final report

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Prepared by:
Meat & Livestock Australia
Locked Bag 991
North Sydney, NSW 2059

Development of an Electronic Nose

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Summary

Development and Field trial for an Electronic Nose

Background

The project addressed the need to improve the monitoring of odours released into the environment by meat processing plants. Management of odour emissions and compliance with environmental regulations would be easier and less problematical if continuous real-time information on odour status at plants were available.

Prior to this project, the industry has relied on odour assessments involving bagging of air at the site, followed by analysis of the air up to 30 hours later by human assessment panel using Dynamic Olfactometry, or less often by chemical analysis (GCMS). These methods require several days for results to be available and are therefore of limited value in odour management.

MLA commissioned the Chemosensory Research Centre of University of New South Wales (UNSW) to design, build and demonstrate an electronic nose device (e-nose) based on the prototype successfully demonstrated in the laboratory under MLA project ENV.007 completed in March 2001. This device consisted of five chemical “odour” sensors, a temperature sensor and an humidity sensor. The system would aim to provide management with continuously available, real-time, knowledge of odour being produced by a meat processing plant. During the project, the research group became a spin-off company called E-Nose Pty Ltd.

An essential objective of this project was to ensure that the technology would be robust, sufficiently sensitive and able to identify and quantify odours from meat processing plants, continuously (24 hours a day, seven days a week) in order to inform plant management of odour levels that needed their attention and provide advance warning that the plant may be exceeding prescribed odour emission levels. Alarm, calibration and testing against external Dynamic Olfactometry measurements were key aspects of the project.

The main project ran over two periods, from March 2002 to January 2003 and from May to August 2003). During these periods and at times between the contracts, the research team developed the device and the odour monitoring system for continuous use both indoors and outdoors at the processing plant of Southern Meats Ltd, Goulburn.

Process

The project was performed in several stages:

- An initial assessment of e-nose sensitivity to odours generated at the Southern Meats site was made to identify suitable locations for installing the equipment and the degree of sensor attenuation required.

- The e-nose instrument was located inside the rendering plant building for several months to test it in a robust, high humidity and high odour indoors environment. During this time a flush-calibration and alarm system was developed.

- The e-nose system was then trialed in a low odour environment (mounted on an exterior wall of a building, where the box might be protected from wind and rain while retaining access to the outdoor air) where it operated without interruption for 3 months (June-August 2003).

- The final stage of the project required testing the e-nose sensor responses against odours from the site with concomitant assessment of the odours using the established Dynamic Olfactometry method.

The E-nose Instrument

The e-nose instrument consists of:

- 5 tin oxide sensors selected for their high sensitivity to meat industry odours and robustness;
- A temperature & humidity sensor;
- An air sampling device and manifold for passing air past the sensors;
- A system for flushing the sensors and recalibrating their response during continuous operation.
- An alarm software to report odour exceedences above a set point.

The “innards” are shown below in the test instrument. Data was saved to computer daily and downloaded to the Sydney office for evaluation during the project.

Results

Indoor Testing in Rendering Plant.

The apparatus and computer link-up was prepared for the hot, humid, high odour conditions in the rendering plant. A robust housing was designed and built, consisting of wall-mountable galvanised box into which air was drawn, through a particulate filter, by a fan.

Three testing campaigns were conducted during which time the e-nose operating continuously for:

- seven days (1-8 August 2002)
- a month (1-31 October 2002), with development of the flush-calibration system conducted simultaneously.
- approximately two weeks in December 2002 during which time data were used to develop the alarm system

inside the rendering plant at Southern Meats Ltd. The e-nose operated successfully during these trials.

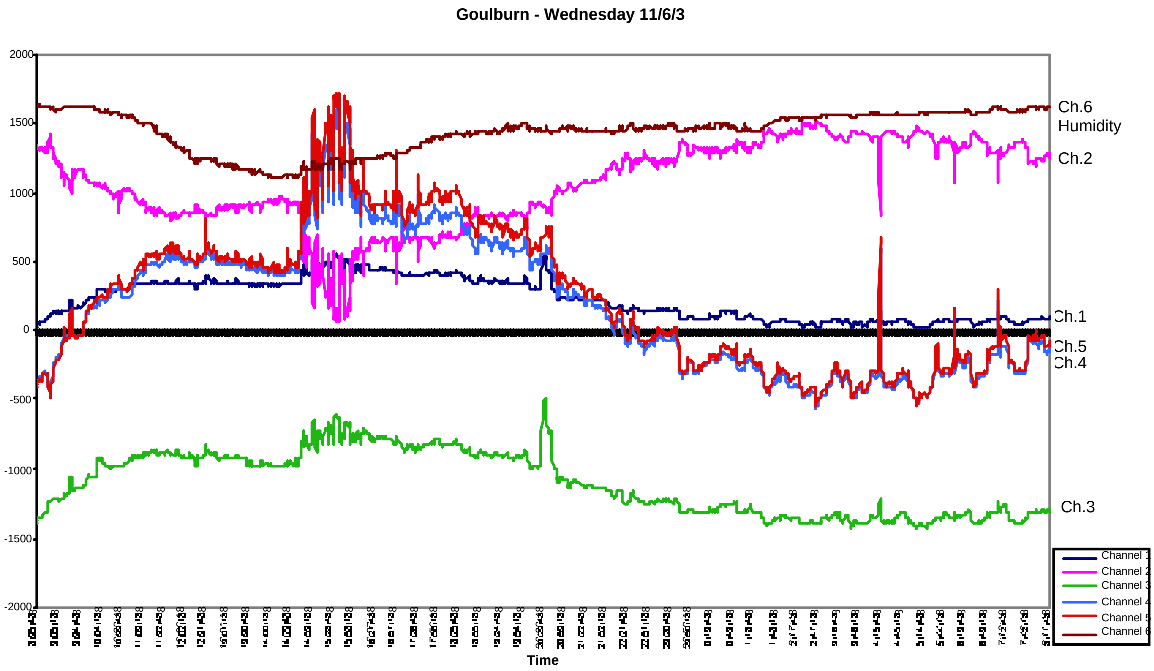
Outdoor Testing

The e-nose instrument and its housing were rebuilt to allow its installation on the external wall of a building near the centre of the Southern Meats site. Several improvements were made to the instrument including the integration of an apparatus for periodically flushing the sensors with clean air, subjecting them to a pure chemical of known concentration then flushing them again with air. This "flush-calibrate" cycle informs the operator of the status of the system on a daily or weekly basis. It also serves to refresh the sensors and possibly prolong their life (expected to be six months).

The system ran without interruption for 3 months (June-August 2003). Responses to the low odours showed that activities on site (Goulburn) could be tracked in terms of odour impacts from a remote location (Sydney).

E-nose instrument located on wall at Southern Meats.

The figure below shows the response from all 7 e-nose sensors to activities on-site during a



normal processing day. The sensors respond rapidly and in real time to indicate the detection of events which generate or emit odours. There is sufficient sensitivity in the system to show residual odours on Saturdays, disappearing by Sunday.

Since the instrument operates 24 hours/day and during the weekend, management can begin to correlate odour events observed by the e-nose with activities on the site. This allows management to identify activities that may pre-dispose the site to higher than desired emissions and take corrective action. It is this real-time monitoring ability of the e-nose which is promising.

Correlation between E-nose output & Dynamic Olfactometry

Calibration of the system against dynamic olfactometry measurements was carried out with the assistance of The Odour Unit Pty Ltd (Terry Schulz). Air from ten locations on site were collected in duplicate bags. One was tested by the e-nose instrument and the other was returned to Sydney for odour concentration measurement by dynamic Olfactometry.

It was found that all the 10 samples taken within the site boundaries close to process buildings measured 20 OU or greater. The e-nose showed a strong response to all odours, but a different response pattern, as is usual for odours emitted by different sources. Further work will need to be done at each site at which a system is installed to set the alarm level appropriate for the particular conditions. This is not regarded as a major issue, and was to be expected. The e-nose is clearly sensitive enough to operate in the 1 to 10 OU range, for systems that might be set up very remotely from the site.

Conclusions & Outcomes

- An electronic nose consisting of 5 tin oxide taguchi-type sensors specific for meat processing plant odours, and coupled with temperature and humidity sensors, was successfully developed and trialed at a meat plant in both high (rendering plant) and low (general environs of a meat plant) odour environments.
- The instrument operated successfully for approximately 5 months in total on-site, with three of these months being in continuous 24-hr operation. The sensors operated stably and without significant drift during this period.
- The sensor outputs showed reasonable correspondence with the expected odour pattern generated by activities on the site and were independent of temperature. The real-time 24-hr output permits management to identify odour generation peaks and to relate them to on-site activities. The opportunity this provides to detect immediately, identify and eliminate odour sources is profound.
- An automatic flush calibration system was developed and successfully trialed in both the laboratory and in the field.
- An alarm system was developed and successfully tested in the field. The actual alarm setpoints will need to be calibrated on-site for each user.
- Off-site logging and analysis of the digital data from the Enose instrument is possible, but only with satisfactory resolution of security issues relating to access to a company's computer network.
- There is reasonable correspondence between sensor output and odour unit (OU) values at low odour unit values (< 100 OU), but poor correlation at OU values above this. Since the instrument is expected to operate in very low odour environments (OU < 10), this is not anticipated to be a difficulty.

The project has demonstrated that the electronic nose is a responsive instrument for automated, objective determination of odour generation at meat processing sites. The instrument provides, for the first time, a means of cataloguing odour generation in real time with a capability for alarming when odour levels exceed a threshold value. Further interrogation of the instrument output offers the ability to discriminate between odour sources, both from sources of odour on the site and those at a distance from it.

Subsequent Progress

MLA and E-nose Pty Ltd have obtained provisional patents protecting the intellectual property developed under this and previous projects developing the e-nose instrument. The Australian meat processing industry will soon be able to explore the benefit of this technology through a syndicated PIP scheme to begin in early 2005.

Acknowledgements

MLA and the e-nose team (lead by Professor Graham Bell) wish to express their deep gratitude to Neville Newton of Southern Meats at Goulburn for permission to use his facility as the test site for the project. Thanks also to Jonathan Lawson, Environmental Officer at Southern Meats without whose enthusiastic participation and support the project would have been stillborn.

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Development and Field Trial for an Electronic Nose Device

Prepared by:

TM

E–Nose Pty Ltd

ABN 14 103 740 567
145 NIC Bldg, Australian Technology Park, Sydney 1430

Meat and Livestock Australia
Locked Bag 991
North Sydney NSW 2059

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MEAT & LIVESTOCK
AUSTRALIA

1. Executive Summary

The meat processing industry wishes to improve its practices by the reduction of odours released into the environment. Management of emissions and compliance with environmental regulations requires knowledge, available continuously and in real time, of the quantity and quality of odour being produced.

Projects 017 and 017A undertook to develop an air monitoring device and system that would be robust, sufficiently sensitive and able to identify and quantify odours from meat processing plants, in order to inform the plant operators of odour levels that needed their attention.

A device consisting of five chemical sensors, a temperature sensor and an humidity sensor was specified for optimal performance on meat processing plant odours in a preliminary study completed in March 2001 (PRENV.007).

This Study ran over two periods, from March 2002 to January 2003 (PRENV.017) and from May 2003 to August 2003 (PRENV.017A). During these periods and at times between the contracts, the research team developed the device and the monitoring system for continuous use in a meat processing plant, both indoors and outdoors.

First Odours sampled at Goulburn Abattoir

Initially, the Project team visited Southern Meats Ltd, Goulburn, NSW, twice early in 2002. Southern Meats agreed to allow the team to work on site and provided services of Mr Jonathan Lawson to facilitate the system trials. Data was collected by two e-noses from air at various locations on site (including air from the biofilter bed, Receival Pits No. 1 and 4, in and around the Rendering Plant, and in and around the Boiler House). Air at each location was sampled for approximately three minutes. The digital outputs from the e-nose were fed directly into a laptop computer and analysed upon return to Sydney.

The results showed that the e-nose data could categorise odours from different sources and was sufficiently sensitive across the range of situations at which samples were taken and that hardware changes would be made to attenuate sensitivity in certain locations such as the rendering plant and receival pits. Options for connecting the e-nose to the relevant computers were formulated for indoor and outdoor uses. It was decided to locate the e-nose for a trial of continuous operation in an indoor setting (the rendering plant).

Continuous E-Nose performance inside a rendering plant. The system and computer link-up was prepared for the hot, humid, high odour conditions in the rendering plant. A robust housing was designed and built, consisting of wall-mountable galvanised box into which air was drawn, through a particulate filter, by a fan.

The e-nose was rebuilt to include the five main chemical sensors plus a temperature and humidity sensor in an integrated unit. (All technical details were reported in a report dated 6th September 2002.) The redesigned e-nose and the lap-top computer were placed in the box and the box placed in a central position in the rendering plant.

First run

The system was run continuously for seven days (1-8 August 2002) inside the rendering plant.

The results showed that the system could operate under the harsh conditions for several days of unbroken recording.

To reduce the risks of damage to the laptop being located inside the harsh environment, the system fitted with additional equipment (an ADC 16 A-D converter and a UDS10 line driver). This allowed transfer of data by cable (CATS 5) from the e-nose in the rendering plant to the computers in the administration building, where the data could be handled by PICO software either on site or after further transmission of the data to the Sydney lab.

Second run

Data was collected continuously for a month (1-31 October 2002) during which the device delivered daily files of information, via e-mail to Sydney. Performance of the e-nose, in real time, was monitored by site personnel (Mr. J. Lawson) who made the daily file transfers to Sydney.

With appropriate IT links it will be possible to monitor each field-located e-nose, in real time, back at a central “base” location, such as the Sydney lab. In this instance, however, it was deemed unnecessary to set up such a facility, as it required a new or different firewall at the site. The results showed that the sensors responded independently and consistently over a prolonged period. The sensor output voltages appeared to rise and fall with daily activities on site in a 24 h cycle.

There was reasonable independence between outputs of the chemical sensors and temperature. The humidity sensor was out of service throughout the period.

At the lab, a flush-calibration system was developed and tested on the bench. This, when fitted, will show a response by the sensors to a known substance of known concentration and will serve to restore the sensors by flushing them with clean air should that be necessary.

Third run

This took place for approximately two weeks in December 2002. The data from Runs 2 and 3 were used to test an idea for a predictive alarm function using neural net processing. This was reported in detail in an appendix to the final report for PRENV.017 on 15/1/03. It was demonstrated that data from approximately 30 mins of operation could predict with a high degree of certainty the values of the next 10 minutes, thereby providing a “predictive alarm” system, to supplement the alarm functions available in the Pico data logger software.

With regard to classifying odours from different sources, our data was restricted to only one site (rendering plant). The neural net process developed for the predictive alarm could equally be used to process data from several e-noses at different locations, such that the alarm might be given for odours from one site but not another, depending on the net’s classification of them.

The remote logging and reporting system was installed and proved adequate for continuous "sentinel" operation at a meat processing plant. The data collected from two periods of several days of uninterrupted logging were used to develop alarm algorithms.

In conclusion to PRENV.017, it can be said that the e-nose stood up to hard conditions of high odour inside a meat plant and data of potential use to management of odours indoors, if needed.

Summary of Objectives:

- Equip and install robust sentinel system in plant. *Achieved*.
- Develop remote logging and reporting system. *Achieved*.
- Monitor plant over interval of several weeks continuously. *Achieved*.
- Develop algorithms for alarm system. *Achieved.*

Continuation of Project in 2003

The research team emerged intact after four months of administrative restructure and are now operating as a private company called E-Nose Pty Ltd. The Project resumed under a renewed contract PRENV.017A. (Progress on this Phase of the project was reported three times between 12/5/03 and 31/8/03).

The objectives for this phase of the study were to trial the e-nose at the Goulburn site, and its flush-calibration system, in low-odour, outdoor conditions, demonstrate the alarm system on site and calibrate the system to human odour detection levels ("odour units").

A position on site was chosen on an exterior wall of the Quality Assurance building, where the box might be protected from wind and rain while retaining broad access to the outdoor air.

The e-nose and its housing were rebuilt. Several improvements were made to the system, including an apparatus for periodically flushing the sensors with clean air, subjecting them to a pure chemical of known concentration (ethanol) then flushing them again with air.

This "flush-calibrate" cycle would inform the operator of the status of the system on a daily or weekly basis. It would also serve to refresh the sensors and possibly prolong their life (expected to be six months).

The system without interruption for 3 months continuously (June-August 2003). Responses to the low odours showed that activities on site (Goulburn) could be tracked in terms of odour impacts from a remote location (Sydney).

The flush-calibrate system proved useful as a standard reference of sensor response and to indicate the status of the system in producing random noise or sensor burnout.

Assessment of the system under low odour was favourable. There is sufficient sensitivity in the system to show residual odours on Saturdays, disappearing by Sunday.

Calibration of the system against human assessment of intensity was carried out with the assistance of The Odour Unit Pty Ltd (Terry Schulz). The OU measurement of perceived odour intensity is determined by the number of times a unit volume of sample (air and odour) must be diluted with the same volume of air, at which a human (the average of a panel of 8 adults) can no longer discriminate it from an air (only) sample.

Environmental Pollution Authorities generally expect ambient odours in the outdoor environment to be no greater than 10 OU.

Air from ten locations on site were collected in duplicate bags and one was put through the instrument and the other was returned to Sydney for human Odour Unit assessment.

It was found that all the 10 samples taken around the site were 20 OU or greater. Use of an e-nose on site would therefore need to be calibrated to allow for the dilution over the distance between the plant and the community.

Further work will need to be done at each site at which a system is installed to set the level appropriate for the particular conditions. This is not regarded as a major issue, and was to be expected. The system is clearly sensitive enough to operate in the 1 to 10 OU range, for systems that might be set up very remotely from the site.

The system is clearly capable of meeting the specifications originally conceived for it at the start of Project PRENV.017.

Demonstration of alarm function on site

The OU measurements allowed alarm levels to be calculated for each of the odours at the ten locations on site. Patterns of voltages showed that some locations produce relatively similar odours, but of varying intensity, which other locations (exemplified by the anaerobic lagoon) produced. From these data it is clearly a simple matter to set the alarm parameters to meet the specific or class of odour that might be giving the most offence to the community.

The alarm parameters were derived for the on-site demonstration from a location that produced a middle level odour common to four other locations. This was considered a typical whole-of-site odour that might be detected and recognised beyond the boundaries. A bucket of miscellaneous waste was then placed near the e-nose and within two minutes the alarm on all five sensors had been given. *Summary of Objectives (PRENV.017A):*

Trial the e-nose at the Goulburn site, and its flush-calibration system, in low-odour, outdoor conditions, demonstrate the alarm system on site and calibrate the system to human odour detection levels (“odour units”). *Achieved.*

E-Nose and calibration equipment now working at Southern Meats.

2. Table of Contents

Appendices

3. Introduction

The meat processing industry wishes to improve its practices by the reduction of odours released into the environment. Management of emissions and compliance with environmental regulations requires knowledge, available continuously and in real time, of the quantity and quality of odour being produced.

Projects 017 and 017A undertook to develop an air monitoring device and system that would be robust, sufficiently sensitive and able to identify and quantify odours from meat processing plants, in order to inform the plant operators of odour levels that needed their attention.

A device consisting of five chemical sensors, a temperature sensor and an humidity sensor was specified for optimal performance on meat processing plant odours in a preliminary study completed in March 2001 (PRENV.007).

This Study ran over two periods, from March 2002 to January 2003 (PRENV.017) and from May 2003 to August 2003 (PRENV.017A). During these periods and at times between the contracts, the research team developed the device and the monitoring system for continuous use in a meat processing plant, both indoors and outdoors. The broad objectives of these studies were to trial an e-nose specified for meat processing plant odours at a plant and collect real-time continuous data for assessment from high and low odour locations. Specific Objectives were:

- Equip and install a robust sentinel system in plant.
- Develop remote logging and reporting system.
- Monitor plant over interval of several weeks continuously.
- Develop algorithms for alarm system
- Develop and assess a flush-calibrate system
- Calibrate the system to human detection levels (“odour units”)
- Demonstrate the alarm system on site

Plate 1: Photograph of a four sensor nose – dimensions: 5 x 10 x 20 cm

Fig. 1 : The sensing equipment for the E-Nose Sentinel

4. Technical Description of the E-Nose

Physical Description

The e-nose consists of a platform for a pre-determined combination of tin-oxide chemical sensors (Taguchi, Figaro, Japan) located on a printed circuit board, housed in a case (measuring 190 x 100 x 35 mm). The outer case is mounted on a wall or pole indoors or outdoors.

Vapour enters the case through holes near the sensors and is drawn over the sensors and out another hole by a small electrical fan (Innovative Technologies Inc.).

The sensors for chemicals and others as required for other information, such as temperature and humidity, and supporting electronics are mains powered (240V).

Gas/vapour is driven into the e-nose box through an opening in one end of the box by a small fan (Innovative Industrial Inc) and out of a larger opening directly below the fan. By this means, vapour from the environment is drawn over the sensors.

The sensors react to compounds in the vapour coming into contact with the surface of an electrode and change the resistance across the electrode in proportion to the amount and kind of molecule reacting with the oxide on the electrode surface. If sufficient material in the vapour reacts with the electrode, a voltage is registered as an output from the sensor.

Sensor output voltages are converted to digital signals and captured after A-D conversion by a datalogger (UDS16, and UDS 10 units, by PICO UK).

The signal is boosted by a line driver for transmission to a PC computer connected at up to 300 metres distance by cable.

The e-nose is calibrated with ethanol and flushed with clean air at intervals (set by the operator) by means of timers, valves and an ethanol and air delivery system located in the outer case in which the e-nose is housed.

Operations of the E-Nose

The e-nose is activated by switching on the power to the units inside the outer casing. The computer receiving the e-nose data is powered up and the resident e-nose software is activated.

The digitized e-nose data is handled at the PC by the PICO software, allowing real-time display (after 1-2 secs latency), alarms and archiving (filing) of data. Long-term storage can be achieved by burning CDs &/or backing up data on a USB-port storage device (e.g. Pretek).

Data can be transmitted directly by internet to a second PC (“back to base function”) using PICO software provided there is no firewall obstruction. In the latter case, the data must be converted to an Excel file and transmitted by e-mail to the off-site computer.

The alarm levels are determined by reference to sensor outputs to odours of varying known perceived intensities. The latter are obtained by bagging odours and making an “odour unit” (OU)assessment by a trained panel (see method defined by Australian Standard “Determination of Odour Concentration by Dynamic Olfactometry AS/NZS 4323.3:2001). An odour has a strength of 1 OU if, when an equal volume of air is mixed with that of the sample of odoriferous air results in the odour no longer being perceived. Thus, OUs are units of number of times a given volume of vapour can be diluted by equal volumes to reach the detection threshold for that odour by a heathy human adult.

There is no existing determination of what strength of abattoir odour (in OUs) is required before it becomes offensive. Indeed there will be several levels depending on the source of the odour. Hence the setting of alarm levels in terms of output voltages will need to be determined for each site, and for each source of odour on the site, using duplicate samples of bagged air, with one sample assessed for OU intensity and one put into the e-nose to determine the equivalent output voltages.

A predictive alarm function was determined using a neural network model. It needs to be determined what kind of alarm function the customers for the e-nose system (and services) will need. This needs a survey of potential client companies to determine further developmental directions of the system.

The system is described in further detail in the following pages. Data from test runs at Southern Meats Ltd, and other useful information is provided in the appendices.

Performance of the E-nose *indoors* (high odour)

The key test of the e-nose was continuous and robust performance inside the hot, humid and high-odour rendering plant, from 1/10/02 to 31/10/02, during which the device delivered daily files of information, via e-mail, to the lab in Sydney.

The device demonstrated that it can run continuously without any obvious malfunction. Data from the four sensors plus temperature was collected .(The humidity sensor malfunctioned at the outset. This was corrected and ran well in later trials.)

Meanwhile, at the lab, a system for flushing and calibrating the sensors has been designed, built and tested on the bench.

Analysis of a batch of E-nose data from Goulburn 14/10/2002 – 17/10/2002

Data analysed here comprises readings on four consecutive days, with about 19 hours from the first day and nearly 24 hours on each subsequent day.

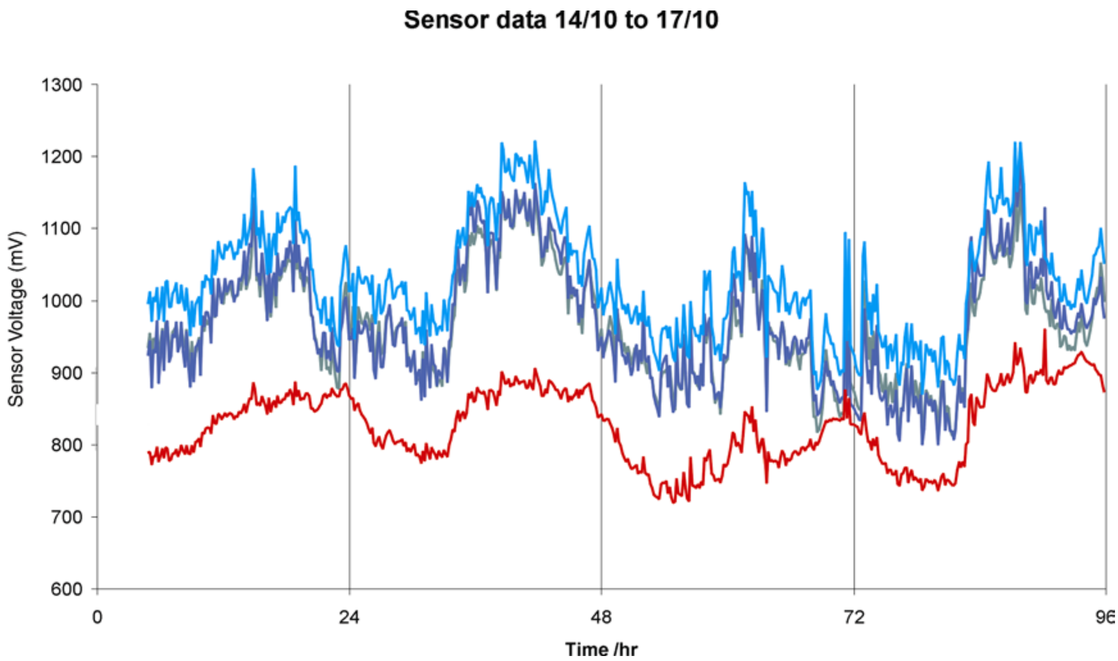
Data were sampled the data every 10 minutes (data is collected every 30 s) and have concatenated the data with the missing 5 hours being left off the front of the first day. The graph below does not show actual time (which can now be introduced), but this “blind” strategy, for this analysis, appears to generate signals that rise and fall with a consistent 24 h constant.

We learned from this that the e-nose is not simply tracking ambient temperature. We now need to relate the “odour activity” recorded by the sensors with the activities at the plant.

The data files included a facility for insertion of comments to be made of what activities were taking place so these can be registered against the sensor data.

Conclusion to Indoor Trial: The E-nose and data collection system are working satisfactorily, on site (indoors). The system is capable of continuous functioning despite fairly hostile conditions of heat, humidity and chemical vapours. Data gathered was used to develop a predictive alarm system using neural nets, the detail of which is described in the appendices.

Figure 2 : Data from four sensors operating in the rendering plant, Goulburn, October 2002.



Performance of the E-nose *outdoors* (low odour)

Background

The system in the rendering plant at Southern Meats was returned to the bench, and completely rebuilt. Minor improvements were made to the settings for the sensors (to suit low odour environment) and the ethanol leakage vessels were reworked to deliver a greater quantity to the sensors during calibration.

Version 2 E-Nose is an improvement on the first e-nose, with seven channels: 5 sensors plus temperature and humidity. It also has selectable sensitivity for the sensors.

The Flushing System is intended to periodically pump charcoal filtered air over the sensors to assist in their recovery from constant loading with airborne compounds. It has been set to run for 10 minutes before and after the calibration substance (ethanol) is delivered to the sensors.

The Calibration System consists of a device for the delivery of a controlled amount of ethanol to the sensors for a set period (10 min). This is intended to provide the operator with a standard response from the sensors to a known substance. Flushing with clean air precedes and follows calibration.

The flush-calibrate cycle is effectively a self-test device to tell the operator whether the E-Nose is functioning normally and whether the sensors have developed any drift during the period of operation.

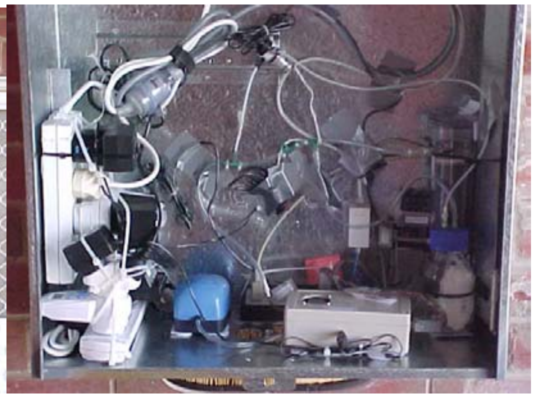
It remains to be determined in the field how many flush-calibrate cycles will be needed and their optimal cycle time.

The outlet from the main fan was fitted with a piece of curved plastic ducting so that the air from the cabinet is exhausted toward the wall on which it is mounted. This is intended to minimise damage to the system from wind and rain.

The contents of the cabinet were physically secured against movement in transport or on site.

Installation Outdoors at Goulburn Plant

The Version 2 E-Nose, in a galvanised steel cabinet, containing timers, valves, ethanol saturator and filters are shown in the following photograph (kindly provided by Jonathan Lawson of Southern Meats Ltd).

After bench testing the system, to satisfactory level of functioning in the lab, the system was reinstalled at the Goulburn meatworks on Saturday 31/5/03.

The E-Nose was fixed to the outside wall of an administrative building (QA Office) at Southern Meats Ltd. It is shielded on two sides by the walls of the building and from above by the eves of the roof of the building which forms a small porch. The cabinet faces west. The prevailing winds are from the west or east. The nearest source of industrial odour is approximately 25m from the E-Nose, viz., the bone and meat trailer. Other sources are at 50m or further from the unit.

Low odour conditions: E-Nose attached to wall outside offices (OH&S Building) facing west. Prevailing winds from south east. Sensors set to max sensitivity.

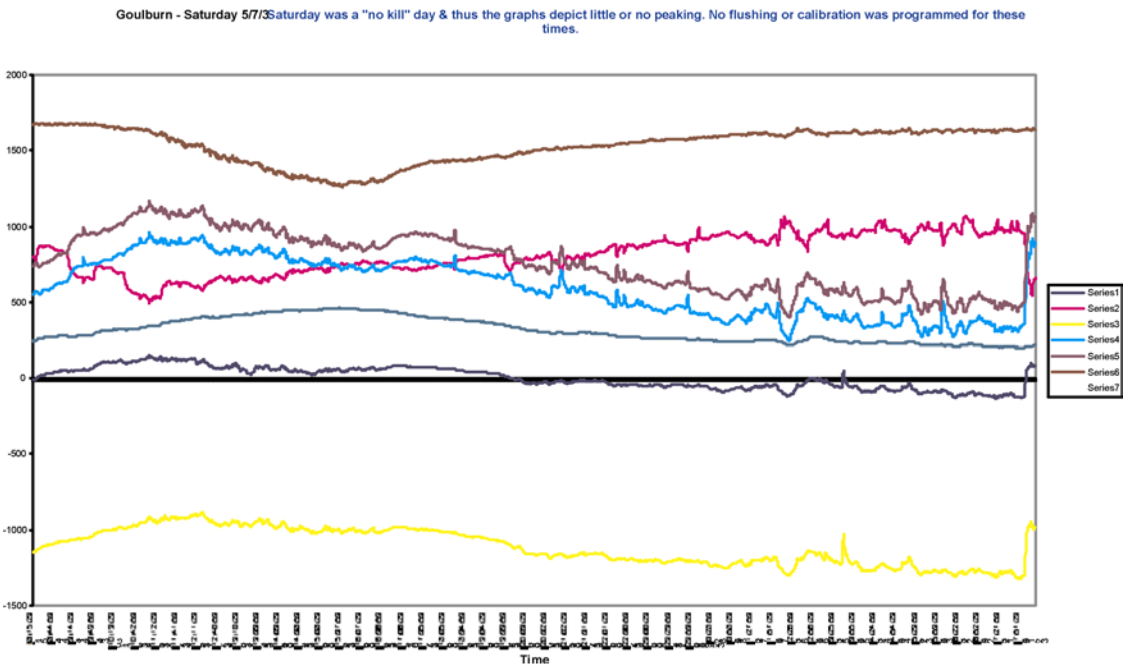
Temperature data was received on some days and not others. This was an operator error which was subsequently corrected.

The following charts are of data from the recording period Monday 26/6/03 to 5/7/03.

Humidity is shown in Channel 6 and Temperature in Channel 7. Note that the outputs from the sensor channels (1 – 5) are not dependent on temperature and humidity.

Example of Baseline Conditions

Chart 1 Saturday 5/7/03 (No kills, No Operations.) Very low odour in morning followed by “baseline” of extremely low/no odour. “Series” = Sensor. No. 6 = Humidity; No.7 = Temperature



Examples of Odour sensing during plant operations

Chart 2 Monday 30/6/03. Kill at 6 a.m. to 2.30 pm. Rendering and blood plant operating from 8 a.m. to 1 a.m. Calibration device operated around 0300h. End of shift can be seen concurrent with largest burst of odour sensing in the night shift. This indicated a 2-3 h period of maximum potential repercussion from the community to the odours emitted from the plant. “Series” = Sensor. No. 6 = Humidity; No.7 = Temperature

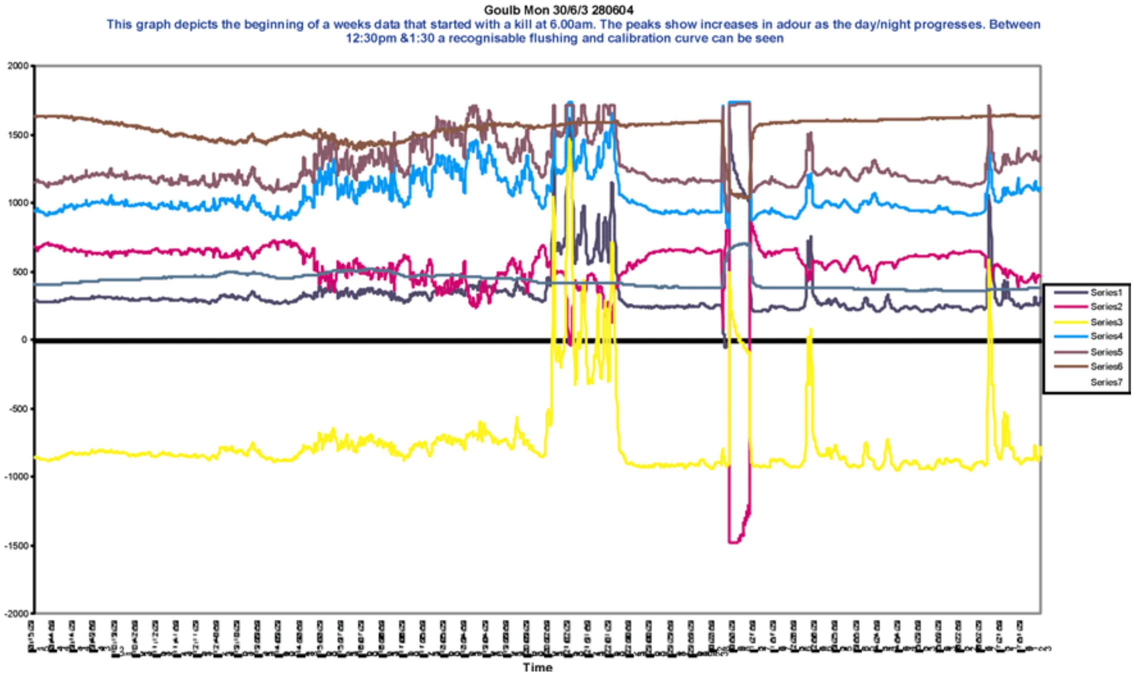
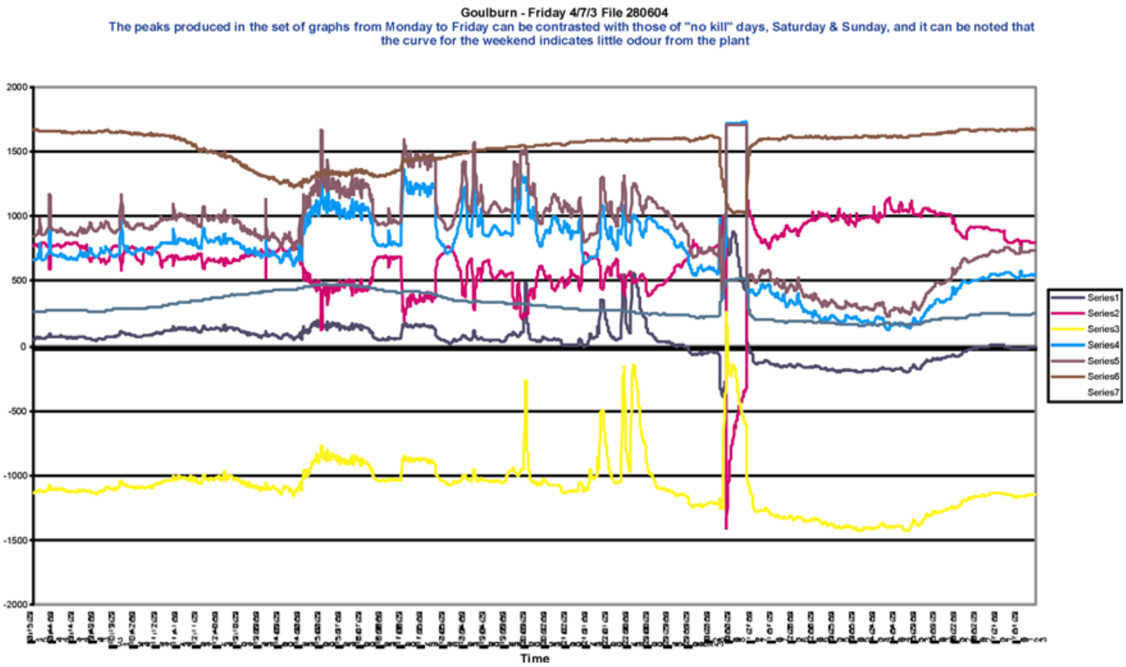


Chart 3 Friday 4/7/03 Kill at 6 a.m. to 2.30 pm. Rendering and blood plant operating from 8 a.m. to 1 a.m. “Series” = Sensor. No. 6 = Humidity; No.7 = Temperature.



Explanation of Operation for Calibration and Zeroing of Sensor Array

The attached schematic indicates the arrangement of components to achieve remote calibration and zeroing of the sensor array located in the Southern Meats Plant.

The sensor array is located in an odoriferous environment (rendering plant) where there is a constant background of odour, fatty vapours and humidity. Under these conditions the sensor array can become contaminated and both the response and the baseline (zero odour values) may be affected or drift.

The following solution has been devised to check the array response periodically and to provide a means of partially cleaning the sensors in a stream of clean air.

The system is controlled by two mains voltage timers, A and B. Timer A will be set to turn on power for, say, 35mins, once weekly. The power operates an air pump with an activated carbon filter in line to provide cleaned air at about 50mL/min.

The clean air flows to a manifold situated directly above the sensor array and a stream of air is directed onto the top of each sensor device. This flow (the rate can be adjusted) will flush away the odours from the plant and essentially zero the sensors. The data from the sensors will indicate this step-shift in response.

Clean air will flow for about 15mins before the second timer, B, switches on and opens the Solenoid gas valve to allow flow of about 15-20mL/min to pass through the ethanol vapour generator and to also pass to the sensors via the manifold. The generator is of the constant leakage type and can be adjusted to provide an adequate concentration of ethanol vapour to give a significant response by the sensors. The solenoid valve will be held open until the response stabilises (ca. 10min) and the power removed by the timer. The manifold flow will return to be clean air only for about 10mins and then timer A will switch the air pump off. Again the data from the sensors will indicate the step-shifts in response. The responses can be tracked as monitoring is continued and their behaviour will indicate if the monitoring unit needs servicing or other adjustment.

Precise conditions of flow, timing and required ethanol concentration need to be decided at the site and with the Version 2 sensor array which is about to be installed.

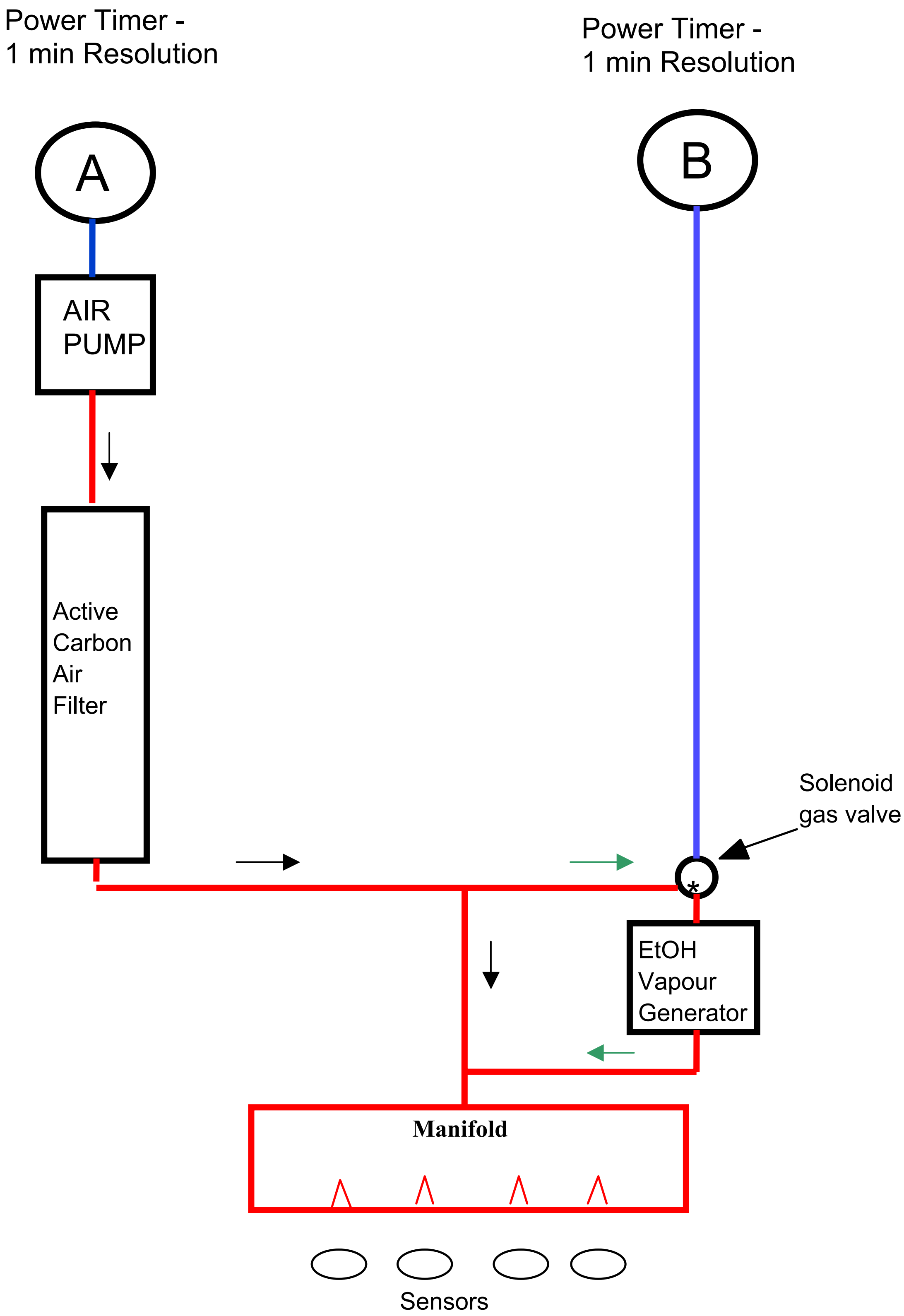
NB. All of the sensors respond to ethanol and it is relatively non-toxic and non-flammable at the generated concentrations.

Figure 3 (overleaf): Schematic diagram of Flush-Calibration system. The system produces clean air directed onto the sensors at and for a specified time, then directs a known concentration of ethanol to the sensors for a specified interval, after which the clean air is again delivered to the sensors to flush away the calibration odorant. Blue lines indicate electrical connections; Red indicates air or gas flows.

Figure 3:

Blue lines indicate Electrical Connections - Red indicates Air or Gas Flows

Schematic for the Calibration and Zeroing of the Sensor Array



Example of the Zeroing and Calibration system in Operation in the Laboratory

The system described above was set up for testing. The timing and switching was made manually.

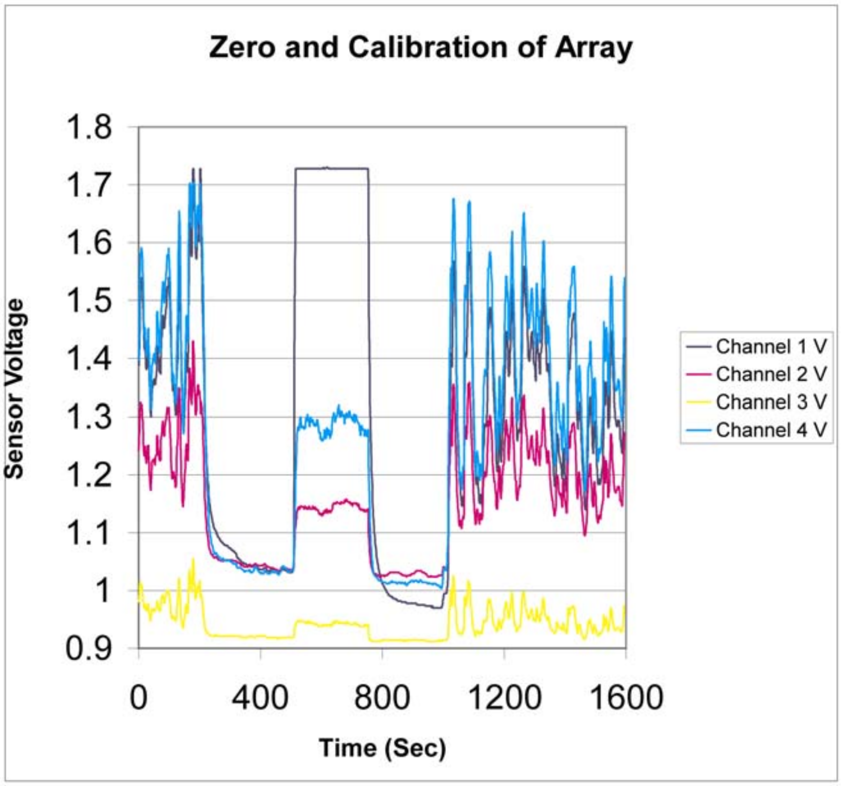
The test was carried out in a laboratory with an atmosphere containing varying amounts of solvent vapours to simulate the rendering plant in Goulburn. The array consisted of only four sensors and the manifold used was arranged for this array (to be modified for the eventual array of five gas sensors).

The graph below displays the sensor responses during the various phases of the operation.

- **From zero to 200 seconds** – the generally smelly laboratory. (Noisy and high responses)
- **201 to 500 seconds** – the power was applied to the air pump (via Timer A) and the sensor responses were considerably reduced and were very steady ("Zero values").
- **501 to 750 seconds** – The solenoid valve was opened by powering up the timer B and ethanol vapour of fixed concentration directed to the manifold and sensors. The responses settled to a high and steady value (response test and calibration).
- **751 to 1000 seconds** – The ethanol flow was switched off and only clean air allowed to flow. The responses returned to low and steady values. (*some drift was observed which may be due to the short operating time before carrying out this test during which the sensors may have not fully settled.)*

  1000 to 1600 seconds – All clean air to the manifold stopped. The sensors responded to the varying and smelly environment as before.

Figure 4: Calibration cycle tested on the bench: E-nose suction fan off (temp rises and humidity drops) clean air pumped over sensors; then solenoid valve opens and releases ethanol over sensors (several sensors go off-scale in response), followed by recovery phase with suction fan on.



Calibration Cycle in the Field

The calibration and flush cycle performed well in the field and four examples are shown in Appendix 1, as large square pulses in the traces, timed to occur routinely at night. One cycle per 24h was deemed sufficient on the basis of the absence of sensor drift and the overall satisfactory performance of the e-nose.

Conclusions (Calibration and Flushing):

The application of a standard substance to the sensors provides a reliable signal which differentiates the sensor responses. This will allow diagnosis of reliability of sensor function of long periods. The effect of flushing the sensors with clean air showed the expected effect of "grounding" the responses of each sensor before and after the calibration substance was applied.

Calibration of E-Nose Output voltages against Odour Units measured from ten samples of air taken at various locations on site.

Collection of Air Samples

Two members of the Project team visited Southern Meats for two consecutive days on 30th and 31st July 2003, with air-sampling equipment provided by Dr. Terry Schulz of The Odour Unit Pty

Ltd. Daytime temperatures reached 8ºC and night time, –2ºC. Winds were 2 to 5 Knots from the North-East during the day.

On the day of sampling, the Plant was about to shut down for a one month period and there was consequently one shift only on each day. General activity and stock handling on site was running at minimal level.

The E-Nose was functioning normally. The wind direction meant that odour from the main plant was blowing away from the location of the e-nose box (on the wall of the QA Office). This made it difficult to find sufficient response from the e-nose with which to sample air contiguously with observed peaks on the record. We therefore decided to collect duplicate bags of air and to put one of each pair through the device, and bring the other back to the Odour Unit Pty Ltd, in Sydney.

10 air samples were collected (in 22-litre Nalothan bags) in duplicate sets from 10 different site locations. One bag of each pair was then delivered directly into the port of the e-nose by means of a tube from the sample bag which fitted snugly into one of the e-nose "nostrils" (ports). The other ports were taped closed. The e-nose fan was running as normal. The air bag was expelled within 5 mins (rate of delivery 4-5l/min).

The duplicate bags were returned, within 12 hours, to Sydney for human assessment. The bags were coded and the peaks thus produced on the e-nose record were similarly coded. Various photographs taken during the taking of samples are shown in the Appendices.

The following table (Table 1) shows the sensor outputs (peak heights in mV) for the ten areas from which samples were taken and the Odour Units determined by a human panel for the duplicates of each sample. The report on the latter process and results is provided in the Appendices (and available as a separate electronic PDF file).

Table 1: Sensor Outputs (peak heights in mV) & Odour Units (OU)

Sample and Location	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	OU
A: Rendering Plant	211	801	322	779	747	128
B: Biofilter	313	1521	488	1010	934	12400
C: Brine Area	240	853	330	913	836	2900
D: Receival Pit 4	551	1810	731	1067	988	1760
E: South Perimeter	125	713	187	721	772	45
F: Anaerobic Lagoon	1044	757	1981	1058	1053	74
G: Skins Area	197	525	287	666	933	24
H: Grassy area near Pet Food	205	810	304	964	998	23
I: Outside Lambing Plant	173	570	245	665	617	23
J: at E-nose box	95	446	115	456	471	20

The following figure 5 shows the sensor outputs (mV) monitored continuously over the period during which the samples were delivered directly into the e-nose from each sample bag. The letters correspond with the code letters for the areas shown in Table 1.

There was no location on the site of the 10 at which air was sampled, that was under 20 OU. To demonstrate the alarm functions in the field we therefore set the levels as those at which a change in 10 OU set off the alarm.

Figure 5:

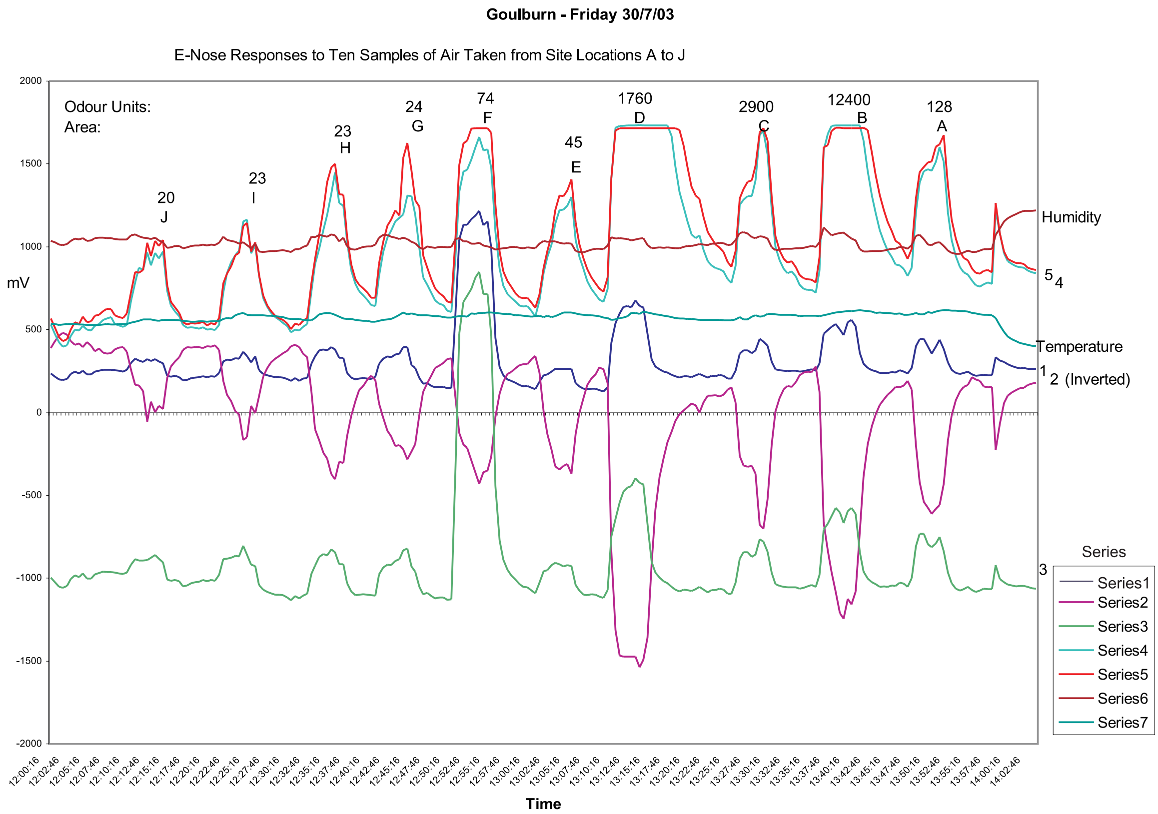


Figure 5: Calibration of e-nose sensor responses to air from ten locations (A to J), against human perceived intensity for the duplicate samples taken from the same locations at the same time (Odour Units shown as numbers above each peak.)

Examination of Figure 1 shows that the air sampled near the e-nose box (J) produced a peak height well above the baseline for that air when sampled in the normal way (that is, not directly delivered by means of the sample bag). This is taken as the magnitude of the effect of the direct delivery method, and will be taken into account in setting the alarm levels for the normally functioning e-nose.

Another feature worth noting is that the five sensors respond fairly uniformly for air from certain locations but not for others (e.g. air sampled near the anaerobic pond). This reflects the similarities and differences in chemical composition of the air at the various sampling locations. It also reminds us that the relationship between the sensor outputs and the OU is not likely to be simple: the OU is, in one sense, an aggregate measure and the sensor outputs reflect the analytical composition of the sample, the parts of which may deviate from the aggregate.

Specification of Alarm Levels

The alarm levels were calculated after due consideration of the relationship between peak height response by sensors and strength of smell for the duplicate sample of air perceived by humans (OU).

Concordance of OU to height of peak can be seen to be high by inspection of Table 1 and Figure 1. As expected the lower the peak height the lower the OU. At the higher intensities, concordance was not perfect: D produced the highest peaks but a lower OU than B.

In addition, variation in the chemical composition of the samples from different areas is reflected in specifically high responses from certain sensors, as illustrated in the response of Sensor 3 to the sample from Area F.

These specific responses characterise the “finger print” of the e-nose response for odours of different qualities, from different sources. The relationship between OU and sensor responses becomes more discordant when the specific responses of each sensor are considered. It must be remembered that the OU is an aggregate measure of all the odorants in the mixture of compounds in the sample. The sensors are effectively breaking the mixture up into constituents and removing the effects of mixture suppression that are well documented in human olfaction. Human perception for the constituents removed from the mixture might give more concordant OU - sensor measurements. Hence, it is not of particular concern that there is less than perfect agreement between sensor peak height and OU.

The OU measurements provide a guide to how high to set the threshold of the sensor voltages for the “sounding” of an alarm. The software in the system allows an alarm to be set for each sensor.

The response to the sample from Area H (the grassy patch about 10 m from the door marked “Pet Food”) was chosen as an example of the e-nose responding to a cocktail of odours from several sources. It had an OU of 23 which is in the lower half of OUs for areas sampled. The peak heights for Area H were about twice the height of those for Area J (sampled near the e-nose box). The latter peaks (for all sensors at J) are taken to represent the responses of the e-nose system to direct delivery of all the odour samples. This is assumed to be invariant and can be subtracted from the peak heights of the corresponding sensors for peak responses to samples from all the other areas to obtain the peak height against which its corresponding OU can be calibrated.

Example: Sensor 1 at H produces a peak height of 205 mV and at J, 95mV.

The calibration peak height against the OU at H (23) is 205-95 = 110mV. This voltage could be put into the software if 23 OUs were the level at which the Palant Management wished to be alerted. To demonstrate the alarm at low odour thresholds we set the desired alarm level at 10 OUs. The optimal level can be determined after further consultation with end-users and regulatory authorities. For the purposes of the demonstration it was taken to be 10 OU.

If an alarm is to “sound when the sensor is exposed to an OU of 10, then the threshold voltage is 10/23 of the calibration peak size of 110mV, viz. 47.83 mV. This assumes a linear relationship at low levels between OU and sensor output. More precise calibration is likely to be difficult to determine from actual measurements at the lower end of the OU range, as 10 OUs falls close to or below the limits of reliable OU measurement (Schulz, personal communication – see also report by The Odour Unit, appended). We therefore need to rely on models of the psychophysical relationship, i.e., the OU-sensor mathematical function.

The linear model and rule of subtracting the J base values produced the following **10 OU alarm function thresholds**:

Sensor	Threshold above sensor's baseline (mV)
1	48
2	158
3	82
4	221
5	229

Demonstration of the Alarm on Site.

The system was tested by placing a bucket of waste material from the Plant under the e-nose and observing the alarm "lights" on the monitor change from green to red. The test was performed by Mr Jonathan Lawson and recorded on a digital camera. (see images in Appendix 3).

The alarm response occurred within a few minutes of placing the smelly bucket near the e-nose. The latency in such a demonstration will be determined by the time taken for the smelly air in the bucket to reach the e-nose. As the test odour was clearly above 10 OU, the alarm responded in minimal time. After removal of the bucket, the alarm signals returned from red to green. However, they tended to come on with regularity, as the ambient odours on site are often over 10 OU.

A sound alarm (beeping) was demonstrated using the computer's sound card and speakers. The same sound is emitted whether one or all five sensors exceed threshold.

The way in which the system alerts the user/operator can be developed to meet the various needs of the customers.

A predictive algorithm is available should the customers require forewarning that odours above threshold are *likely* to occur in a given period.

Outcomes of the Outdoor Trials and Alarm Function Demonstration

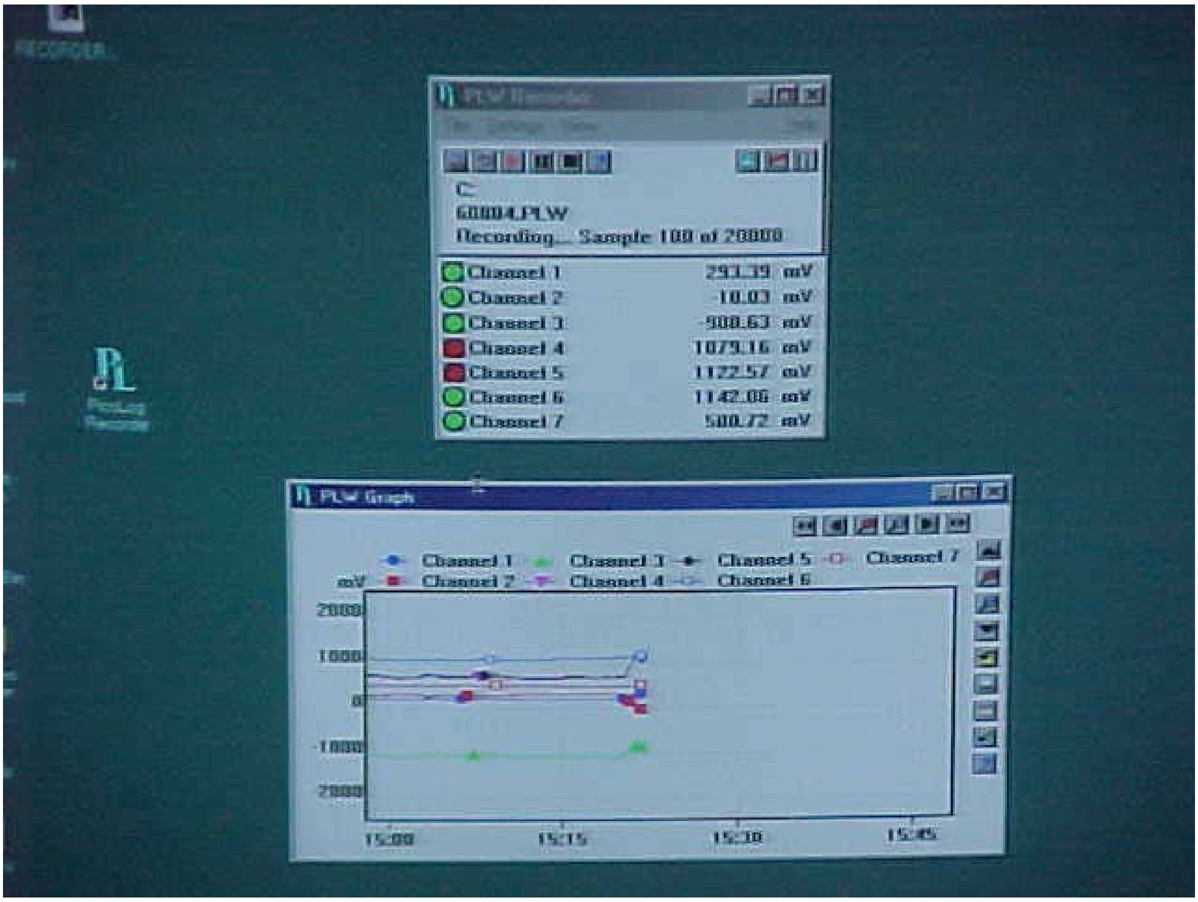
The e-nose sentinel system works at low odour levels in the field (outdoors, within the boundaries of Southern Meats Ltd., and can alert an operator by means of a console light or a sound, when odorants in the ambient air rise above 10 Odour Units. This level is frequently exceeded at the test site.

There is sufficient sensitivity in the sensors for the alarm functions to be set at a lower Odour Unit level (5-10 OU).

A site using the e-nose to reduce complaints from beyond its perimeter will need to set the e-nose alarm levels such that a change recorded inside the site predicts an unacceptable level at a greater distance. Wind speed and direction information will need to be built into an e-nose alarm serving such a purpose.

In the final phase of development of the E-Nose Sentinel, the alarm settings, display and other operator interactive functions, will be tailored to the needs of the customers (meat processors) and/or the regulations that have, or may have to be complied with.

Figure 6: Two sensors showing "Alarm On" during on-site demonstration.



Conclusions & Outcomes

- An electronic nose consisting of 5 tin oxide taguchi-type sensors, specified after experiments, for meat processing plant odours, and coupled with temperature and humidity sensors, was successfully developed and trialed at a meat plant in both high (rendering plant) and low (general environs of a meat plant) odour environments.

- The instrument operated successfully for approximately 5 months in total on-site, with three of these months being in continuous 24-hr operation. The sensors operated stably and without significant drift during this period.

- The sensor outputs showed reasonable correspondence with the expected odour pattern generated by activities on the site and were independent of temperature. The real-time 24-hr output permits management to identify odour generation peaks and to relate them to on-site activities. The opportunity this provides to detect immediately, identify and eliminate odour sources is profound.

- An automatic flush calibration system was developed and successfully trialed in both the laboratory and in the field. The system flushes the sensors with purified air, followed by calibration with a stream of air containing a known concentration of ethanol, then a second flush of clean air.

- An alarm system was developed and successfully tested in the field. The actual alarm setpoints will need to be calibrated on-site for each user.

- Off-site logging and analysis of the digital data from the Enose instrument is possible, but only with satisfactory resolution of security issues relating to access to a company's computer network.

- There is reasonable correspondence between sensor output and odour unit (OU) values at low odour unit values (< 100 OU), but poor correlation at OU values above this. Since the instrument is expected to operate in very low odour environments (OU < 10), this is not anticipated to be a difficulty.

The project has demonstrated that the electronic nose is a responsive instrument for automated, objective determination of odour generation at meat processing sites. The instrument provides, for the first time, a means of cataloguing odour generation in real time with a capability for alarming when odour levels exceed a threshold value. Further interrogation of the instrument output offers the ability to discriminate between odour sources, both from sources of odour on the site and those at a distance from it. Information from the system can be accessed at the site office or at a remote location, using the internet, if required.

Appendices

Appendix 1

Daily Records from Outdoors

This Appendix contains six daily records from the E-Nose in the outdoor location. The graphs represent each 24 hr period in the week of the 31^{st} June to the 6^{th} July, 2003 (excepting the 1^{st} July, Tuesday,). Significant peaks occur during the “kill days”, which disappear during Saturday and Sunday when no kill occurred. These graphs also show the flushing and calibration responses very clearly on Monday, Wednesday, Thursday & Friday when this function was timed to occur. The calibration was not set for Saturday or Sunday and thus no peaks appear.

On Monday at Goulburn, a kill took place at 6.00am. The many peaks show increases in odour picked up by the e-nose as the day progresses. The night is characterised by a number of short-lived sharp peaks. These relate to the cleaning of the offices and buildings around the e-nose, and the arrival of trucks loaded with animals for the following day’s activities. Temperature and humidity traces remain “flat” relative to the chemical sensor outputs.

Between 12:30pm & 1:30 a recognisable flushing and calibration curve can be seen.

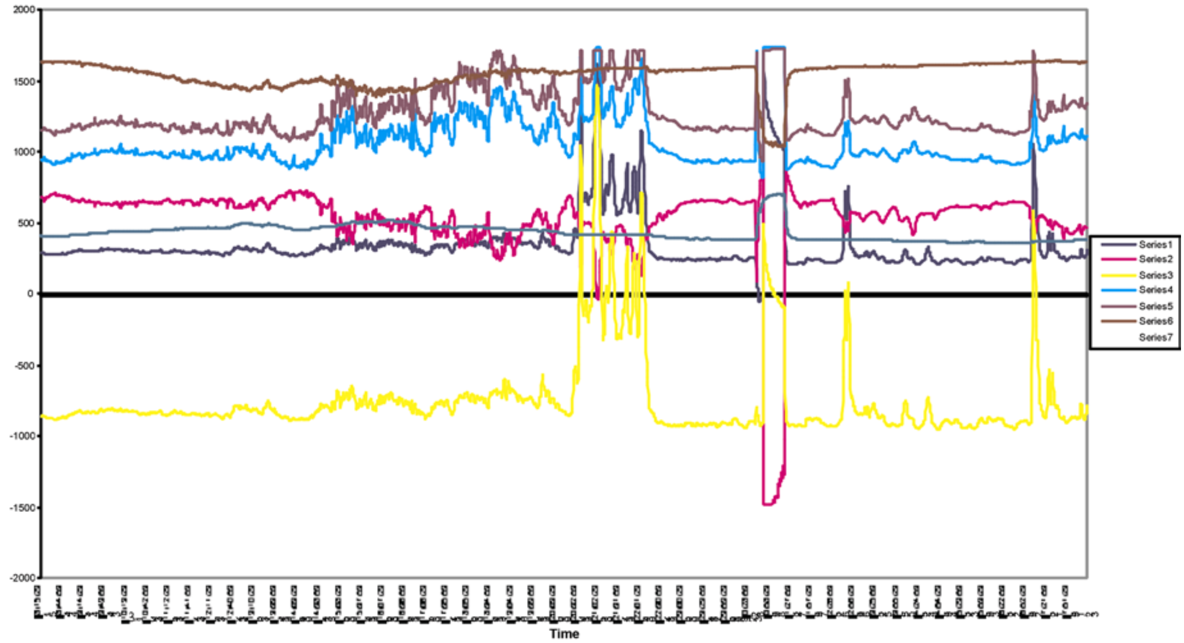
On Wednesday we note patterns of activity consistent with those of Monday.

On Thursday we observe a large peak in sensor No. 3 between 16.15 and 17.27h, and again between 03.15 and 0415h, which indicates relatively large emissions of compounds including and related to methane and of human perceived strength in the order of 75-100 Odour Units (measured at the e-nose (not source), approximately 150m from the lagoon). Such sensor No. 3 spikes are part of the profile of the emissions from the anaerobic lagoon. The site engineer would typically need to check if such short-lived spikes represented a problem that might be addressed. The release of such an odour on a still night or during a low-strength wind blowing in the direction of the suburbs could easily constitute a nuisance. Thus, the e-nose provides the patterns of sensor outputs, their intensities, likely sources, and durations of occurrence, which with the prevailing atmospheric conditions can predict and facilitate management of site effluents and emissions, on a 24 hr basis.

The records from Monday to Friday can be contrasted with those of "no kill" days, Saturday & Sunday. There is some residual odour at the plant on Saturday which has disappeared by Sunday. There should be no basis for complaint from the community on days of such low odour.

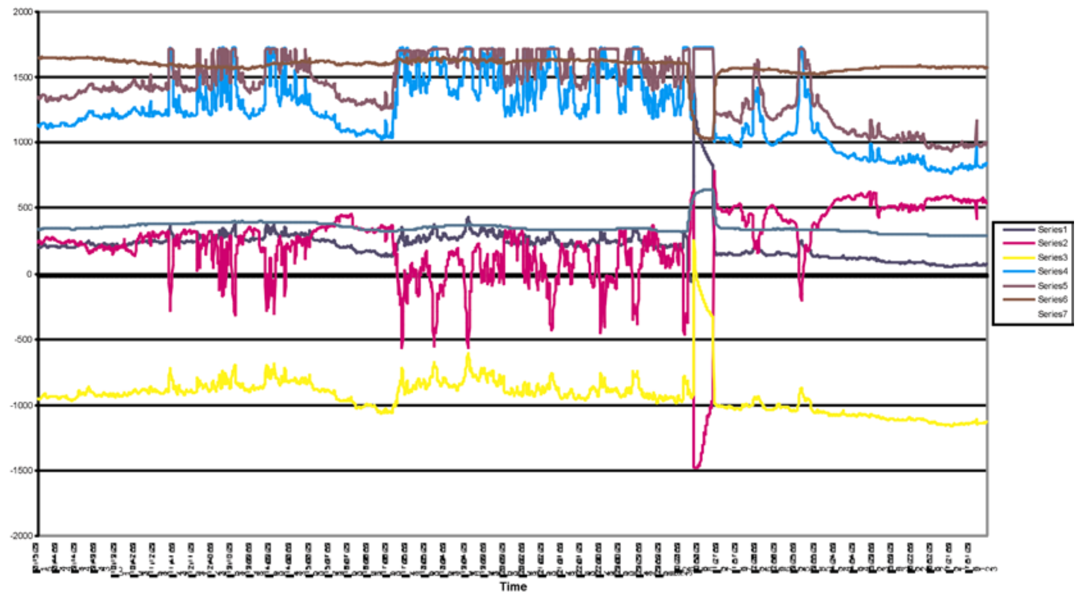
Goulb Mon 30/6/3 280604

This graph depicts the beginning of a weeks data that started with a kill at 6.00am. The peaks show increases in adour as the day/night progresses. Between 12:30pm &1:30 a recognisable flushing and calibration curve can be seen

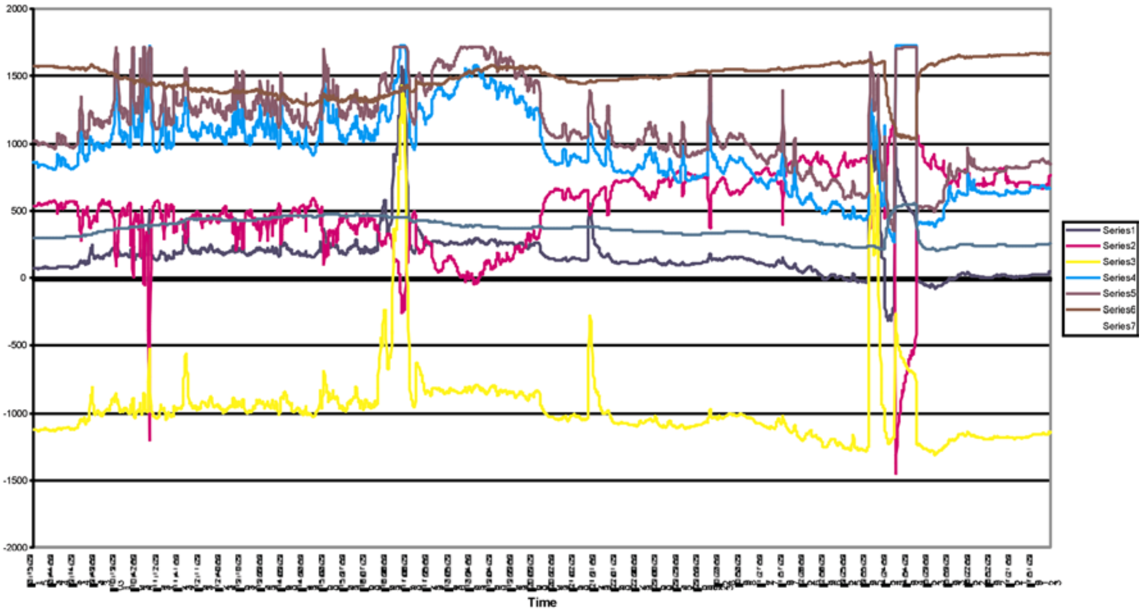


Goulburn - Wednesday 2/7/03 File 280604

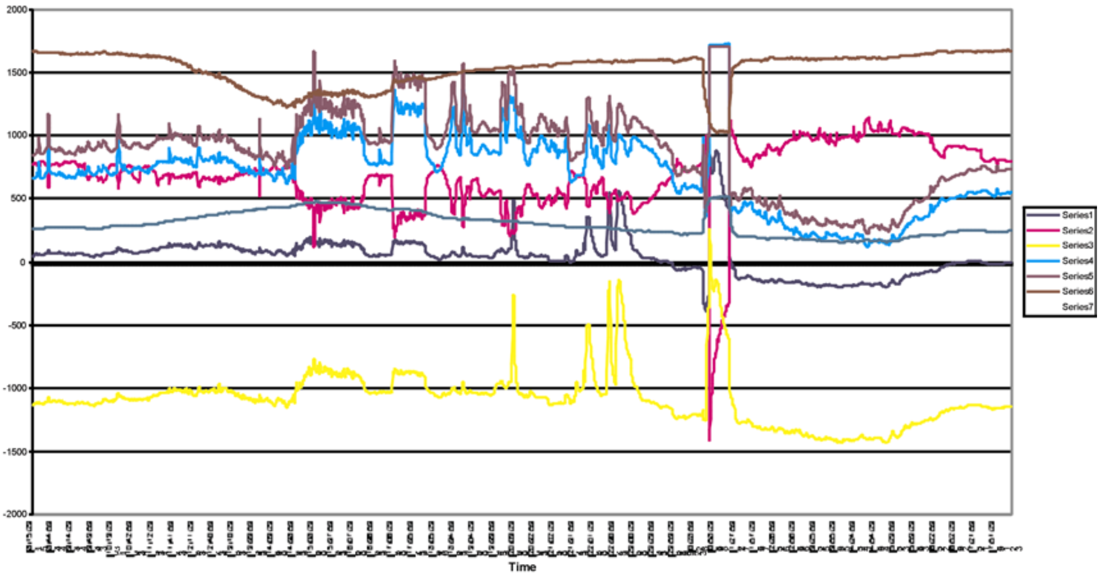
Again we see the odour registering as peaks with the flushing & calibration curve being depicted in the he same time spot as the previous days.

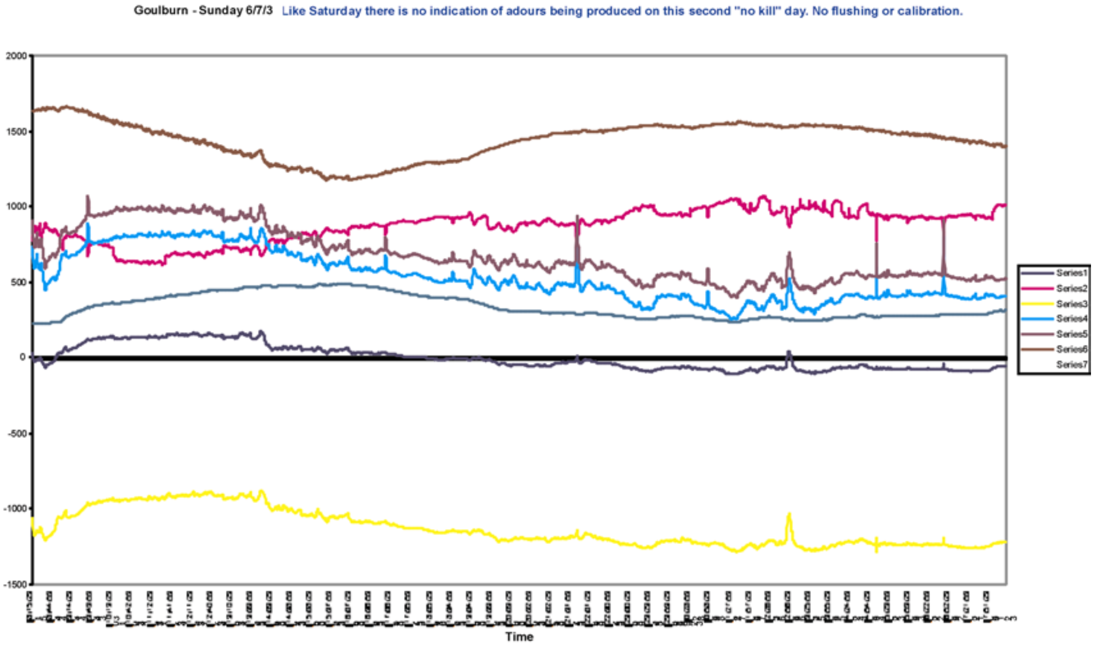


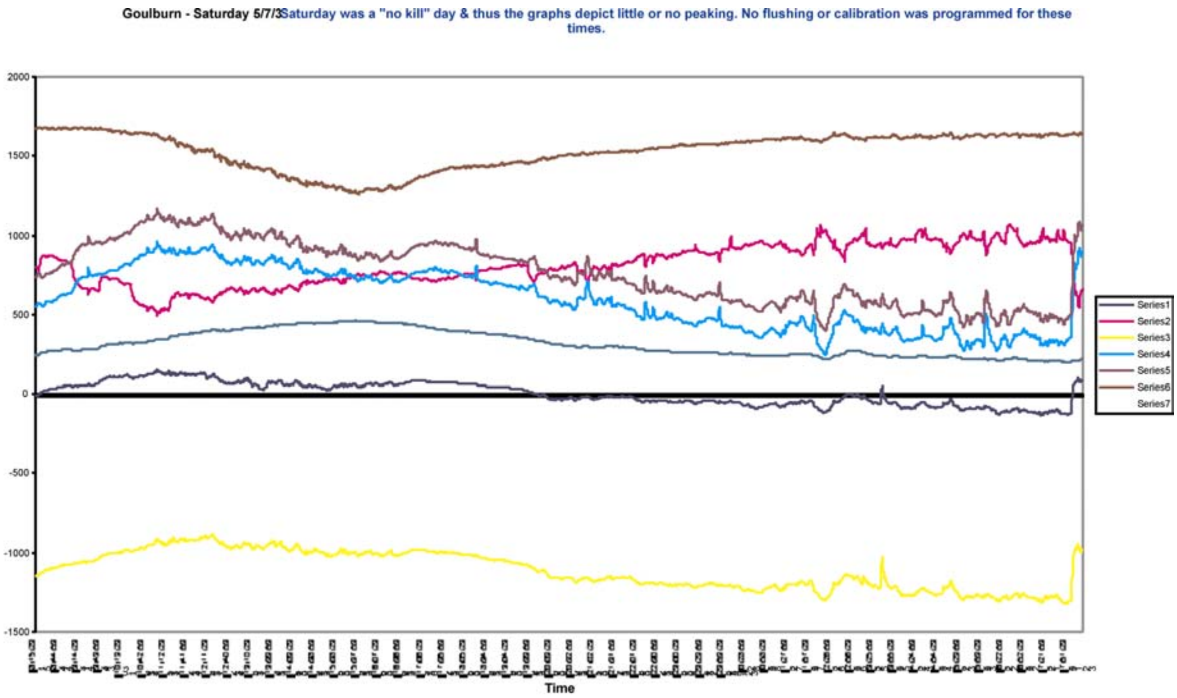
Goulburn - Thursday 3/7/3 Again the observation of many peaks indicating odour in the air with a particularly large peak in series 3 (yellow) which indicates larger emissions of methane than usual from the sewage plant.



Goulburn - Friday 4/7/3 File 280604
The peaks produced in the set of graphs from Monday to Friday can be contrasted with those of "no kill" days, Saturday & Sunday, and it can be noted that the curve for the weekend indicates little odour from the plant




Goulburn - Sunday 6/7/3 Like Saturday there is no indication of adours being produced on this second "no kill" day. No flushing or calibration.
2000
1500
1000
500
0
-500
-1000
-1500
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Time


Goulburn - Saturday 5/7/3Saturday was a "no kill" day & thus the graphs depict little or no peaking. No flushing or calibration was programmed for these times.
2000
1500
1000
500
0
-500
-1000
-1500
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Time

Appendix 2

Sentinel Alarm Function

By A. K. Srivastava

Summary

A method has been developed to set the alarm function of the e-nose by predicting its responses in the rendering plant in Goulburn. An Artificial Neural Network (ANN) was trained with the discrete time series data of the whole sensor array as input variables and the output of the most sensitive sensor (channel number 2) for the next 30 min, as an output variable.

A three layer feed-forward backpropagation neural network was trained with the data sets collected from October 8, 2002 to October 28, 2002 to model the output of sensor #2 as a function of input variables. The simulation experiment showed that upon testing with the test data from December 5, 2002 to December 9, 2002, correlation between the predicted and target ("desired") output of the channel 2 was of the order of 0.95, which is a very encouraging result. Prior knowledge of the output of Channel 2 can, therefore, be used to set the alarm function.

Other sensors can be added to the output set if they are shown to improve the predictive validity of the model. This may be necessary in different applications or conditions to which the e-nose is subjected. However, the experiment showed that the ANN sets up a predictive algorithm which closely matches the actual values obtained over thirty minutes.

An alarm display and alerting protocol can now be developed according to the specific needs of the plant operator. Parameters such as EPA acceptable levels of odour will have to be built in to the alarm display features when these are known and are calibrated against the sensor outputs. The display can be continuously updated every few seconds if necessary. Data for a previous and future period can be made available to an operator. The ergonomic requirements of the alarm system remain to be determined.

Details of the simulation experiments are described herein.

1. Data Analysis

The data sets used in this study were from the period Oct. 8, 2002 to Oct. 28, 2002 and Dec. 5, 2002 to Dec. 9, 2002. Original data were collected every 30 seconds and were supplied into the several small pieces, which were later on re-sampled every 10 minutes and concatenated together. Figure 1 and 2 show the odour profile in the rendering plant during the period Oct. 8, 2002 to Oct. 28, 2002 and Dec. 5, 2002 to Dec. 9, 2002 respectively.

Figure 1: Response of gas sensors (Ch1 to Ch 4), humidity sensor (Ch5) and temperature sensor (Ch6) sensor from Oct. 8 to Oct 28. Each mark on the time scale (horizontal axis) represents the start of a new day at approx. 00.00 hrs.

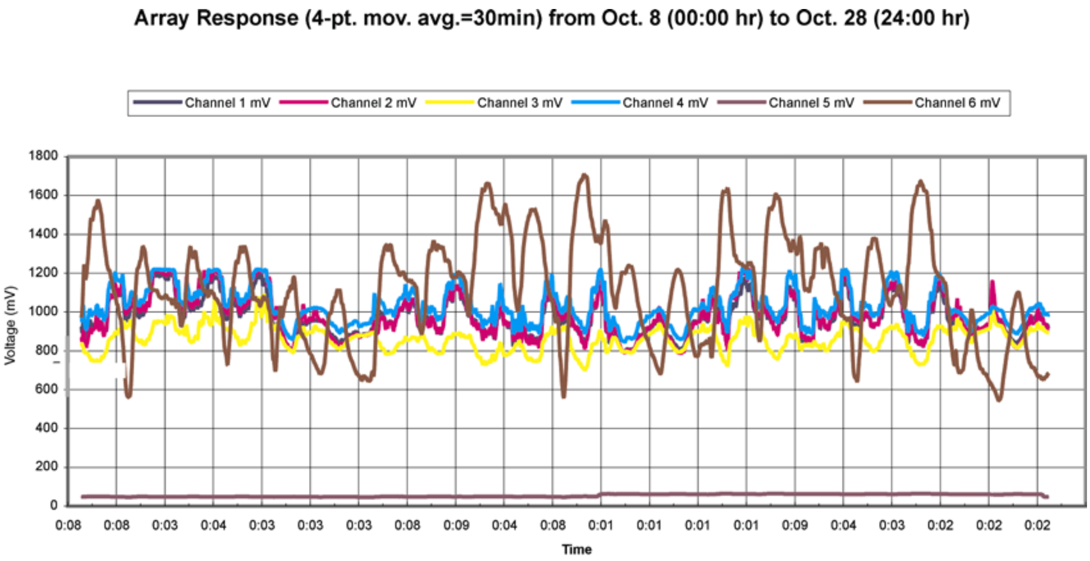
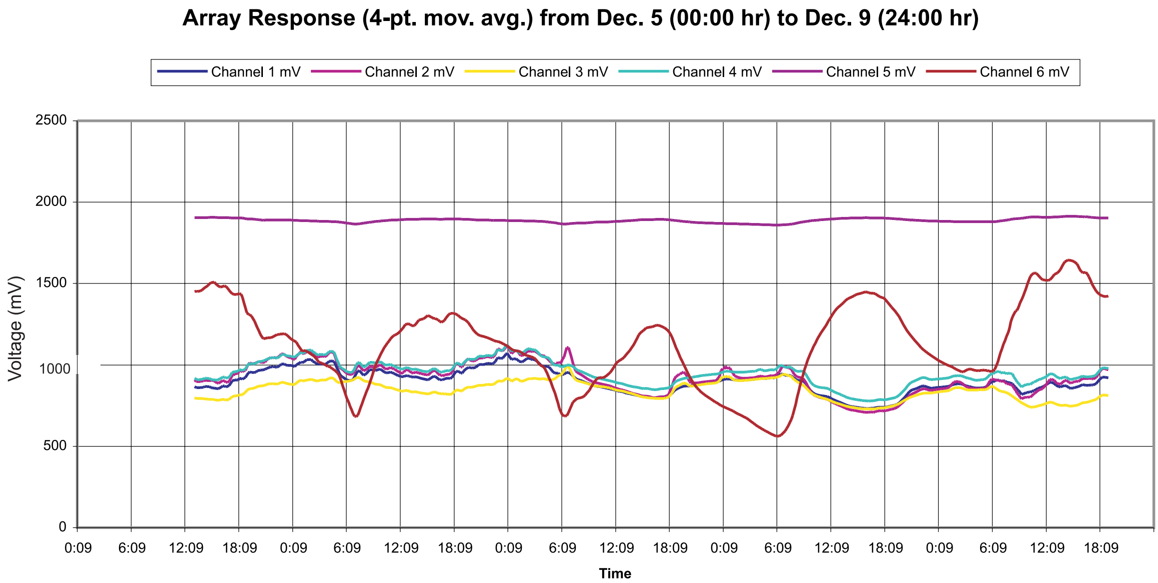


Figure 2: Response of gas sensors (Ch1 to Ch 4), humidity sensor (Ch5) and temperature sensor (Ch6) sensor from Dec. 5 to Dec. 9.

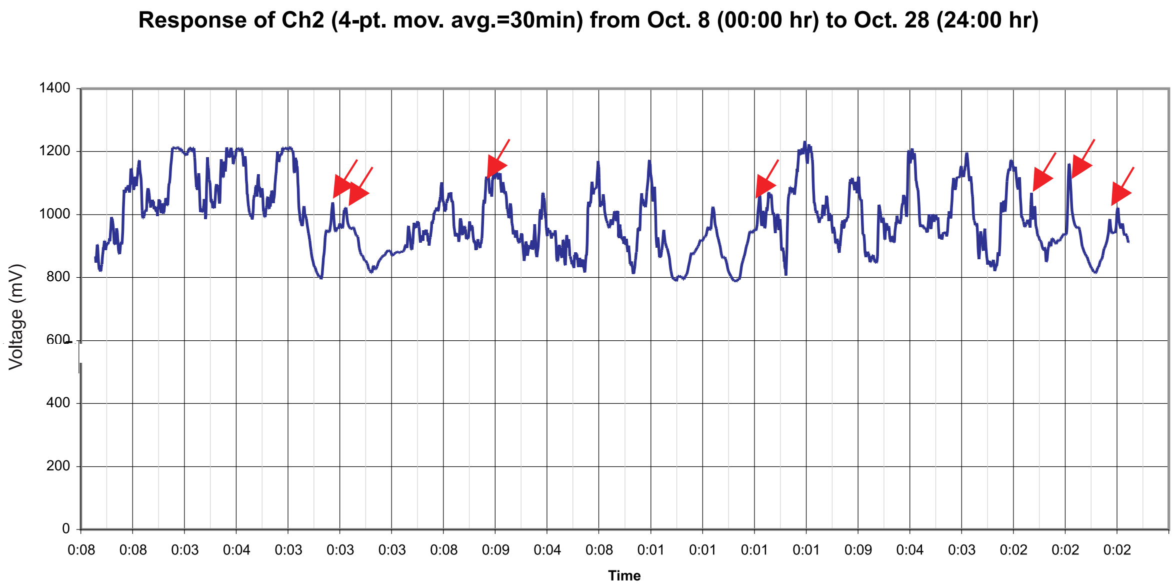


The graphs shown in Figure 1 and 2 are filtered response. 4-point moving average filter is used to clean the data. Filter-width of 30 minute is appropriate for the data smoothing as the change is odour level in the plant is not so fast. Response of humidity sensor in Figure 1 is constant and close to zero. This is because the humidity sensor was damaged.

Sensor response in Figure 1 show a clear-cut periodicity in the odour profile. During weekend sensors outputs are low, which probably show less activity in the plant. Responses of sensors are found to be high around midnight when the temperatures are low. This is strange. Normally sensors are expected to give high response in the daytime when the temperature is high and plant is running at its full strength. One of the reasons why sensor responses are low in the daytime could be due to the reason that when the temperature goes up, odour molecules diffuse very fast into the air and easily drift outside the rendering plant. Whereas in the night time ambient is cool and there is not much turbulence in the air. This allows odour molecules to be confined inside the plant. As a result odour concentration inside the plant goes up which is reflected as high sensor response. There are some instances where high peaks are observed even during the daytime. If we expand the graph these peaks last for about 1-3 hours. Sometimes these peaks are narrow and sometimes they are wide enough. There are also numbers of small peaks.

If we look closely into the response of sensors, we notice that of the four sensors sensor number 1, 2, and 4 give high response. Response of sensor 4 is comparatively higher than that of sensor 1 and 2. But sensor 2 is found to be most sensitive among all the four sensors. Sensor 2 gives few extra peaks (marked with RED arrows in Figure 3), which are either absent in rest of the three sensors or their amplitude is very small. This shows that sensor 2 is able to sense something else which the rest of the sensors are not able to detect sufficiently. Sensor 2 is, therefore, selected for the alarm function.

Figure 3: Response of sensor 2 (Ch2) from Oct. 8 to Oct 28. Peaks marked with red arrow shows some extra information, which are either absent in other sensors, or their amplitude is very small to be detected.



2. Training and Testing Data

Data from Oct. 8 to Oct. 28 are used for training the neural network. In order to predict the response of Sensor 2 a look up table is prepared as illustrated in Figure 4. Three successive snap shots of normalised sensor array response at time t_i, t_{i+1} and t_{i+2} each in the interval of 10 minutes are arranged row-wise. This is called input pattern. There are about 2868 patterns in the input data set. Each of these patterns corresponds to a target output. Target output is basically is the response of sensor 2 in the next half an hour i.e. at the time t_{i+6}. As such training database consists of the input data set and the output data set. As the response of the gas sensor is temperature dependent, temperature sensor (output of Channel 6) is also incorporated into the input data set. Humidity sensor (Channel 5) is not included because of its malfunctioning. Input and output data sets in the training data are illustrated in Figure 4. Data are normalised between 0 and 1 by dividing the sensor outputs by the maximum response of the sensor fixed as 2500 mV in the hardware.

Date	Time	Ch 1 mV t (i+1)	Ch 1 mV t (i+2)	Ch 1 mV t (i+3)	Ch 2 mV t (i+1)	Ch 2 mV t (i+2)	Ch 2 mV t (i+3)	Ch 3 mV t (i+1)	Ch 3 MV t (i+2)	Ch 3 mV t (i+3)	Ch 4 mV t (i+1)	Ch 4 mV t (i+2)	Ch 4 mV t (i+3)	Ch 6 mV t (i+1)	Ch 6 mV t (i+2)	Ch 6 mV t (i+3)	Ch 2 mV t (i+6)
10/8/2002	6:48:17	0.3690	0.3576	0.3596	0.3467	0.3392	0.3417	0.3360	0.3331	0.3319	0.3925	0.3803	0.3861	0.3893	0.3978	0.4076	**0.3618**
10/8/2002	6:58:17	0.3576	0.3596	0.3653	0.3392	0.3417	0.3473	0.3331	0.3319	0.3307	0.3803	0.3861	0.3943	0.3978	0.4076	0.4198	**0.3617**
10/8/2002	7:08:17	0.3596	0.3653	0.3732	0.3417	0.3473	0.3544	0.3319	0.3307	0.3291	0.3861	0.3943	0.4038	0.4076	0.4198	0.4363	**0.3552**
10/8/2002	7:18:17	0.3653	0.3732	0.3821	0.3473	0.3544	0.3618	0.3307	0.3291	0.3272	0.3943	0.4038	0.4140	0.4198	0.4363	0.4572	**0.3462**
10/8/2002	7:28:17	0.3732	0.3821	0.3796	0.3544	0.3618	0.3617	0.3291	0.3272	0.3242	0.4038	0.4140	0.4094	0.4363	0.4572	0.4769	**0.3391**
10/8/2002	7:38:17	0.3821	0.3796	0.3713	0.3618	0.3617	0.3552	0.3272	0.3242	0.3199	0.4140	0.4094	0.3998	0.4572	0.4769	0.4932	**0.3336**
10/8/2002	7:48:17	0.3796	0.3713	0.3621	0.3617	0.3552	0.3462	0.3242	0.3199	0.3170	0.4094	0.3998	0.3888	0.4769	0.4932	0.4972	**0.3300**
10/8/2002	7:58:17	0.3713	0.3621	0.3540	0.3552	0.3462	0.3391	0.3199	0.3170	0.3160	0.3998	0.3888	0.3794	0.4932	0.4972	0.4925	**0.3295**
10/8/2002	8:08:17	0.3621	0.3540	0.3498	0.3462	0.3391	0.3336	0.3170	0.3160	0.3155	0.3888	0.3794	0.3746	0.4972	0.4925	0.4839	**0.3298**
10/8/2002	8:18:17	0.3540	0.3498	0.3452	0.3391	0.3336	0.3300	0.3160	0.3155	0.3166	0.3794	0.3746	0.3701	0.4925	0.4839	0.4716	**0.3280**

Figure 4: Illustration of input and output data sets in the training data. There are 2868 patterns (rows) in the actual training set.

Same as training data testing data are also prepared by arranging the sensor outputs at discrete times. This is shown in Figure 5. Data collected during the period Dec. 5 to Dec. 9 are used for testing. There are 604 testing patterns in the test data set.

Date	Time	Ch 1 mV t (i+1)	Ch 1 mV t (i+2)	Ch 1 mV t (i+3)	Ch 2 mV t (i+1)	Ch 2 mV t (i+2)	Ch 2 mV t (i+3)	Ch 3 mV t (i+1)	Ch 3 mV t (i+2)	Ch 3 mV t (i+3)	Ch 4 mV t (i+1)	Ch 4 mV t (i+2)	Ch 4 mV t (i+3)	Ch 6 mV t (i+1)	Ch 6 mV t (i+2)	Ch 6 mV t (I+3)	Ch 2 mV t (i+6)
12/5/2002	13:39:08	0.3438	0.3438	0.3446	0.3593	0.3589	0.3603	0.3177	0.3172	0.3173	0.3638	0.3638	0.3647	0.5809	0.5823	0.5841	**0.3611**
12/5/2002	13:49:08	0.3438	0.3446	0.3451	0.3589	0.3603	0.3608	0.3172	0.3173	0.3167	0.3638	0.3647	0.3657	0.5823	0.5841	0.5876	**0.3619**
12/5/2002	13:59:08	0.3446	0.3451	0.3470	0.3603	0.3608	0.3622	0.3173	0.3167	0.3165	0.3647	0.3657	0.3676	0.5841	0.5876	0.5901	**0.3619**
12/5/2002	14:09:08	0.3451	0.3470	0.3468	0.3608	0.3622	0.3611	0.3167	0.3165	0.3156	0.3657	0.3676	0.3674	0.5876	0.5901	0.5930	**0.3618**
12/5/2002	14:19:08	0.3470	0.3468	0.3464	0.3622	0.3611	0.3619	0.3165	0.3156	0.3159	0.3676	0.3674	0.3667	0.5901	0.5930	0.5953	**0.3622**
12/5/2002	14:29:08	0.3468	0.3464	0.3462	0.3611	0.3619	0.3619	0.3156	0.3159	0.3154	0.3674	0.3667	0.3662	0.5930	0.5953	0.5992	**0.3602**
12/5/2002	14:39:08	0.3464	0.3462	0.3445	0.3619	0.3619	0.3618	0.3159	0.3154	0.3152	0.3667	0.3662	0.3647	0.5953	0.5992	0.6023	**0.3584**
12/5/2002	14:49:08	0.3462	0.3445	0.3431	0.3619	0.3618	0.3622	0.3154	0.3152	0.3156	0.3662	0.3647	0.3631	0.5992	0.6023	0.6031	**0.3560**
12/5/2002	14:59:08	0.3445	0.3431	0.3429	0.3618	0.3622	0.3602	0.3152	0.3156	0.3143	0.3647	0.3631	0.3631	0.6023	0.6031	0.6035	**0.3552**
12/5/2002	15:09:08	0.3431	0.3429	0.3421	0.3622	0.3602	0.3584	0.3156	0.3143	0.3139	0.3631	0.3631	0.3629	0.6031	0.6035	0.5999	**0.3572**

Figure 5: Illustration of input and output data sets in the testing data. There are 604 patterns (rows) in the actual test set.

3. Neural Network Training

A three-layer feed-forward backpropagation neural network with sigmoidal activation function is used to map input data set to the output data set of the training data. Neural network consists of input, hidden and output layer all connected in feed forward fashion. In the input layer there are 15 nodes corresponding to each of the features (columns) in the input data set. Input layer nodes are the receiving terminals of the neural network. Output layer consists of only one neuron, as there is only one feature in the output data set. Hidden layer neurons were optimised as 15 after a large number of experiments. Neural network architecture thus determined is depicted in Figure 6.

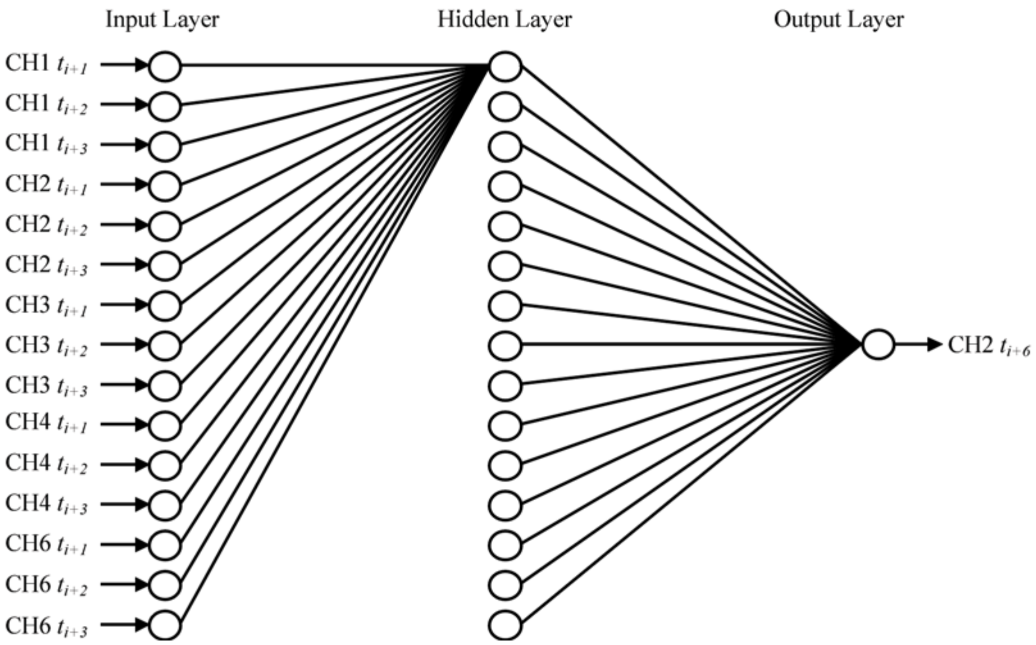


Figure 6: Artificial neural network for time series prediction. In the actual implementation all the neurons in the hidden layer are fed with the output of each node in the input layer.

After having optimised network topology, network parameters were optimised. Learning rate of 0.7 and momentum term of 0.6 were determined to be optimum network parameters. Network was trained over the training data for maximum leaning cycle of 15000 at which mean square error between the calculated and target output was found to be of the order of 0.000120. Result of the training session is illustrated in Figure 7. A good fit is observed between the target and calculated output. This is the output of network when the training data itself is presented to the trained network. This shows that network has sufficiently learnt the training patterns.

A high correlation coefficient of 0.93 as shown in the scatter plot of Figure 8 also corroborates this result.

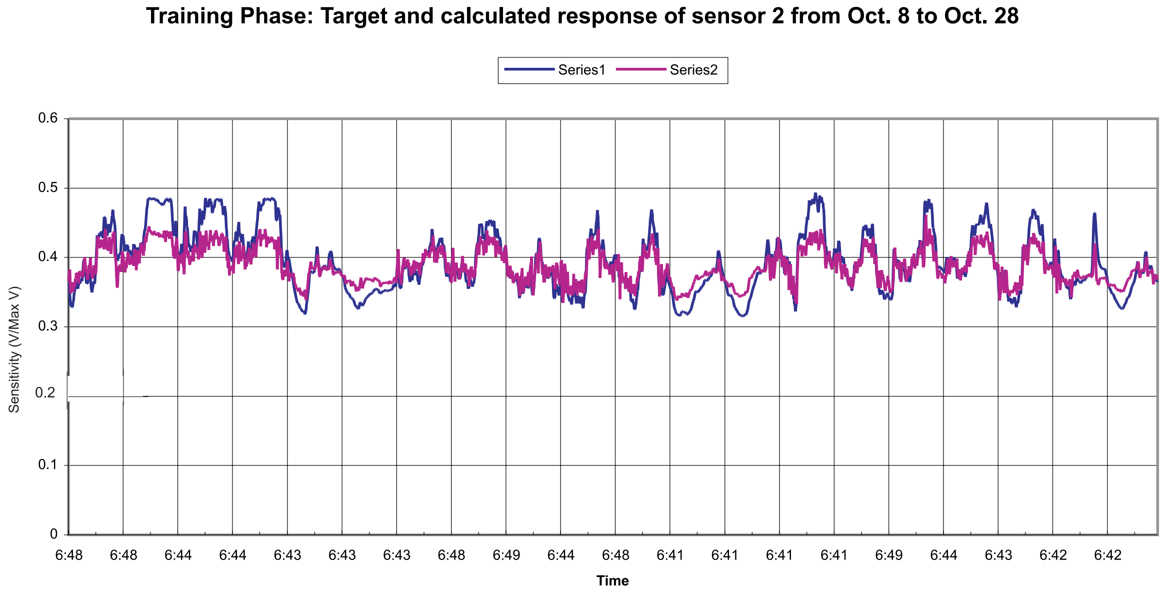


Figure 7: Target and calculated response of sensor 2 when the training data itself is tested with the trained neural network.

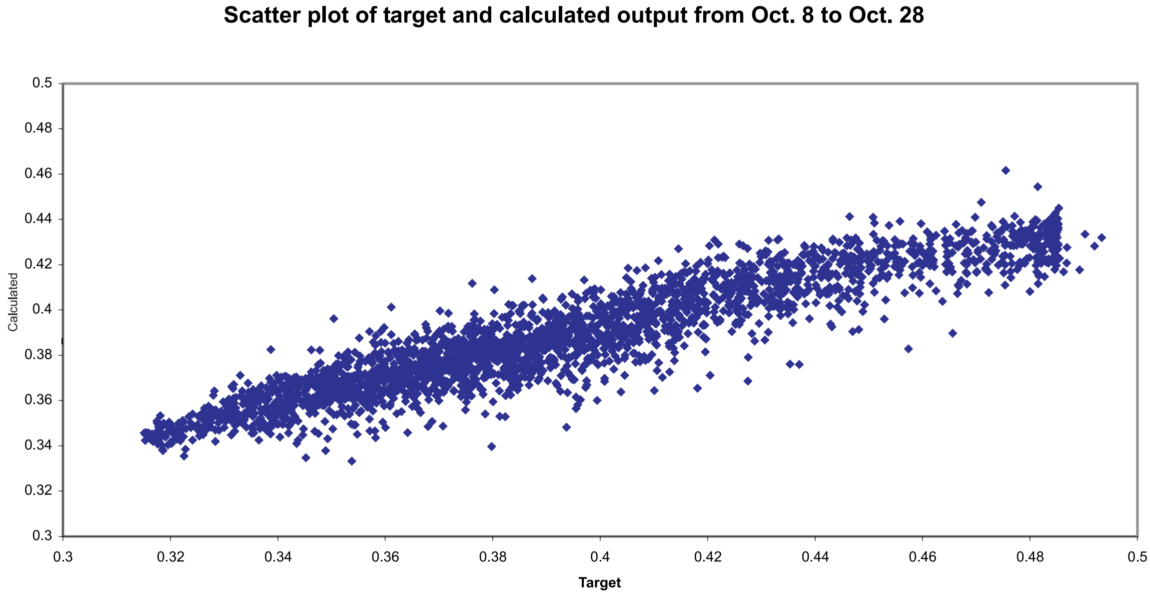


Figure 8: Scatter plot of target and calculated outputs of the training patterns

4. Prediction

After the training was over, performance of neural network was tested with the test patterns (Figure 5) from the period Dec. 5 to Dec. 9. Predicted output of neural network to the test data is compared with the desired (target) output in Figure 9. Figure 10 shows scatter plot of the predicted and desired outputs, having correlation coefficient of 0.95.

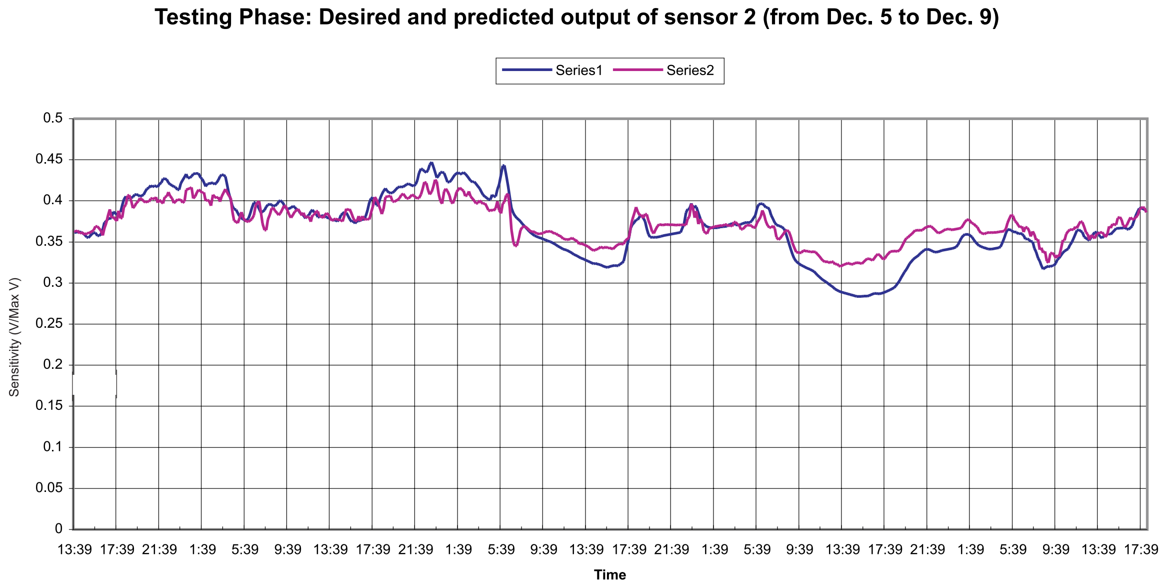


Figure 9: Target (desired) and calculated (predicted) response of sensor 2 when the testing data is presented to the trained neural network.

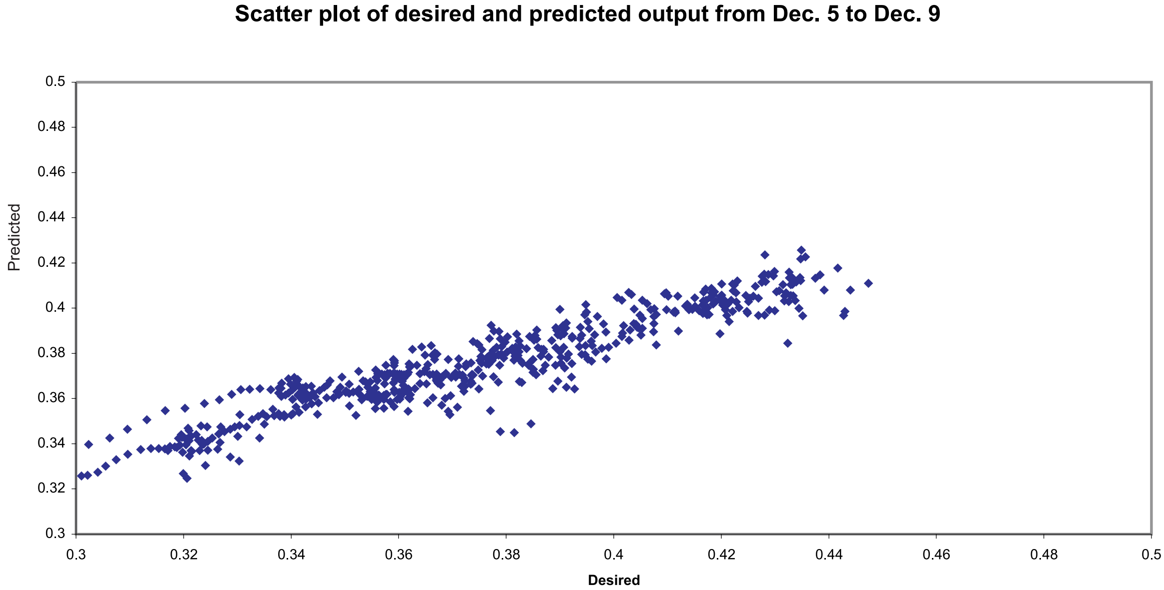


Figure 10: Scatter plot of target and calculated outputs of test patterns.

5. Alarm activation

In order to set on the alarm in real-time monitoring there are basically six steps as described below:

Step 1: Data sampling: Sample the data in the interval of 10 minutes. This is because the neural network is trained on the data collected in the interval of 10 minutes.

Step 2: Preparation of test pattern: Prepare test pattern by taking 3 successive snap shots of each of the sensor outputs in the array in the interval of 10 minutes.

Step 3: Preprocessing: Normalize response of all the sensors in the array (including temperature sensor) between 0 and 1 by dividing sensors outputs by 2500 mV.

Step 4: Prediction: Feed in the normalized sensor array responses to the trained neural network. Since the neural network hasn't any information about the humidity, output of humidity sensor cannot be used for the prediction.

Step 5: Post processing: Multiply the predicted output of channel 2 with 2500 mV.

Step 6: Alarm: This comprises of the various if else conditions. Different beep tones can be set for the different voltage levels up to the maximum of 2500 mV to signify various activities inside the plant.

6. Discussion

The results shown in Figure 9 and 10 are quite encouraging. Predicted outputs clearly follow the desired outputs. However, in some of the cases, particularly when the sensor response goes up or down, predicted value deviates from the target value. This is due to:

i. *Insufficient data for the training:* Neural network works on the example. Larger the examples, better is the result. Particularly in the situation where the output of the neural network is based on the previous history, large data sets over an extended period of time are required for the reliable and accurate prediction. The data, which have been used in this study, consist of only three weeks of measurements, which is not adequate for the prediction.

ii. *Absence of humidity sensor:* Besides their response to gases/ odours, Taguchi sensors are also susceptible to the change in humidity. Effect of humidity on the sensor response is missing in the current neural network modelling. In order for neural network to give accurate prediction, variation in humidity must be included in the training data set, as must the change in temperature.

iii. *Temperature compensation:* As the output of gas sensors also depends upon the temperature fluctuation, there are two ways to overcome this problem. This can be done either by the hardware/ software compensation or by including information about the ambient temperature in the training data set for neural network modelling. In the present study, output from the temperature sensor has been incorporated into the training data set, but at the same time effect of temperature is also compensated in hardware. The Sentinel system installed in the rendering plant uses global temperature compensation. Ideally sensors should be compensated separately as the temperature coefficient of each of the sensors is different. Furthermore, compensation circuit is linear whereas actual effect of the temperature to sensor is non-linear. Moreover, compensation circuit used in the Sentinel is based on the data sheet of Taguchi gas sensor in which sensors have been characterised for a single vapour (e.g. methanol or ethanol). In the present study, by contrast, the Sentinel is exposed to a complex mixture of several hundreds of volatile compounds. The effect of temperature on the sensor response cannot be compensated correctly unless the sensors are calibrated with bagged odour in the laboratory. However, for the neural network modelling, temperature and humidity compensation is not required. If the output of humidity and temperature sensors are also included in the training and testing data sets without any hardware/ software compensation, even more accurate model can be developed for the prediction. (Note: in Version 2 of the E-nose, hardware compensation for temperature will be turned off.)

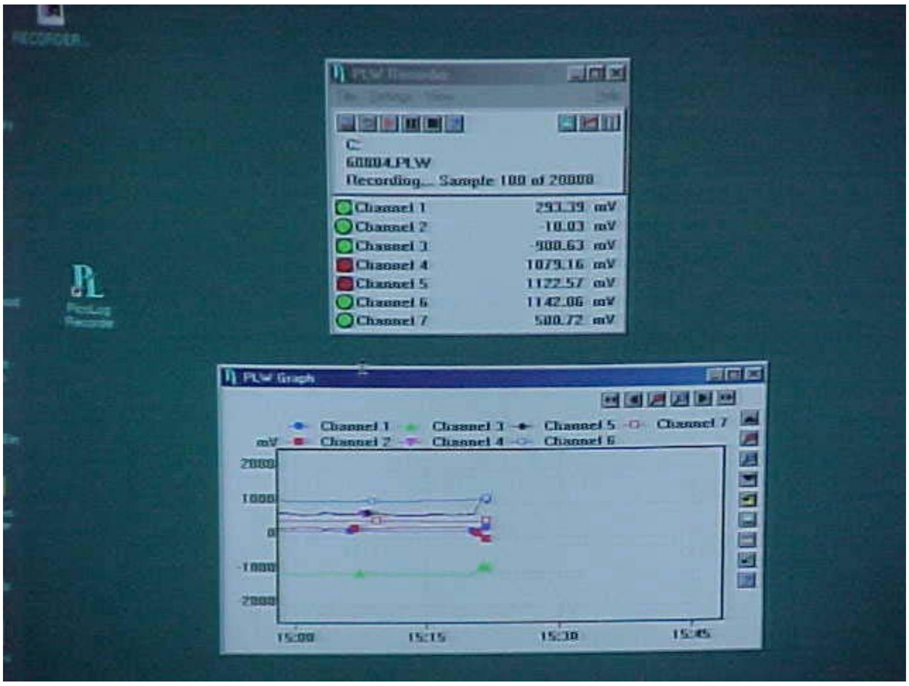
7. Conclusion

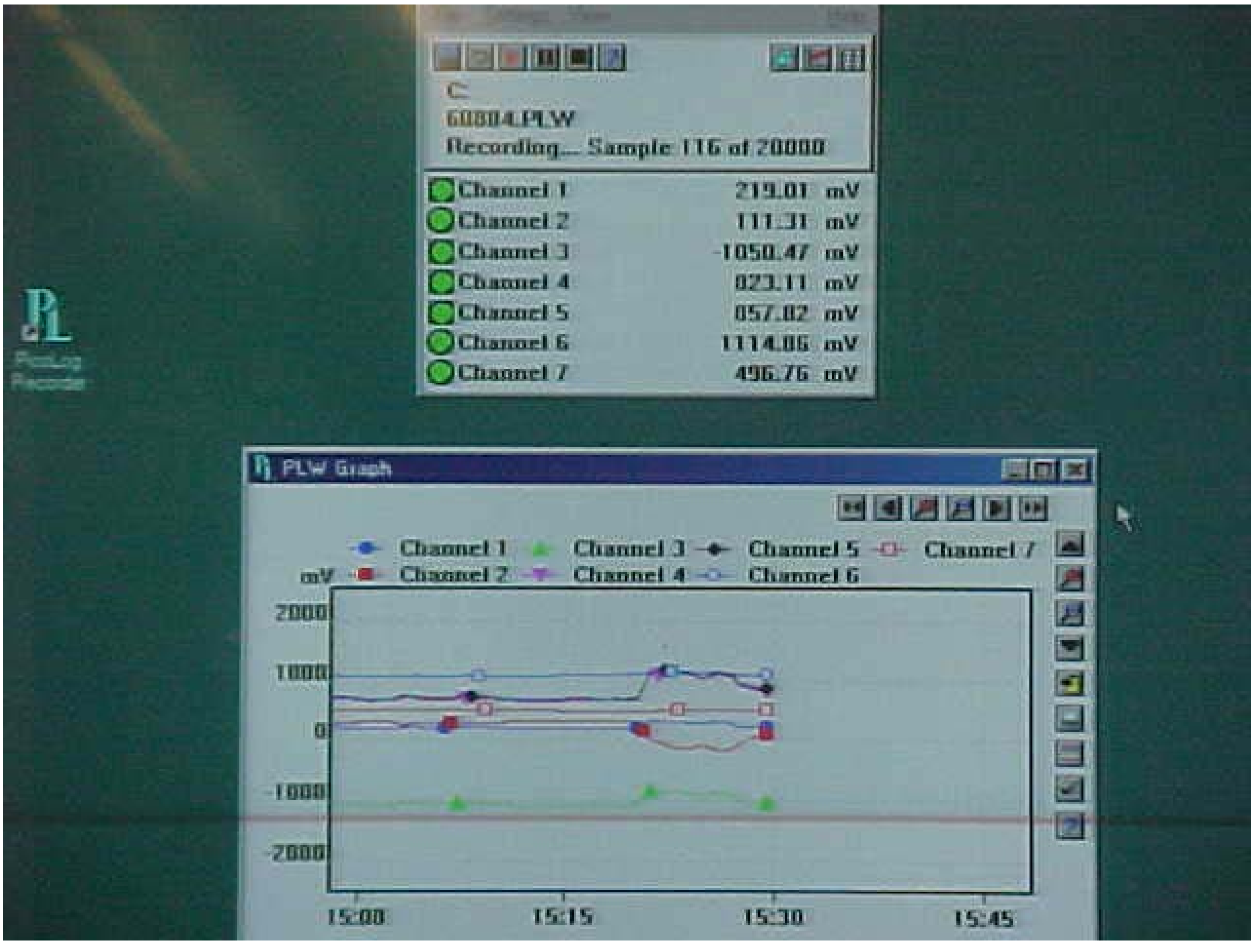
Use of artificial neural network in predicting complex and multivariable process is a powerful technique. Such types of prediction system are generally based on the previous history of the process. Due to the cyclic nature of odour profile in the rendering plant, future prediction can be made on the basis of historical information as has been shown in this study. But the process where there is human activity involved, there is always a degree of uncertainty in the prediction. Due to this reason actual sensor response may be different from the predicted value. The method presented in this study is just an estimate, which can be used to alert the operator about the future odour level inside the rendering plant.

AKS/07.01.03

Appendix 3 Alarm Function Demonstration on Site (photographic record)

1. Two sensors showing "Alarm On" during on-site demonstration.





2. Sensors have returned to "off" alarm status

3. Odour source below e-nose for field demonstration of alarm

Appendix 4

Odour Unit Report

THE ODOUR UNIT PTY LIMITED

THE ODOUR UNIT

Australian Technology Park
Locomotive Workshop
Bay 16 Suite G03
Garden St
Redfern NSW 2106

Phone: +61 2 9209 4420
Facsimile: +61 2 9209 4421
Email: tschulz@odourunit.com.au
Internet: www.odourunit.com.au
ABN: 53 091 165 061

Sydney Laboratory
Odour Concentration Measurement Results

Client

The measurement was commissioned by:

Organisation	E-Nose Pty Ltd	Telephone	02 9209 4083
Contact	Graham Bell	Facsimile	02 9209 4081
Sampling Site	Southern Meats	Email	g.bell@atp.com.au

Order

Order details:

Order requested by	Graham Bell	Order accepted by	Terry Schulz
Date of order	30.07.2003	TOU Project #	C1023
Order number	N/A	Project Manager	Andrew Balch
Signed by	N/A	Testing operator	Andrew Balch

Investigated Item Odour concentration in odour units 'ou', determined by sensory odour concentration measurements, of an odour sample supplied in a sampling bag.

Identification The odour sample bags were labelled individually. Each label recorded the testing laboratory, sample number, sampling location (or Identification), sampling date and time, dilution ratio (if dilution was used) and whether further chemical analysis was required.

Method The odour concentration measurements were performed using dynamic olfactometry according to the Australian Standard 'Determination of Odour Concentration by Dynamic Olfactometry AS/NZS4323.3:2001. The odour perception characteristics of the panel within the presentation series for the samples were analogous to that for butanol calibration. Any deviation from the Australian standard is recorded in the 'Comments' section of this report.

Measuring Range The measuring range of the olfactometer is $2^2 \le \chi \le 2^{18}$ ou. If the measuring range was insufficient the odour samples will have been pre-diluted. The machine is not calibrated beyond dilution setting 2^{17}. This is specifically mentioned with the results.

Environment The measurements were performed in an air- and odour-conditioned room. The room temperature is maintained between 22°C and 25°C.

Measuring Dates The date of each measurement is specified with the results.

Instrument Used The olfactometer used during this testing session was:
ODORMAT SERIES V02

Instrumental Precision The precision of this instrument (expressed as repeatability) for a sensory calibration must be $r \le 0.477$ in accordance with the Australian Standard AS/NZS4323.3:2001.
ODORMAT SERIES V02: $r = 0.2418$ (17/18 June, 2003) Compliance – Yes

Instrumental Accuracy The accuracy of this instrument for a sensory calibration must be $A \le 0.217$ in accordance with the Australian Standard AS/NZS4323.3:2001.
ODORMAT SERIES V02: $A = 0.1332$ (17/18 June, 2003) Compliance – Yes

Lower Detection Limit (LDL) The LDL for the olfactometer has been determined to be 16 ou (four times the lowest dilution setting)

Traceability The measurements have been performed using standards for which the traceability to the national standard has been demonstrated. The assessors are individually selected to comply with fixed criteria and are monitored in time to keep within the limits of the standard. The results from the assessors are traceable to primary standards of n-butanol in nitrogen.

Date: 7th August, 2003

T. Schulz
Principal and Managing Director

A. Balch
Testing Supervisor

THE ODOUR UNIT PTY LIMITED

Australian Technology Park
Locomotive Workshop
Bay 16 Suite G03
Garden St
Redfern NSW 2106

Phone: +61 2 9209 4420
Facsimile: +61 2 9209 4421
Email: tschulz@odourunit.com.au
Internet: www.odourunit.com.au
ABN: 53 091 165 061

THE ODOUR UNIT

Odour Sample Measurement Results

Sample Location	TOU Sample ID	Sampling Date & Time	Analysis Date & Time	Panel Size	Valid ITEs	Nominal Sample Dilution	Actual Sample Dilution (Adjusted for Temperature)	Sample Odour Concentration (in the bag) (ou)	Sample Odour Concentration (Final) (ou)	Odour Character
Rendering Plant	SC 30409	31.07.2003 10:59	01.08.2003 12:06	5	10	-	-	128	128	Meat, lamb, BBQ
Biofilter	SC 30410	31.07.2003 11:05	01.08.2003 13:14	5	10	-	-	12,400	12,400	Meaty, earthy
Brine Area	SC 30411	31.07.2003 11:10	01.08.2003 14:32	5	10	-	-	2,900	2,900	Cooked meat, blood, fat
Receival Pit 4	SC 30412	31.07.2003 11:13	01.08.2003 15:16	5	10	-	-	1,660	1,660	Fresh meat, sheep dags
Southern Perimeter Fence	SC 30413	31.07.2003 11:17	01.08.2003 16:03	5	10	-	-	45	45	Musty, cool
Anaerobic Lagoon	SC 30414	31.07.2003 11:26	01.08.2003 16:42	5	10	-	-	74	74	Earthy, greasy, fatty
Skins Area	SC 30415	31.07.2003 16:35	01.08.2003 17:09	5	10	-	-	24	24	Musty
Grassy Area Near Pet Food Door	SC 30416	31.07.2003 11:40	01.08.2003 17:31	5	10	-	-	23	23	Musty, weak
Outside Lambing Plant	SC 30417	31.07.2003 11:47	01.08.2003 17:55	5	10	-	-	23	23	Musty
At E-nose box	SC 30418	31.07.2003 12:05	01.08.2003 18:13	5	10	-	-	20	20	Musty

The Odour Unit Pty Ltd — *Form 06 – Olfactometry Measurement Results* — *Page 2 of 3*

THE ODOUR UNIT PTY LIMITED

Australian Technology Park
Locomotive Workshop
Bay 16 Suite G03
Garden St
Redfern NSW 2106

Phone: +61 2 9209 4420
Facsimile: +61 2 9209 4421
Email: tschulz@odourunit.com.au
Internet: www.odourunit.com.au
ABN: 53 091 165 061

Odour Panel Calibration Results

Reference Odorant	Concentration of Reference gas (ppm)	Panel Target Range for n-butanol (ppb)	Measured Concentration (ou)	Measured Concentration (ppb)	Does this panel calibration measurement comply with AS/NZS4323.3:2001 (Yes / No)
n-butanol	51	$20 \leq \chi \leq 80$	724	70	Yes

Comments Two samples were unable to be performed to AS 4323.3:2001, namely SC 30415 and SC 30418. There was insufficient volume to perform a third round for SC 30415 and the results from the first two rounds were used to calculate the result. Sample SC 30418 was collected at 12:05 on 31.08.2003 and was finished being analysed at 18:13 the following day, which is 8 minutes outside the 30 hours recommended by AS 4323.3:2001.

Appendix 5

E-Nose Research Team

The E-Nose Project team was led by Assoc. Prof. Graham Bell (M.D., E-Nose Pty Ltd) and included the following persons:

- Professor Bryan Hibbert, Chair, Analytical Chemistry, UNSW
- Assoc. Professor Don Barnett, Adjunct Research Fellow, Chemical Sciences, UNSW
- Assoc. Professor David Levy, School of Electrical Engineering, U.Syd
- Mr. Brian Crowley, Laboratory Manager, E-Nose Pty Ltd
- Mr. Winston Wu, Electrical Engineer, U. Syd. and E-Nose Pty Ltd
- Mr Jonathan Lawson, Southern Meats Ltd.