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Real-time Odour Detection using Electronic Nose Technology

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1 General background

Odour complaints are the dominant source of community irritation with the meat processing industry in Australia. Unfortunately, the current scientific technology to measure odour concentrations or characteristics (dynamic Olfactometry) requires air samples to be taken and analysed off-site typically with a turnaround time of days to weeks and at a cost of $400/sample. EPAs typically fall back to an “authorised nose” for immediate complaints - typically an EPA officer who visits the site. For development applications, complex mathematical odour models are typically used to evaluate odour impact. Past MLA work has shown that these models can be subject to significant error when area sources and complex topographies occur. Very often, sensitised neighbours or odours from other sources (sewer vents, etc) generate incorrect complaints, which are difficult to dismiss in the absence of real-time monitoring. None of these current approaches allows measurement and analysis of odours in real-time, which is essential if the industry is to have an effective means for odour management and control.

MLA has therefore developed an electronic nose (Enose) instrument specific to meat processing odours. The instrument was successful in monitoring odours during a research project based on a meat processing site. However, the technology remains in its infancy and numerous critical matters remain to be settled before the instrument can be adopted by the industry. The current project aimed at proving the suitability and limits of the Enose instrument in real site application.

1.1 Purpose

The purpose of the project was to prove the sustainability and limits of the Enose instrument at a number of lamb and beef processing sites. Altogether five complementary projects (P.PIP.145-149) have been conducted at red meat processing sites. The five projects provided very useful information in determining the suitability of Enose for the red meat processing sector.

2 Overview of the separate aims of each participating company

The companies had broadly agreed that they would like to see the E-Nose tested for reliability, related to known odours on sites and data to be collected from comparable areas across sites with a view to being able eventually to understand the cross-site reliability and validity of its measurements. Each company submitted a list of aims for their participation in the trial and these are listed below.

The work carried out addressed the expressed specific aims using data taken from the instruments belonging to each company. Some further work independent of this project, was carried out at E-Nose P/L, and in as much as it bears upon the general aim, results was reported here for the information of MLA and the participating companies.

2.1 AMH (P.PIP.0147)

AMH communicated its wish that Stage 2 should address the following questions:

- To use the e-nose at distances from a point source of odour – to see if each odour could be distinguished at a distance
- An operator stayed with the e-nose for a few hours at various locations to identify the odours picked up by the e-nose. Varying sensitivity levels was to be tested.

- Determine the usefulness of the nose to the meat industry.

The data was collected by Mr Brad Wheeler, and supplied as Excel tables and charts to E-Nose Pty Ltd for analysis.

The following conclusions were drawn:

- The Bayesian algorithm successfully identified odours from the same point source but taken from different distances.
- Operator intensity judgments of ambient odour showed weak but not entirely insignificant correlations with the e-nose signal heights. An example of a qualitative change (arrival of diesel odour) concurred in time with both human and E-nose.
- The device can function as an identifier of specific odours on a site and be useful to the meat industry as a continuous monitor of the odour status at a site.
- The human perceived intensity and quality – A-nose voltage relationships were demonstrated weakly, but were not adequately tested in this study, as adaptation to ambient odour by the single judge was not controlled.
- It is recommended that the E-nose be set up in a semi-permanent location and linked to the Company's SCADA system.

2.2 ACC (P.PIP.0146)

ACC communicated its aim to achieve the following:

- Run the E-Nose for 6 consecutive weeks at the Lairage at Sensitivity Level 5 with the aim of enlarging the lairage data library, as part of the industry-level study.
- Run the E-Nose for four consecutive weeks at a position down-wind of the lairage, at sensitivity level 9, to enlarge the ACC library of data and obtain data downwind from a known odour source
- Run the E-Nose in close proximity to the biofilter fan house at sensitivity level 7, for 3 consecutive weeks, to add biofilter proximity data to the ACC data library.

The data was collected by Mr Michael Campbell, and supplied as Pico files to E-Nose Pty Ltd for analysis. The second and third objectives were varied from the original aim, and two sets of data were collected from two points down wind of the lairage, thereby giving a "dilution gradient" to analyse, at a constant sensitivity level (SL7). In addition a long record over several weeks was supplied for this report, taken from the main ACC gatehouse at SL 1.

The following conclusions were drawn:

- The lairage odour at source was highly variable and relatively intense (in terms of E-nose data).
- Upon moving to 40 m from the lairage this situation changed dramatically with amplitudes dropping and the general characteristics of the data being less varied and holding a consistently recognizable pattern.
- At 100 metres from the lairage, the patterns observed at 40 metres persist and the overall amplitudes of signals dropped a little further.
- The record from the main gatehouse showed many spikes probably related to vehicles. Mr Campbell reported that there was no discernable difference in these between unladen and laden with cattle (more potentially smelly) incoming vehicles.
- The overall amplitudes measured at the three sites at a distance from the lairage showed general patterns consistent with low odour.
- It is recommended that the E-Nose be deployed as a general long-term sentinel on the

site at a location down-wind from the lairage, this being a source of odours of concern to the company and the neighbours. The system alarm levels should be set to levels suggested in this report and the "hold" function deployed to eliminate short term spikes caused by vehicles. The appropriate officer of ACC should have responsibility for being alerted by the E-Nose (proactive action) and for archiving the data in case of complaints or other issues (retroactive action).
- A study in which individuals in the community downwind of the ACC site keep odour logs/diaries, for corroboration against the long term E-Nose data records is recommended.
- It is recommended that the data from ACC lairage be pooled with data from other PIP Project sites and tested for consistency of characteristics with the odour recognition algorithm.

2.3 Cargill Meats (P.PIP.0149)

Cargill's aim was to collect odour data from approximately ten locations on the site with a view to categorizing the data and if possible, determining whether the odours measured near their source remained identifiable at some distance from the source.

Visits to the site in March and April 2007 by E-Nose Pty Ltd found the E-Nose located at the Gatehouse, but with two channels not registering signals. The device was returned to Sydney for cleaning, service, and an upgrade of its manifold system (Mk3.1). Some corrosion to the motherboard was found and removed, and the two non-functioning sensors once again became fully functional.

A B&R steel cabinet was purchased and fitted out for better protection of the e-nose at the gatehouse. On the return visit the E-Nose staff took a set of recordings (approximately 15 min each) at 11 locations on site. These formed the basis for the report.

The measurements were made with the device inside the new cabinet, to retain equivalence between these and future data taken from within the protective cabinet. The cabinet was then installed on the outer wall of the Gate house and left to run in monitor mode. It is recommended that this use of the E-Nose be continued.

Short recording made at various parts of the site were analysed in two ways: rank ordering of sensor channels from highest overall voltages to lowest; and the Bayesian algorithm.

These analyses showed that in some cases the odour changed dramatically even a short distance from the source (in the case of the biofilter). However, in the case of odour measured at the aerobic lagoon, the odour near the lagoon (weak because of wind conditions) and that measured 500m away, near the southern site boundary, retained its distinctive character despite considerable dilution. A control odour (saveall) was immediately distinguished as not pond odour.

This lent strong support to the hypothesis that the device can recognize an odour from a known source despite dilution across a space of at least 500m, and despite the overall amplitude of the signals becoming greatly attenuated.

Other recommendations arising from the Cargill Study:

- Increase usefulness of the device using the alarming function. The alarm "hold for" setting can be used to eliminate passing trucks and alarm only after a sustained high odour has been detected. High levels (above 1000mV) on Channels 2, 3 and 5 are indicative of strong "organic" odours as shown in the profiles from the rendering area and biofilter.

- Very low odour recording sites near the boundary and on the north bank of the aeration lagoon showed measurable profiles consistent with odours on site.
- Some attention might be paid to why odours as far as the boundary have a high hydrocarbon (LP gas, propane etc) component.
- Measurement of human perception of odours, particularly near the boundary is warranted.
- The recognition algorithm should be implemented for the long term monitoring function of the E-Nose at the Gatehouse.

2.4 Teys Bros (Beenleigh) (P.PIP.0148)

The Company's aim to have the equipment housed in a weatherproof box and set up in the rendering area to record continuously for a period of time, then to move it to the areas of potential sources of odour such as the aerobic lagoon.

The fit-out of a weatherproof cabinet was completed by the Company. Visits from E-Nose Pty Ltd found the equipment back in the admin office with an unserviceable power supply to the wireless data transmission unit. This was remedied and the e-nose was serviced, and data was collected during another visit by E-Nose P/L at the rendering area and near and at increasing distances downwind of the stock piled paunch paddock (a source of odour identified by the environmental officer on the day – owing to recent disturbance of the stockpile).

The device was set up again to run continuously at a location of the Company's choosing.

The set of measurements taken at different distances from the stock piled paunch paddock showed attenuation of signal with increasing distance consistent with reduction of odour due to dilution. At 150 m distance there was very little variation as contrasted with recording made closer to it, however, the pattern of voltages remained consistent.

It was concluded that by 500 m no discernable stock piled paunch paddock odour would be contributing to the ambient odour.

On the day the record at the rendering plant was obtained the odour levels as implied by the sensor amplitudes was similarly high enough to warrant attention to the emissions from this part of the plant. Long term records need to be provided to E-Nose P/L to determine whether this is typical or not.

It is recommended that the Company set up the equipment at a location where continuous long term records can be made. These records should serve to inform the Company if they have any times when odour issues may be a problem so that they can take appropriate action.

It is recommended that odour diaries be kept by trustworthy individuals and these be used to check the e-nose records against reported odour events as perceived by reliable humans. If possible human odour measurements should be logged beyond the boundary and downwind from the plant.

2.5 T&R Lobethal (P.PIP.0145)

T&R has used a Mk 3.1 E-Nose at their abattoir operations at Lobethal, South Australia. The system performed reliably throughout the Phase 1 period of over three months (February to May

2007) and continued to run consistently and continuously through the following three months (Phase 2: June - August 2007).

The calibration system continued to work perfectly in both phases. There was no apparent drift or poisoning of the sensors as shown by the calibrations.

The system was set up at a location 500-1000m from the sources of the odour on the site (lairage, liquid waste etc), in a house beyond the boundary, in the proximity to where complaints have been received in the past. It operated remotely and transmitted data by wireless to an on-site computer. The data files were accessible to T&R staff through their in-house computer system. Their IT set-up served as a good example to others in the red meat industry.

A reduction in productivity in the second three months of the trial was reflected as a drop in overall output from the E-nose. Productivity at the site, in terms of stock numbers, had a direct bearing on the odour levels reaching the remote sensing unit.

The trial provided an important test for the efficacy of the E-nose as an outdoor, ambient air quality sentinel and gave information used in an odour audit of the site performed by a third party in mid-2007.

To know if “smell events” recorded by the E-nose were significant in terms of annoyance, it was necessary to calibrate the E-nose with systematic dilutions of the odour from its source, sniffed and assessed by a panel of normal healthy adults.

There remains a need to collect corroborative evidence of what smells could be perceived throughout the measurement period, and to link periods of high e-nose recorded activity to definitive production variables on site.

3 Other developments at E-Nose P/L relevant to the Project

3.1 Hardware developments

Other work at E-Nose Pty Ltd has included gradual improvement to the hardware and presentation of the device. Mk 3.1 E-Nose now has a machined delron (white plastic) manifold located above the sensors with inset brass nozzles for delivery of calibrant or clean air from the “flush-cal” system directly onto each sensor. It also includes a lockable toggle switch for the monitor and sniff mode settings. A new design of mother board is in progress and will be the platform for E-Nose Mk 3.3. Tailored daughter boards containing three application-specific sensor arrays have been designed, built and tested. E-Nose P/L is now moving these tailored devices into markets other than red meat processing.

The sniff mode setting was modified in Mk3.2 to bypass the charcoal filter and allow the intersniff interval to be used to pull air in through the dedicated nostril which can now be fitted with 5 metres of 6mm (ID) teflon tubing. This has been proved work well when samples of vapour need to be drawn from confined or hazardous spaces.

The outside of the e-nose box now has a set of labels produced by an industrial-designer. In due course it is intended that the E-Nose will have a customized outer container. The E-Nose company has also worked with plastic and metal B&R cabinets and can now supply these modified for use with our equipment at industrial sites.

3.2 Synthetic Rendering Calibration Study

A human calibration study was carried out with synthetic rendering odour, in the E-Nose P/L lab. Six healthy adult humans assessed the presence or absence of a target (rendering) odour in a forced choice by sniffing six pairs of 20L air bags, one of which contained an odour at varying dilutions of stock (strong) odour. The results were plotted as peak heights for the E-Nose voltages for each “sniff” of odour received by the device, against the increasing concentration of the vapour, expressed as number of dilutions of a unit volume of the stock odour. A calibration curve for E-Nose mV and Odour Units was demonstrated, curves of best fit (mostly second order polynomials) were computed, and the mathematical functions for each sensor (for a specified sensitivity level) was derived from these curves. Results are reported in detail in the body of this report.

3.3 Calibration of E-Nose voltages against human judgments of perceived odour strength.

A human perception calibration exercise was carried out, using the socially acceptable odour, benzaldehyde, at UNSW in 2006, with 20 students acting as a sensory panel. Perceived odour strength was plotted against peak heights of odours delivered from a set of vapour vessels at different dilutions controlled by a flow-dilution olfactometer.
Resulting graphs are shown in this report.

Despite some limitations in this method (including inexact intervals between dilutions) this kind of analysis may be useful to a company having to deal with complaints about smells detected beyond its boundaries, where the perceived intensity and degree of dislike of the odour may be far more important than the abstract and unreliable nature of the Odour Unit.

3.4 Repeated Odour Signatures

Reliability checks were carried out by analyzing the calibration signals recorded by a device in its working context at a client’s site and in-house at E-Nose with other Mk 3 models using three single compound odorants (methylated spirit, benzadehyde, and limonene). There is a high degree of reliability between “signatures” created from the same odorant applied consistently to the e-nose. Various models of Mk3 e-noses have all been tuned independently (they were manufactured one at a time) so some degree of variation can be expected. A test of reliability of readings taken across e-noses and across sites has still to be done.

3.5 Odour Discrimination Algorithm and Software Development

Software development and testing of the patented odour discrimination algorithm continued during the life of Phase 2 of the PIP Project.

A program (called “ODD”) was developed to allow creation of templates while the device was running and to test the discrimination power of the algorithm in real time. Try-outs of the program have been successful, but further developments will be made before it is released onto the market. This is a work in progress.

The Bayesian odour discrimination algorithm has been further tested as part of this study and the hypothesis that odour from a known source can remain identifiable even as much as 500 metres distant from it has been supported. Discrimination can however fail if the odour is not conveyed in the direction of the e-nose or if other odours co-mingle with it.

4 General Discussion and Recommendations

The aim of MLA and E-Nose P/L was to bring the benefits of E-nose technology to the red meat industry in Australia. These were likely to be:

- reduction in risk of prosecution under increasingly stringent environmental laws
- savings in resources needed to defend and continually attend to complaints leveled at meat processors about smells from their operations.
- better control and reduced costs of odour abatement infrastructure and energy by harnessing e-nose technology to odour abatement infrastructure.

The Mk 3 E-Nose is currently ideally suited to long-term continuous monitoring of a site's odour status from a point where it can be protected and occasionally attended to by a responsible member of staff.

This project tested the hypothesis that odours retain their recognizable qualities when they are diluted by atmospheric air with increasing distance from the source.

The Bayesian algorithm clearly demonstrated that in certain circumstances the source odour identity was retained, even at 500m from the source.
In other circumstances odours merged and became a "cocktail" not associated with any known source.

Participating companies expressed the desire to have more information about the relationship between human perception of odour and the E-nose outputs (voltages).
At two of the participating sites, single human judgments were applied to try to make progress toward this goal.

In addition, two lab experiments was carried out using panels of humans: one experiment involved calibrating perceived odour intensity to e-nose sensor voltages; and the other used a human panel to determine the human threshold for synthetic rendering odour, which was serially diluted and given to both the humans and the device to sniff. A calibration chart of sensor voltages against human Odour Units was obtained by this means.

This study provided a clear demonstration of the relationship between Odour Units and sensor voltages. The usefulness of this calibration was predicated upon a complete set of data being available for odours from known sources and the derivation of equations for each at the range of available sensitivity settings.

It is recommended that an easier and more practical approach to use of the E-nose might be best achieved by use of odour diaries which can be correlated with E-nose output levels and salient events. The E-nose will gain its highest value for the user, when it is used for proactive rather that reactive responses to odour emissions.