novel Approach for Early Detection of Lung Cancer. *Lung Cancer*, Vol. 63, pp. 164–168

Choopun, S.; Hongstit, N.; Mangkorntong, P. & Mangkorntong, N. (2007). Zinc oxide nanobelts by RF sputtering for ethanol sensor. *Physica E*, Vol. 39, No. 1, pp. 53-56

Cramp, A.P.; Sohn, J.H. & James, P.J. (2009). Detection of cutaneous myiasis in sheep using an ‘electronic nose’. *Veterinary Parasitology*, Vol. 166, pp. 293–298

Curran, A.M.; Rabin, S.I., Prada, P.A. & Furton, K.G. (2005a). Comparison of the Volatile Oranic Compounds Present in Human Odor using SPME-GC/MS. *Journal of Chemical Ecology*, Vol.31, pp. 1607-1619

Curran, A.M.; Rabin, S.I., Prada, P.A. & Furton, K.G. (2005b). Analysis of the Uniqueness and Persistence of Human Scent. *Forensic Science Communications*, Vol. 7, No. 2

Dapkevicius, M. L.N. E.; Nout, M. J. R; Rombouts, F. M.; Houben, J. H. & Wymenga, W. (2000). Biogenic amine formation and degradation by potential fish silage starter microorganisms. *International Journal of Food Microbiology*, Vol. 57, pp. 107–114

Drake, M.A.; Gerard, P.D.; Kleinhenz, J.P. & Harper, W.J. (2003). Application of an electronic nose to correlate with descriptive sensory analysis of aged Cheddar cheese. *Lebensm.-Wiss. U.-Technol.*, Vol. 36, pp. 13–20

Espinosa, E.H.; Ionescu, R.; Chambon, B.; Bedis, G.; Sotter, E.; Bittencourt, C.; Felten, A.; Pireaux, J.-J.; Correig, X. & Llobet, E. (2007). Hybrid metal oxide and multiwall carbon nanotube films for low temperature gas sensing. *Sensors and Actuators B*, Vol. 127, pp.137–142

Fanger, P.O. (1988). Introduction of the olf and the dezipol units to quantify air pollution perceived by humans indoors and outdoors, *Energy and Buildings*, Vol.12, pp. 1–6

Fanger, P.O. (2001). Perceived Air Quality and Ventilation Requirements, *Indoor air quality handbook*, pp. 22.1-22.11. McGraw-Hill

Fleischer, M. & Meixner, H. (1997). Fast gas sensors based on metal oxides which are stable at high temperatures. *Sensors and Actuators B*, Vol. 43, pp. 1–10

Ghaly, A.E.; Dave, D.; Budge, S. & Brooks M.S. (2010). Fish Spoilage Mechanisms and Preservation Techniques: Review. *American Journal of Applied Sciences*, Vol. 7, No. 7, pp. 859-877
Gram, L. & Dalgaard, P. (2002). Fish spoilage bacteria – problems and solutions. *Current Opinion in Biotechnology*, Vol. 13, No. 3, pp. 262-266

Gram, L. & Huss, H.H. (1996). Microbiological spoilage of fish and fish products. *International Journal of Food Microbiology*, Vol. 33, pp.121-137

Hamelin, L.; Godbout, S.; Thériault, R. & Lemay, S.P. (2010). Evaluating ammonia emission potential from concrete slat designs for pig housing. *Biosystems Engineering*, Vol. 105, No. 4, pp. 455-465

Haze, S.; Gozu, Y.; Nakamura, S.; Sawano, K.; Ohta, H.; & Yamazaki, K. (2001). 2-Nonenal Newly Found in Human Body Odor Tends to Increase with Aging. *Journal of Investigative Dermatology*, Vol.116, pp. 520-524

Henshaw, P.; Nicell, J. & Sikdar, A. (2006). Parameters for the Assessment of Odour Impacts on Communities. *Atmospheric Environment*, Vol. 40, pp. 1016–1029

Hidalgo, P.; Castro, R.H.R.; Coelho, A.C.V. & Gouvêa, D. (2005). Surface Segregation and Consequent SO₂ Sensor Response in SnO₂–NiO, *Chemistry of Materials*, Vol.17, pp. 4149–4153

Hooper, D.C.; Johnson, G.A. & Peter, D. (1981). Deodorant Compositions. *US Patent 4278658*

Hooper, D.C.; Johnson, G.A. & Peter, D. (1982). Detergent Product Containing Deodorant Compositions. *US Patent 4322308*

Howgate, P (2010a). A critical review of total volatile based and trimethylamine as indices for freshness of fish. Part.1. Electric *Journal of Environmental, Agricultural and Food Chemistry*, Vol. 9, No. 1, pp. 29-57, ISSN: 1579-4377

Howgate, P (2010b). A critical review of total volatile based and trimethylamine as indices for freshness of fish. Part.2. Electric *Journal of Environmental, Agricultural and Food Chemistry*, Vol. 9, No. 1, pp. 58-88, ISSN: 1579-4377

Huang, X.; Liu, J.; Pi, Z. & Yu, Z. (2003) Detecting Pesticide Residue by Using Modulating Temperature Over a Single SnO₂-Based Gas Sensor, *Sensors*, Vol. 3, pp. 361-370

Huang, X.;Xin, J. & Zhao, J. (2011). A novel technique for rapid evaluation of fish freshness using colorimetric sensor array, *Journal of Food Engineering*, doi: 10.1016/j.jfoodeng.2011.03.034

Huis in't Veld, J. H. J. (1996). Microbial and biochemical spoilage of foods: an overview. *International Journal of Food Microbiology*, Vol. 33, No. 1, pp. 1-18

Hyung G. B.; Krishna C. P.; Soad M.K.; Philip J. H. & Tom H. M. (1997). Application of unsupervised clustering methods to the assessment of malodour in agriculture using an array of conducting polymer odour sensors. *Computers and Electronics in Agriculture*, Vol. 17, No. 2, pp. 233-147

Ivanova-Peneva, S.G.; Aarnink, A.J.A. & Verstegen, M.W.A. (2008). Ammonia emissions from organic housing systems with fattening pigs. *Biosystems Engineering*, Vol. 99, No.3, pp. 412 – 422

James, D.; Scott, S. M.; Ali, Z. & O'Hare, W. T. (2005). Chemical Sensors for Electronic Nose Systems. *Microchimica Acta*, Vol. 149, No.1-2, pp. 1-17
Malodor Detection Based on Electronic Nose

Kent, M.; Oehlenschlager, J.; Mierke-Klemeyer, S.; Manthey-Karl, M.; Knöchel, R.; Daschner, F. & Schimmer, O. (2004). A new multivariate approach to the problem of fish quality estimation. Food Chemistry, Vol. 87, No. 4, pp. 531-535

Kim, K. H. & Park, S.Y. (2008). A Comparative Analysis of Malodor Samples between Direct (Olfactometry) and Indirect (Instrumental) Methods. Atmospheric Environment, Vol. 42, pp. 5061-5070

Kim, K. Y.; Ko, H. J.; Kim, H. T.; Kim, Y. S.; Roh, Y. M.; Lee, C. M. & Kim, C. N. (2008). Quantification of ammonia and hydrogen sulfide emitted from pig buildings in Korea. Journal of Environmental Management, Vol. 88, pp. 195-202

Krajewski, A.; Allen, B.; Hoss, D.; Patel, C. & Chandawarkar, R. Y. (2009). Cutaneous myiasis. Journal of Plastic, Reconstructive & Aesthetic Surgery, Vol. 62, pp. e383-e386

Korotcenkov, G. (2005). Gas response control through structural and chemical modification of metal oxide films: state of the art and approaches. Sensors and Actuators, Vol. 107, No. 1, pp. 209-232

Korotcenkov, G. (2007). Metal oxides for solid-state gas sensors: What determines our choice?. Materials Science and Engineering B, Vol. 139, No. 1, pp. 1-23

Kuske, M.; Romain, A.C. & Nicolas, J. (2005). Microbial volatile organic compounds as indicators of fungi. Can an electronic nose detect fungi in indoor environments?. Building and Environment, Vol. 40, No. 6, pp. 824-831

Lane, A.J.P. & Wathes D.C. (1998). An Electronic Nose to Detect Changes in Perineal Odors Associated with Estrus in the Cow. Journal of Dairy Science, Vol. 81, No. 8, pp. 2145-2150

Lee, C.Y.; Chiang, C.M.; Wang Y.H. & Ma, R.H. (2007). A self-heating gas sensor with integrated NiO thin-film for formaldehyde detection, Sensors and Actuators B: Chemical, Vol. 122, pp. 503-510

Leyden, J.J.; McGinley, K.J.; Hölzle, E.; Labows, J.N. & Kligman, A.M. (1981). The Microbiology of the Human Axilla and Its Relationship to Axillary Odor. Journal of Investigative Dermatology, Vol. 77, pp. 413-416

Liao, F.; Yin, S.; Toney, M. F. & Subramanian, V. (2010). Physical discrimination of amine vapor mixtures using polythiophene gas sensor arrays. Sensors and Actuators B, Vol. 150, No. 1, pp. 254-263

Liao, L.; Zhang, Z.; Yan, B.; Zheng, Z.; Bao, Q.L.; Wu, T.; Li, C.M.; Shen, Z.X.; Zhang, J.X.; Gong, H.; Li, J.C. & Yu, T. (2009). Multifunctional CuO nanowire devices: p-type field effect transistors and CO gas sensors, Nanotechnology, Vol. 20, pp. 085203(1-6)

Lorwongtragool, Panida; Wisitsoraat, A. & Kerdcharoen, T. (2011). An Electronic Nose for Amine Detection Based on Polymer/SWNT-COOH Nanocomposite. Journal of Nanoscience and Nanotechnology, in press

Lorwongtragool, P.; Wongchoosuk, C. & Kerdcharoen, T., Portable artificial nose system for assessing air quality in swine buildings, Proceedings of ECTI-CON2010 7th International Conference of Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology Association, pp. 532 - 535, ISBN 978-1-4244-5606-2, Chaing Mai, THAILAND, May 19-21, 2010

www.intechopen.com
Lubczyk, D.; Siering, C.; Lörgen, J.; Shifrina, Z. B.; Müllen, K. & Waldvogel, S. R. (2010). Simple and sensitive online detection of triacetone triperoxide explosive. *Sensors and Actuators B*, Vol. 143, No. 2, pp. 561-566

Marsal, A.; Cornet, A. & Morante, J.R. (2003). Study of the CO and humidity interference in La doped tin oxide CO$_2$ gas sensor, *Sensors and Actuators B: Chemical*, Vol. 94, pp. 324-329

McGraw, T.A. & Turiansky, G. W. (2008). Cutaneous myiasis. *Journal of the American Academy of Dermatology*, Vol. 58, No. 6, pp. 907-926

Melse, R. W. & Timmerman, M. (2009). Sustainable intensive livestock production demands manure and exhaust air treatment technologies. *Bioresource Technology*, Vol. 100, No. 22, pp. 5506-5511

Negri, R.M. & Reich, S. (2001). Identification of Pollutant Gases and its Concentrations with a Multisensor Array. *Sensors and Actuators B*, Vol. 75, pp. 172-178.

Nicell, J.A. (2003). Expressions to Relate Population Responses to Odor Concentration. *Atmospheric Environment*, Vol. 37, pp. 4955-4964

Ólafsdóttir, G.; Martinsdóttir, E.; Oehlenschläger, J.; Dalgaard, P.; Jensen, B.; Undeland, I.; Mackie, I.M.; Henehan, G.; Nielsen, J. & Nilsen H. (1997). *Trends in Food Science & Technology*, Vol. 81, pp. 258-265

Ólafsdóttir, G.; Nesvadba, P.; Natale, C. D. Careched, M.; Oehlenschläger, J.; Tryggvadóttir, S. V.; Schubring, R.; Kroeger, M.; Heia, K. Esaiasssen, M.; Macagnano, A. & Jørgensen, B. M. (2004). Multisensor for fish quality determination. *Trends in Food Science & Technology*, Vol. 15, pp. 86-93

Önal, A. (2006). A review: Current analytical methods for the determination of biogenic amines in foods. *Food Chemistry*, Vol. 103, pp. 1475-1486

O'Sullivan, M.G; Byrnea, D.V.; Jensen, M.T.; Andersen, H.J. & Vestergaard, J. (2003). A comparison of warmed-over flavour in pork by sensory analysis, GC/MS and the electronic nose. *Meat Science*, Vol. 65, pp. 1125-1138

Pacquit, A.; Lau, K. T.; McLaughlin, H.; Frisby, J.; Quilty, B. & Diamond, D. (2006). Development of a volatile amine sensor for the monitoring of fish spoilage. *Talanta*, Vol. 69, pp. 515-520

Panigrahi, S.; Balasubramanian, S.; Gu, H.; Logue, C.M. & Marchello, M. (2006). Design and Development of a Metal Oxide Based Electronic Nose for Spoilage Classification of Beef. *Sensors and Actuators B*, Vol. 119, pp. 2-14

Pan, L.; Yang, S.X. & DeBruyn, J. (2007). Factor Analysis of Downwind Odours from Livestock Farms. *Biosystems Engineering*, Vol. 96, No. 3, pp. 387-397

Pan, L.; Yang, S.X.; Otten, L. & Hacker, R.R. (2006). Component and Factor Analysis of Pork Farm Odour using Structural Learning with the Forgetting Method. *Biosystems Engineering*, Vol. 94, No. 1, pp. 87-95

Pan, L. & Yang, S. X. (2007). Analysing livestock farm odour using an adaptive neuro-fuzzy approach. *Biosystems Engineering*, Vol. 97, pp. 387 – 393

Pan, L. & Yang, S. X. (2009). An Electronic Nose Network System for Online Monitoring of Livestock Farm Odors. *IEEE/ASME Transactions on Mechatronics*, Vol. 14, pp. 371-376
Pearce, T.C.; Schiffman, S.S.; Nagle, H.T. & Gardner, J.W. (2003) Handbook of Machine Olfaction, WILEY-VCH
Penn, D.J.; Oberzaucher, E.; Grammer, K.; Fischer, G.; Soini, H.A.; Wiesler, D.; Novotny, M.V.; Dixon, S.J.; Xu Y.; & Breteton, R.G. (2007). Individual and Gender Fingerprints in Human Body Odour, Journal of the Royal society interface, Vol.4, pp. 331-340
Pogfay, T.; Watthanawisuth, N.; Pimpao, W.; Wisitsoraat, A.; Mongpraneet, S.; Lomas, T.; Sangworasil, M. & Tuantranont, A. (2010). Development of Wireless Electronic Nose for Environment Quality Classification, Proceedings of ECTI-CON 2010, pp. 540 – 543
Qu, J.; Chai, Y. & Yang, S. X. (2009). A Real-Time De-Noising Algorithm for E-Noses in a Wireless Sensor Network. Sensors, Vol. 9, pp. 895-908
Ragazzo-Sanchez, J.A.; Chalier, P.; Chevalier, D.; Calderon-Santoyo, M. & Ghommidh, C. (2008). Identification of different alcoholic beverages by electronic nose coupled to GC. Sensors and Actuators B, Vol. 134, No.1, pp. 43-48
Rajamäki, T.; Alakomi, H.-L.; Ritvanen, T.; Skyttä, E.; Smolander, M. & Ahvenainen, R. (2006). Application of an electronic nose for quality assessment of modified atmosphere packaged poultry meat. Food Control, Vol. 17, No. 1, pp. 5-13
Santonico, M.; Pittia, P.; Pennazza, G.; Martinelli, E.; Bernabei, M.; Paolesse, R.; D’Amico, A.; Compagnone, D. & Di Natale, C. (2008). Study of the aroma of artificially flavoured custards by chemical sensor array fingerprinting. Sensors and Actuators B, Vol. 133, No. 1, pp. 345-351
Sauerbrey, G. (1959). Verwendung von Schwingquarzen zur Wägung dünner Schichten und zur Mikrowägung, Zeitschrift für Physik, Vol. 155, pp. 206–222.
Schiffman, S.S.; Bennett, J.L. & Raymer, J.H. (2001). Quantification of odors and odorants from swine operations in North Carolina. Agricultural and Forest Meteorology, Vol. 108, No. 3, pp. 213–240
Scorsone, E.; Pisanelli, A.M. & Persaud, K.C. (2006). Development of an Electronic Nose for Fire Detection. Sensors and Actuators B, Vol. 116, pp. 55–61
Seo, S.-G.; Ma, Z.-K.; Jeon, J.-M.; Jung, S.-C. & Lee, W.-B. (2011). Measurements of key offensive odorants in a fishery industrial complex in Korea. Atmospheric Environment, in press
Seregély, Z.; Farkas, J.; Tuboly, E &Dalmadi, I. (2006). Investigating the properties of egg white pasteurised by ultra-high hydrostatic pressure and gamma irradiation by evaluating their NIR spectra and chemosensor array sensor signal responses using different methods of qualitative analysis. Chemometrics and Intelligent Laboratory Systems, Vol. 82, pp. 115 - 121
Sheridan, B.; Curran, T.; Dodd, V. & Colligan, J. (2002). Biofiltration of Odour and Ammonia from a Pig Unit-a pilot-scale Study. Biosystems Engineering, Vol. 82, No. 4, pp. 441-453
Shurmer, H.V.; Gardnera, J.W. & Corcoran, P. (1990). Intelligent vapour discrimination using a composite 12-element sensor array. Sensors and Actuators B: Chemical, Vol. 1, No. 1-6, pp. 256-260
Shurmer H. V. & Gardner, J. W. (1992). Odour discrimination with an electronic nose. *Sensors and Actuators B: Chemical*, Vol. 8, No.1, pp. 1-11

Sohn, J. H.; Dunlop, M.; Hudson, N.; Kim, T. & Yoo, Y. H. (2009). Non-specific conducting polymer-based array capable of monitoring odour emissions from a biofiltration system in a piggery building. *Sensors and Actuators B: Chemical*, Vol. 135, No. 2, pp. 454-464

Sohn, J. H.; Hudsonb, N.; Gallagher, E. & Dunlop, M. (2008). Implementation of an electronic nose for continuous odour monitoring in a poultry shed. *Sensors and Actuators B*, Vol. 133, pp. 60–69

Suman, M.; Riani, G. & Dalcanale, E. (2007). MOS-based artificial olfactory system for the assessment of egg products freshness. *Sensors and Actuators B*, Vol. 125, pp. 40–47

Su, P.-G. & Pan, T.-T. (2011). Fabrication of a room-temperature NO2 gas sensor based on WO3 films and WO3/MWCNT nanocomposite films by combining polyol process with metal organic decomposition method. *Materials Chemistry and Physics*, Vol. 125 pp.351–357

Surnev, S.; Ramsey, M.G. & Netzer, F.P. (2003). Vanadium oxide surface studies. *Progress in Surface Science*, Vol. 73, No. 4-8, pp. 117-165

Tikk, K.; Haugen, J.-E.; Andersen, H. J. & Aaslyng, M. D. (2008). Monitoring of warmed-over flavour in pork using the electronic nose – correlation to sensory attributes and secondary lipid oxidation products. *Meat Science*, Vol. 80, No. 4, pp. 1254-1263

Tikuisis, P.; Kane, D.M.; McLellan, T.M.; Buick, F.; Fairburn, S.M. (1992). Rate of formation of carboxyhemoglobin in exercising humans exposed to carbon monoxide. *Journal of Applied Physiology*, Vol.72, pp. 1311–1319

Timmer, B.; Olthuis, W.; Berg, A. v. d. (2005). Ammonia sensors and their applications—a review. *Sensors and Actuators B*, Vol. 107, pp. 666–677

Trabue, S.L.; Anhalt, J.C. & Zahn, J.A. (2006). Bias of Tedlar Bags in the Measurement of Agricultural Odorants. *Journal of Environmental Quality*, Vol. 35, No. 5, pp.1668–1677

Tomchenko, A. A.; Harmer, G. P.; Marquis, B. T. & Allen, J. W. (2003). Semiconducting metal oxide sensor array for the selective detection of combustion gases. *Sensors and Actuators B*, Vol. 93, pp. 126–134

Tuantranont, A.; Lomas, T.; Jaruwongrungsee, K.; Jomphoak, A. & Wisitsoraat, A. (2008). Symmetrical PolyMUMPs-Based Piezoresistive Microcantilever Sensors With On-Chip Temperature Compensation for Microfluidics Applications. *IEEE Sensors Journal*, Vol. 8, No. 5, pp. 543-547

Uttiya, S.; Kerdcharoen, T.; Vatanayon, S. & Pratontep, S. (2008). Effect of structural transformation to the gas sensing properties of phthalocyanine thin films. *Journal of the Korean Physical Society*, Vol. 52, No. 5, pp. 1575-1579

Vallejos, S.; Khatko, V.; Aguir, K.; Ngo, K.A.; Calderer, J.; Gràcia, I.; Cané, C.; Llobet E. & Correig, X. (2007). Ozone monitoring by micro-machined sensors with WO3 sensing films, *Sensors and Actuators B: Chemical*, Vol.126, pp. 573-578

www.intechopen.com
Van der Werf, H.M.G.; Petit, J. & Sanders, J. (2005). The environmental impacts of the production of concentrated feed: the case of pig feed in Bretagne. *Agricultural Systems*, Vol. 83, No. 2, pp.153-177

Vercelli, B.; Zecchin, S.; Comisso, N.; Zotti, G.; Berlin, A.; Dalcanale, E. & Groenendaal, L.B. (2002). Solvconductivity of polyconjugated polymers: The roles of polymer oxidation degree and solvent electrical permittivity. *Chem. Mater.*, Vol. 14, pp. 4768-4774

Vernat-Rossi, V.; Garcia, C.; Talon, R.; Denoyer, C. & Berdagué, J.-L. (1996). *Sensors and Actuators B: Chemical*, Vol. 37, No. 1-2, pp. 43-48

Vito, S.D.; Massera, E.; Burrsca, G.; Girolamo, A.D.; Miglietta, M.; Francia, G.D. & Sala, D.D. (2008). TinyNose: Developing a wireless e-nose platform for distributed air quality monitoring applications, *Proceedings of 2008 IEEE Sensors Conference*, pp. 701-704

Wilkes, J. G.; Conte, E. D.; Kim, Y.; Holcomb, M.; Sutherland, J. B. & Miller, D. W. (2000). Sample preparation for the analysis of flavors and off-flavors in foods. *Journal of Chromatography A*, Vol. 880, No. 1-2, pp. 3-33

Winquist, F.; Hornsten, E G; Sundgren, H & Lundstrom, I. (1993). Performance of an electronic nose for quality estimation of ground meat. *Meas. Sci. Technol*, Vol. 4, pp.1493-1500

Wongchoosuk, C.; Lutz, M. & Kerdcharoen, T. (2009a). Detection and Classification of Human Body Odor using an Electronic Nose. *Sensors*, Vol. 9, pp.7234-7249

Wongchoosuk, C.; Choopun, S.; Tuantranont, A. & Kerdcharoen, T. (2009b) Au-doped Zinc Oxide Nanostructure Sensors for Detection and Discrimination of Volatile Organic Compounds. *Materials Research Innovation*, Vol. 13, pp. 185-188

Wongchoosuk, C.; Wisitsoraat, A.; Phokharatkul, D.; Tuantranont, A. & Kerdcharoen, T. (2010a). Multi-walled Carbon Nanotubes Doped Tungsten Oxide Thin Film for Hydrogen Gas Sensing. *Sensors*, Vol.10, pp. 7705-7715, ISSN 1424-8220

Wongchoosuk, C.; Wisitsoraat, A.; Tuantranont, A. & Kerdcharoen, T. (2010b). Portable Electronic Nose Based on Carbon Nanotube-SnO$_2$ Gas Sensors: Feature Extraction Techniques and Its Application for Detection of Methanol Contamination in Whiskeys. *Sensors and Actuators B*, Vol. 147, pp. 392-399

Yaglou, C.P.; Riley, E.C. & Coggins D.I. (1936). Ventilation Requirements. *ASHVE Transactions*, Vol.42, pp. 133-162

Yongwei, W.; Wang, J.; Zhou, B. & Lu, Q. (2009). Monitoring storage time and quality attribute of egg based on electronic nose. *Analytica Chimica Acta*, Vol. 650, pp. 183-188

Yu, H. & Wang, J. (2007). Discrimination of Longjing green-tea grade by electronic nose. *Sensors and Actuators B*, Vol. 122, No. 1, pp. 134-140

Zhang, D.; Liu, Z.; Li, C.; Tang, T.; Liu, X.; Han, S.; Lei, B. & Zhou, C. (2004). Detection of NO2 down to ppb Levels Using Individual and Multiple In$_2$O$_3$ Nanowire Devices, *Nano Letters*, Vol.4, pp. 1919-1924

Zhang, Z; Li, G.; Luoc, L. & Chen, G. (2010). Study on seafood volatile profile characteristics during storage and its potential use for freshness evaluation by headspace solid
phase microextraction coupled with gas chromatography–mass spectrometry. *Analytica Chimica Acta*, Vol. 659, No. 1-2, pp. 151-158

Zhang, S.; Xie, C.; Bai, Z.; Hu, M.; Li, H. & Zeng, D. (2009). Spoiling and formaldehyde-containing detections in octopus with an E-nose. *Food Chemistry*, Vol. 113, No. 4, pp. 1346-1350

Zhang, S.; Xie, C.; Zeng, D.; Zhang, Q.; Li, H.; & Bi, Z. (2007). A feature extraction method and a sampling system for fast recognition of flammable liquids with a portable E-nose. *Sensors and Actuators B*, Vol. 124, No. 2, pp. 437-443
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