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Addressing the Market Demands for Artificial Olfaction Systems

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Artificial olfaction system (AOS) instruments, more specifically, electronic noses containing non-specific sensor arrays capable of discriminating and quantifying target environmental odours, e.g. nuisance odours, can provide significant advantages over traditional, human-dependent odour assessment methods. To determine the market's receptiveness, needs and expectations, survey responses from 92 potential AOS users worldwide, including regulators, researchers, and service providers were analysed. There is a general lack of confidence in reliability of odour data using current field methods and dissatisfaction with the costs of conducting lab and field odour assessments. Though not yet commercialised, recognition of AOS-type technology is high and demand for reliable, portable odour sensing devices is strong. Accuracy and reproducibility/precision are considered the two most important factors, followed by sensitivity, portability and cost. A portable field device could expect to retail for $10,000-$15,000 Australian Dollars and should weigh around 10 kg or less. Portability is secondary to reliability, provided the instrument can be left *in situ*. Including additional sensors to measure specific odorants like H_2S is highly desirable, where cost-effective.

Keywords: artificial olfaction system, electronic nose, market research, odour

1. Introduction

Use of commercial electronic noses (eNoses) is largely limited to lab-based, qualitative odour assessments. They provide no odour quantification capability in their current form. In recent years, researchers have overcome significant hurdles in applying eNose-type technology to environmental odour assessment, including monitoring of nuisance odours from intensive livestock facilities (Pan *et al.*, 2007; Sohn *et al.*, 2008), landfill sites (Micone and Guy, 2007) and wastewater treatment plants (Littarru, 2007), and for pinpointing the main contributor to odour nuisance where multiple odour sources exist (Sohn *et al.*, 2009). These new artificial olfaction systems (AOS) are a significant advance on currently available instruments because they: 1) include odour concentration

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prediction models calibrated against olfactometry data to accurately measure odour concentrations continuously real-time; 2) can discriminate a target odour within a mixture of odours, using a customised pattern recognition engine; and 3) can operate on-site and unmanned.

For environmental monitoring applications, potential AOS users are regulators, odour assessment service providers, consultants and researchers. For successful AOS development, a clear understanding of the needs and expectations of users is necessary. We provide details of preliminary market research, focusing on design features, for the benefit of those developing AOS-type devices aimed at a commercial market.

2. Survey Method

The survey was developed using the Survey Monkey online survey development software (http://www.surveymonkey.com/). Around 230 prospective AOS users worldwide were invited to do the survey. They were predominantly Australian and New Zealand government regulatory authorities, environmental consultants, odour assessment service providers and odour researchers. Participants could respond anonymously.

The survey questions were grouped in five categories to evaluate: (1) current odour assessment practices; (2) needs for alternative solutions for odour measurement; (3) ideal design for an AOS device; (4) market demands for AOS; and (5) AOS applications. The results of the first three categories are presented in this paper.

3. Results and Discussion

3.1 Response level and categorisation

A total of 92 responded and, of those, 86 completed the survey in full and 50% provided their name and contact details. Of those who gave their location, 77% were from Australia, 10% from New Zealand and the remaining 13% were from Germany, Belgium, Japan, Ireland, UK, USA, Canada, Netherlands and Spain.

Respondents were mainly regulators (41%) from government authorities (49% of all respondents). Private businesses (consultants/odour assessment providers) accounted for 35% of respondents and researchers 13%. Eight percent of respondents were from universities or non-government research institutions.

3.2 Current odour measurement practice

3.1.1. Respondents' knowledge level on odour measurement

Most (80%) had at least a fair knowledge of odour monitoring and measurement techniques, while 51% indicated their knowledge was good or better. Thus, the sampling pool for the target audience is considered well-defined and conducive to confidently addressing the needs of potential AOS users.

3.1.2. Frequency of dealing with odour problems

Most respondents (87%) dealt with odour problems at least seasonally, 46% at least weekly, and 20% daily. These results provide further confidence that the survey results will be meaningful and useful, particularly regarding current odour assessment issues.

3.1.3. Current odour measurement techniques

Of the instruments currently being used, the human nose (75%) was the most common, followed by olfactometry (53%), GC-MS (25%), field panels (23%), and eNose (6.5%), the eNose result reflecting the fact there are none commercially available for odour measurement.

3.1.4. Respondents' satisfaction levels on current odour measurement techniques

Table 1 summarises opinions about current odour assessment. For laboratory data, of the 61 respondents who offered their opinion, 62% considered the data good or very good. Only 8% considered the data excellent. For field results, the majority considered them at best fair (44%) or good (26%). Only 20% considered them any better. This highlights the need to improve confidence in odour measurements, particularly in-field assessments, which the AOS solution should be able to fulfill.

Odour assessment costs were considered only fair to good for both field-based and lab-based assessments. The usefulness of the odour measurements was generally considered good to very good for lab results, but only fair to good for field results. This reinforces the need for improvement in field odour assessments; a niche AOS technology can fill.

Table 1. Opinions about lab and field odour assessments: data reliability, cost-effectiveness, and usefulness in performing duties.

	Poor	**Fair**	**Good**	**Very good**	**Excellent**	**Total**
Laboratory data	6.6% (4)	23.0% (14)	**31.1% (19)**	**31.1% (19)**	8.2% (5)	100% (61)
Field data	9.6% (7)	**43.9% (32)**	**26.0% (19)**	16.4% (12)	4.1% (3)	100% (73)
Laboratory costs	22.2% (14)	**38.1% (24)**	**28.6% (18)**	9.5% (6)	1.6% (1)	100% (63)
Field costs	16.0% (12)	**30.7% (23)**	**26.7% (20)**	21.3% (16)	5.3% (4)	100% (75)
Laboratory results usefulness	4.7% (3)	20.3% (13)	**37.5% (24)**	**25.0% (16)**	12.5% (8)	100% (64)
Field results usefulness	6.5% (5)	**26.0% (20)**	**42.8% (33)**	15.6% (12)	9.1% (7)	100% (77)

3.3 Needs for alternative solutions for odour measurement

The majority of respondents (64%) had some knowledge of existing eNose technology, though most respondents (88%) had never used an eNose. Of the 12% that had, usage was mostly limited to lab-based eNose technologies such as Aromascan, Alpha-MOS and z-Nose. The results demonstrate a high recognition of the eNose technology despite the lack of firsthand experience and unavailability of eNoses suitable for quantitative environmental odour assessment tasks.

3.4 Ideal design for an AOS solution

To help determine the most important features and therefore the trade-offs needed to deliver a timely, cost-effective AOS solution, respondents had to rank the following factors in order of importance: sensitivity, accuracy, reproducibility/precision, portability and price. The collated results of the 86 respondents shown in Table 2 indicate accuracy is ranked highest, followed by reproducibility/precision, sensitivity, portability and price.

For sensitivity, *i.e.* the minimum magnitude of the input signal required to produce a meaningful output signal, after taking any "noise" into account, 30% nominated the most sensitive set category offered (2.5 OU), which is the standard requirement for many of the environmental air quality regulations. The results for 10, 20 and 50 OU were 15, 14 and 0%, respectively. Of the 21% "other" responses, *i.e.* 18 respondents, 11 of them specified a sensitivity of ≤ 2 OU. Of these, five specified 1 OU. The need for sensitivity of ≤ 10 OU was the prevailing message conveyed. Interestingly, 28% replied they did not know, or had no opinion about the sensitivity required, which implies these respondents were unfamiliar with quantifying odour in terms of odour units, as opposed to qualifying an odour, *e.g.* by intensity, hedonic tone.

For accuracy, *i.e.* degree of closeness of the measured odour to the actual (true) value as determined by standard procedure using a human panel, *i.e.* olfactometry, the majority (33%) specified ± 10%, 23% indicated ± 5% and 15% indicated ± 20% as the acceptable level for their purposes. The rest (20%) offered no opinion, or were unsure.

Table 2. Rankings for five key factors in development of a portable AOS (86 respondents)

	1 (most)	2	3	4	5 (least)
Sensitivity	10.5%	18.6%	**40.7%**	14.0%	16.2%
Accuracy	**41.9%**	27.9%	17.4%	7.0%	5.8%
Reproducibility/precision	**33.7%**	**33.7%**	17.5%	11.6%	3.5%
Portability	7.0%	8.1%	12.8%	**40.7%**	31.4%
Price	7.0%	11.6%	11.6%	26.7%	**43.1%**

For precision, *i.e.* ability to achieve a consistently accurate measurement of the same odour in independent tests, a level of ± 5 to 10% was most acceptable (60%). Only 16% opted outside this range, while 24% gave no opinion, or were unsure. It is not surprising that allowances of ± 10% are considered acceptable given the vagaries of odour, the uncertainties of odour measurement, and the inherent variability when calibrating AOS instruments against olfactometry results.

For portability, 70% chose a weight category of 10 kg or less. While the 10 kg category (33%) scored highest, 37% of respondents chose a category of 5 kg or less. Opinion on price was well spread as shown in Figure 1 with 80% of respondents indicating a retail cost between $5,000 and $15,000 Australian Dollars was acceptable. The $10,000 option scored highest overall (22%).

Most (71%) believe it is important to also measure VOCs in conjunction with odour and to a lesser extent H_2S (67%) and Ammonia (54%), which are common nuisance odorants, and NO_x (27%) and CO_2 (15%), being greenhouse gases. Other specific chemicals were considered by various respondents to be useful depending on the odour source, *e.g.* sulfur dioxide, reduced sulfides, mercaptans, organic acids, aldehydes, ketones and other carbonyl groups. There would be considerable benefits incorporating suitably sensitive VOC, H_2S and ammonia into an AOS, if available and affordable.

3.5 Additional considerations

In view of this market research, developing AOS solutions for monitoring environmental odours would appear commercially viable. However, system recalibration and serviceability become issues for any commercial AOS product. Periodic recalibration and maintenance of the AOS sensor array and associated pattern recognition models will be important, non-trivial issues AOS developers need to address before releasing AOS solutions to the market.

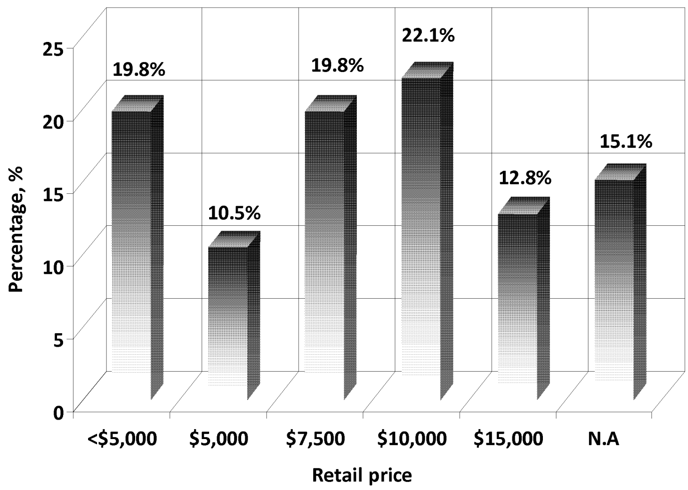

Figure 1. Expected retail price (in Australian Dollars) for portable AOS

Convenient, cost-effective calibration methods for developing new solutions and to account for: sensor drift, replacement of faulty sensors, sensor substitution (in the case of discontinued lines) are needed in practice. The ability to cross-reference AOS measurements to other techniques is also highly desirable to ensure the ongoing development and commercial success of the technology.

4. Conclusions

Advanced artificial olfaction systems are poised to revolutionise quantitative odour assessment and the monitoring of environmental odours on-site. A ready market exists and prospective users are prepared to compromise on portability provided the AOS results are reliable. Precision and accuracy levels of the order of ± 10% for AOS outputs would be acceptable.

AOS devices will increase both capability and capacity to perform objective, cost-effective odour assessments, and decrease dependency on less reliable techniques that depend on human perception. AOS outputs will complement standard olfactometry results, reducing the number of olfactometry analyses required.

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