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Potential of a Network of Electronic Noses to Assess in Real Time the Odour Annoyance in the Environment of a Compost Facility

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This paper presents a complete approach of continuous odour monitoring around an industrial plant, with an e-nose network named FIDOR, providing in real time the five components of the odour annoyance, the frequency, the intensity, the duration, the offensiveness and the impact on the receptor.
Such FIDOR network was placed in the immediate surroundings of a compost facility in Belgium. Results show a good coherence between information provided by FIDOR system and odour level assessment with human noses. Some interesting correlations are also found between e-nose responses at different distances in a same radial direction from the source.
The discussion is mainly focused on the potentialities and the limitations of such system.

1. Introduction

In the past decade, environmental applications of electronic noses have received growing attention. However, while intense research in e-nose technology has resulted in significant progress in the domain of continuous odour monitoring in the field, more successful long term case-studies are still needed to overcome the early overoptimistic performance expectations (Munoz et al, 2010). Some first experiments of e-noses network in industrial area show promising results, but only few papers relate continuous e-nose monitoring around industrial sites with the aim of predicting odour impact (Micone and Guy, 2007; Sironi, 2007).
This contribution presents a complete approach of real size odour monitoring able to provide a fast response aiming at odour annoyance assessment for decision making purpose. The array of 5 electronic noses tries to display in real time the 5 components of the odour annoyance: the frequency, the intensity, the duration, the offensiveness and the impact on the receptor.
Frequency and duration are provided through the detection of odour-events emerging above a given threshold. Intensity of the odour is estimated thanks to a regression model calibrated with dynamic olfactometry measurements compared to the sensor signals. Offensiveness can be tackled by identifying the odour type on the site and the receptor exposure is translated in terms of downwind perception distance. This system is installed around a waste treatment work for 2 years and is used by the plant manager to anticipate odour annoyance in the surroundings.

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2. Materials and methods

The implemented FIDOR network consists in 3 weather stations and 5 home-made electronic noses comprising each 6 metal oxide sensors from Figaro®, arranged in a PTFE chamber. The instruments are placed around a waste treatment facility in the South of Belgium, at distances between 20 and 25 m from the sources. The plant consists in a rather complex site, with different facilities distributed on a wide area: non-organic waste landfilling, green composting area, raw waste material arrival, biogas valorisation motor and biodrying hall aiming at producing a fuel used in cement works. The topology of the network (Figure 1) mainly depends on prevailing wind directions (NE and SW) and on the location of residents (N, NE).

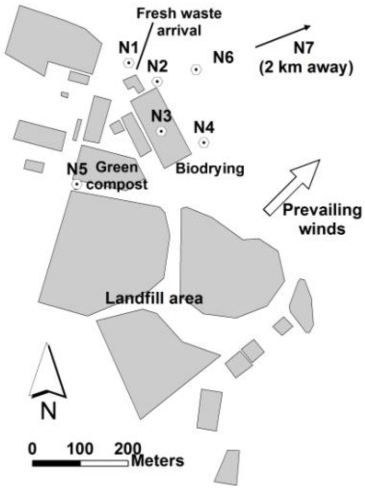

Figure 1: Topology of the five e-noses network N1-N5 with the two additional instruments N6 and N7

The originality of the approach is the detection of odour-events for each e-nose in different steps. Firstly, the odour type is classified into five possible categories: odour-free atmosphere, engine exhaust gases, green compost, biodrying or fresh waste emissions. Then, a quantitative model assesses the "level" of the odour and estimates the odour emission rate at the e-nose location. Next, a special filtering algorithm detects the exceedance of a given odour threshold to possibly acknowledge the emission as an "odour-event". Lastly, according to the wind direction, the responses of one or two electronic noses in the right wind sector are used to assess the maximum downwind distance of odour perception which is displayed on a background map.

Besides the e-nose signals, these models use the data from three met-stations specifically designed for this application and comprising anemometer, weather vane, pyranometer, pressure, humidity and temperature sensors. They are included in the network of instruments and connected to the field bus like the e-noses.

Models are calibrated against external measurements. Qualitative odour type recognition use supervised modelling, essentially Discriminant Function Analysis (DFA), to determine if the set of sensor signals is effective in predicting odour category membership. Odours are sampled in Tedlar® bags or measured directly in the field. Obviously, the target odour group is identified by the proximity of the sampled atmosphere to the emission source (compost, biodrying, etc.).

Quantitative odour level prediction is obtained by statistical procedures using Partial Least Square Regression (PLS) as well as some distance concepts from a reference "non-odour" group. The dependant variable used in regression procedures is the odour concentration as measured by dynamic olfactometry according to the European standard EN13725. The used instrument is Odile olfactometer (Odotech, Canada) with 6 assessors. The final model is a linear combination of the sensor signals.

The transformation of concentration data into odour emission rates is made through a model calibrated against field inspection and reverse modelling using a bi-Gaussian atmospheric dispersion model (Tropos Impact, Odotech, Canada). The procedure is described by Nicolas et al. (2006).
These measurements and additional observations from 15 residents during 6 months are then used to validate the prediction of maximum odour perception distance, which is estimated by a simplified Gaussian model implemented into the control computer. Models and Graphical User Interface (GUI) are implemented in LabWindows/CVI.

3. Results

Concerning first the qualitative odour type classification, the predictive capabilities of the DFA model have proved rather correct. A total of 192 samples collected at different locations on the site were presented to the sensor array for calibration purpose and the classification functions of DFA were used to predict the category membership.
For efficiency reason, it was decided to work with a hierarchical recognition scheme with 3 successive models. Firstly, the exhaust gas of trucks and engines was separated from other emissions because it was clearly recognizable by the e-nose system (100 % of correct classification), while it is not a worrying atmosphere in terms of odour annoyance. The second level of the hierarchy classed the odourless atmospheres apart from the odorous ones. They were identified by light sensor responses and may have included some polluted atmospheres, but with low odour level. For this second step, the performance of the model was around 80 % of correct classification. Then, when an odorous sample was recognized, the third step consisted in trying to identify its type among three possibilities: green compost, fresh waste or biodrying. Globally, when implemented in the whole monitoring system, these 3 levels implied thus, for each instrument, 7 simple linear classification functions with 42 coefficients. The predictive capability of the third step was only 70 %, with much confusion between the odour of "compost" and "biodrying" emissions, which were actually very similar one another.
Concerning the odour quantification, for each e-nose, a PLS model of odour level assessment was calibrated against 37 olfactometric measurements, all odour types combined. Figure 2 shows the scatterplot of odour concentration estimated by partial least square model for one instrument versus the concentration as measured by dynamic olfactometry.

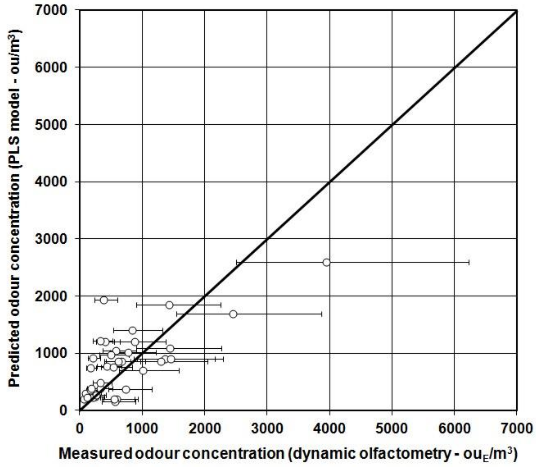

Figure 2: Scatterplot of odour concentration predicted by partial least square model for one of the noses vs the concentration as measured by dynamic olfactometry. Ideal identity line and uncertainty bars of dynamic olfactometry ("reference method") measurements are also drawn on the figure

When examining the discrepancies with respect to the ideal identity line, the model seems quite bad. However, the error can not only be attributed to the sensor system or to the model. Figure 2 shows also the uncertainty bars due to the olfactometry method, which, thought, is the "reference" method. Apart some extreme cases, the uncertainty bars cut the ideal identity line, which proves that the model estimation is not really worse than the reference measurement itself. In terms of 95 % confidence interval, the prediction error by the PLS model is around 200 uo/m^3 for the whole concentration range. Of course, olfactometry is not the sole responsible of the uncertainty. Possible causes are: sensor drift, influence of the odour type on its concentration, influence of the sample bag or of the relative humidity of the sample.

Other leads were also explored to assess the odour level, such as the Mahalanobis distance from the "non-odour" group centroid in the space of the raw signals. And this method provided results as good as the PLS ones.

But one of the most difficult tasks in modelling odour emission is the conversion of odour "level" or concentration (e.g. in ou/m^3) into odour emission rate (e.g. in ou/s), necessary to calculate atmospheric dispersion and downwind perception distance. That was done through 22 field inspections and back calculations. However, only 14 out of the 22 measurements were valid, since, for 8 of them, the odour plume was oriented towards a direction where no electronic nose was installed. So, a total of 14 emission rates (in ou/s) were estimated and compared to the odour concentration calculated for the e-nose placed in the right wind sector. The relationship between the two parameters was far from being linear and, of course, depended on the weather conditions and of the characteristics of the source (height of the compost heap, ventilation of the hall, …). Moreover, in many cases, the axis of the odour plume did not exactly cross an electronic nose location. So, while a simple y=bx model was used for any situation, that was the most doubtful step of the modelling procedure, not only for the present studied case, but each time diffuse sources are considered.

Finally, the odour emission rate of the source estimated from the response of the electronic nose concerned (according to the wind direction) was used in a simple bi-Gaussian dispersion model to assess in real time the downwind perception distance, which can be drawn on the background map. The model assumed source emission and receptors at ground level and used the Pasquill stability classes estimated from the central met-station records.

4. Validation

Such rather complex procedure to detect odour events, to identify their source and to transform the raw signals of the sensors into a distance of odour perception is affected by a lot of uncertainties at the different levels: sensor reliability (e.g.: drift or influence of ambient parameters), quality of the reference olfactometric measurement, location of the considered instrument with respect to the axis of the odour plume, accuracy of the various models, and chiefly of the conversion of odour level into odour emission rate … However, the final goal of such system is to provide just an approximate estimation of possible odour annoyance in the surroundings. It is not used as a laboratory instrument requiring very accurate results. So, a special attention was paid to the field validation of assessed annoyance elements and to the robustness testing of used methods.

A first simple validation was carried on by comparing the detection of odour events by FIDOR system and the subjective feeling of field observers placed near the electronic noses. It was reassuring that about each event detected by FIDOR system was validated by field observer. False positives were rare and false negatives occurred each time the odour plume did not cross any e-nose location.

Then residents in the neighbouring villages were appealed to regularly provide their estimation of the odour annoyance, according to a procedure described by Nicolas et al. (2010). The period November, 2010-April, 2011 was particularly analysed with 15 involved residents and a total of 2,348 observations at different hours of the days. Among them, only 218 referred to odour events, other ones were "non-odour" observations. The remaining ones were then sorted to eliminate all odour occurrences not clearly identified as generated by the waste treatment plant (e.g.: "wood" odour, which came from a local woodwork factory). There was 74 left from which only 21 were kept after plausibility check by crossing the resident responses with the wind direction. Thus, finally, with such quite heavy method,

only 1 % of the resident observations could really be used for validation purpose. While statistical criteria were not truly reliable for so low sample size, it was encouraging to observe that, in 17 cases out of 21, the FIDOR system detected an odour event when residents identified an odour coming from the waste treatment plant.
On a more quantitative level, for 10 cases among these 17, the resident concerned was included in the perception zone predicted by the FIDOR system. The 7 remaining cases corresponded to unstable atmospheric conditions (Pasquill classes B) for which the simplified Gaussian model implemented in FIDOR underestimated the real perception distance. An increased account of atmospheric stability should be taken for further improvement of the calculation of the maximum downwind odour perception distance.

5. E-noses at farther locations

From the above results, it is clear that an array of 5 electronic noses surrounding such large diffuse odour source can provide valuable information to the plant manager in terms of annoyance prediction. However, it is difficult for such system, placed very close to the emission level, to extrapolate its local response to the large areas concerning residents living at 1…2 km from the odour source. It was particularly demonstrated that a single assessment of odour concentration supplied by the instrument placed in the right wind sector is insufficient to appraise the odour emission rate of the whole site so as the odour level at remote locations towards residents. For those reasons, the study placed emphasis on the performance evaluation of FIDOR system when sensor arrays are positioned at more distant locations with respect to the odour emitting facility. Two additional e-noses were placed at 100 and 2,000 meters away in the direction of residents, with the double aim of trying to estimate the odour emission rate from gradient measurements of odour level and of appraising the resident annoyance from measurements made close to their home. Figure 3 shows the comparison of 3 nose responses as resulting of an odour-event: N2, N6 and N7 are placed respectively at distances of 25 m, 100 m and 2000 m away from the source. A clear correlation can be observed between the nose placed at the source level and the nose placed 100 m away, while the most distant nose reacts less to the odour-event.

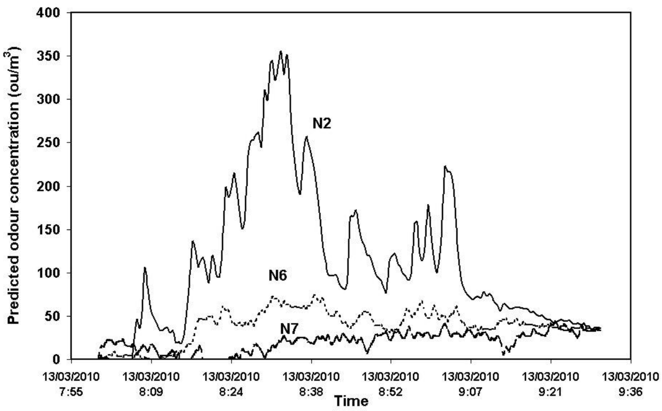

Figure 3: Comparison of the responses of 3 noses resulting of an odour-event. Responses are expressed as predicted odour concentration in ou/m^3

It is particularly worth noting that the three measurements are cross-correlated. The maximum cross-correlation coefficient between N2 and N6 is 0.68 with a time-lag between 30 seconds and 1 minute, while the correlation is maximum (and reaches 0.60) between N6 and N7 with a time lag of 7.5 min. During these measurements, the wind speed was 4 m/s, so that the travelling time for the odour between N2 and N6 was 20 s, while the one between N6 and N7 was about 8 min. Hence, the

observed lag between recordings could be explained by the wind transport of the odour generated by the site.
Now, the three signals exhibit also a damping from N2 to N6 and N7 which could be explained by the atmospheric dispersion. However, considering that the calculated response shown on Figure 3 is a true odour concentration in ou/m^3, the FIDOR system should underestimate the odour decrease from N2 to N6 and N7 with respect to a dispersion model (Tropos Impact).

6. Conclusion

The real size odour monitoring experimented in Habay with FIDOR system proves sufficiently efficient to predict in real time possible odour annoyance in the surroundings of the plant. Nevertheless, the used approach suffers from various uncertainties at the different levels, from the sensors to the final determination of the annoyance downwind distance. But, if the final-user is sufficiently warned and aware of the limits of the system, the supplied results present a real interest for decision making purpose.
Uncertainties are inherent to the methodology and to the model calibration. Of course, it is impossible to provide more accurate odour prediction than what can be expected with reference methods, such as dynamic olfactometry. The calculation of odour emission rate on the basis of the measurement of a variable related to the odour concentration is particularly challenging. Moreover, to be able to predict the odour annoyance in any weather situation, the industrial plant should be encircled by a large number of electronic noses, in all possible wind sectors. Finally, validation by field measurements or by resident diaries is complicated and cumbersome and results in few suitable cases for which comparison with e-nose response is possible.
These basic uncertainties make excessive the use of sophisticated on-line dispersion models which should provide a false impression of accuracy when interpreting nice coloured 3-D plumes.
But such limitations are chiefly applicable for large and diffuse odour sources. Using e-nose for channelled emissions should undergo less limitation.
In conclusion, there is a huge potential for the use of electronic nose to monitor environmental odours, but the use of electronic nose needs an expertise: it is not a classical instrument which is simply placed on a site without any precaution. Moreover, there isn't any universal electronic nose, but provided that each instrument should be specifically tailored to the application, it constitutes a very promising method, complementary to other ones to monitor the time evolution of odour sources.

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