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Electronic noses for environmental applications: field tests for reference humidity optimization

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One of the most critical aspects associated with the use of electronic noses on field is represented by the sensor sensitivity to humidity. This paper discusses two possible solutions to the sensor sensitivity to humidity problem. The approach adopted in order to face the problem is the "relative" humidity stabilization, which consists in making the humidity of the reference air and of the sample air change in a proportional manner, so that the humidity difference between reference air and sample air (△RH) remains constant. This paper describes how these solutions were further studied performing a field test, represented by an experimental monitoring campaign, in which two electronic noses, working with different conditions corresponding to the above mentioned solutions, where used simultaneously for the continuous analysis of the ambient air at a wastewater treatment plant. The exploratory analysis of the training and monitoring data enabled to verify that both tested humidity management solutions are effective in improving the sensor responses, by enhancing their stability, repeatibility and reproducibility. Though, the most evident improvements, especially as far as the instrument sensitivity is concerned, were observed for the sensor responses of the electronic nose working with the humidity regulation system that adjusts the reference air humidity making it equal to the sample air humidity.

1. Introduction

Since 2003, one of the main research activities at the Olfactometric Laboratory of the Politecnico di Milano is the study and the development of a system for the continuous monitoring of environmental odours at specific receptors.

The system, based on the use of electronic noses, should be capable to continuously analyze the ambient air at directly where the presence of odours is lamented and, in real time, it first should qualitatively classify the analyzed air by attributing it to a specific olfactory class, and then quantify odours by estimating the odour concentration of the analyzed air. The system should have some specific characteristics for the desired application: it must be extremely sensitive, in order to detect the presence of odours at receptors, i.e. at far distance from the emission source, and it must be suitable for outdoor use, i.e. with varying atmospheric conditions.

One of the most critical aspects associated with the use of electronic noses on field is represented by the sensor sensitivity to humidity (James et al., 2005, p. 1; Welle et al., 2000, p. 372). Humidity variations can cause problems both in the reference air, influencing the base line, and in the air to be analyzed (sample air), influencing the response curve amplitude, and therefore making the instrument responses to odours not repeatable.

This paper discusses two possible solutions to the sensor sensitivity to humidity problem. The approach adopted in order to face the problem is the "relative" humidity stabilization, which consists in making the humidity of the reference air and of the sample air change in a proportional manner, so that the humidity difference between reference air and sample air (△RH) remains constant.

These solutions were first compared in laboratory tests, which were conducted with the aim of evaluating the sensitivity of a set of MOS sensors by determining their detection limit towards different odorous compounds. This paper describes how these solutions were further studied performing a field test, represented by an experimental monitoring campaign, in which two electronic noses, each working with one of the above mentioned reference conditions, where used simultaneously for the continuous analysis of the ambient air at a wastewater treatment plant.

This monitoring was conducted with the primary aim of comparing the sensor responses of the electronic noses working with two different reference conditions. For this reason, this section doesn't describe the criteria and the experimental methods adopted for the single monitoring phases, i.e. training, monitoring and data processing (Sironi et al., 2007, p. 336), but it just focuses on the comparison of the results of the exploratory data analysis and of the qualitative classification relevant to the two instruments.

2. Materials And Methods

2.1 Methods for the humidity management

According to the approach of the relative humidity stabilization, two different solutions were tested. The first one consists in the partial dehydration of the reference air. In order to keep △RH constant we used a system, consisting of a permeation tube containing a selective membrane, which enables to reduce the humidity of the reference air proportionally to the sample air humidity content. The second solution tested is based on the principle of keeping the reference air at the same humidity level as the sample air, which entails that the appearance of peaks in the sensor response curves during the measurement phase is due exclusively to the sensing of odours and not to the difference of humidity between reference and sample air.

2.2 Electronic nose training and monitoring

Two electronic noses were employed for this study, the first instrument, named "EOS1", working with "wet" reference air, i.e. with a humidity regulation systems that adjusts the reference air RH to the sample air RH, while the second instrument, named "EOS2", used partially dehumidified reference air, achieved by using a partial dehydration system based on the use of a permeation tube containing a selective membrane. It was decided to employ the instruments for the ambient air monitoring at an industrial wastewater treatment plant located in the North of Italy.

For this purpose, the electronic noses first had to be trained to recognize the plant principal odour emissions. In general, the training is performed by analyzing a set of samples, representative of the plant odour sources. In this case, the sampling points considered were:

- the wastewater arrival tank;
- the mixing and flocculation tank;
- the outlet of the scrubber treating the effluents from the wastewater arrival and flocculation tanks and from the sludge dehydration room;
- the container for the dehydrated sludge storage.

Moreover, some ambient air samples were collected near the wastewater plant to be monitored, in particular moments in which odours attributable to the plant were not perceivable, in order to create a reference olfactory class, corresponding to non-odorous, i.e. "neutral" air.

Once trained, the electronic noses could be transported to the wastewater treatment plant. Both instruments were installed inside the plant, at the offices, near to the eastern fence line. The monitoring had a duration of 17 days, from 19.00 of Tuesday, 4th December 2007 to 14.00 of Friday, 21st December 2007. During this period, the electronic noses analyzed the ambient air every 15 minutes. For each of these time intervals, the instruments sucked the external ambient air for 3 minutes, while during the remaining 12 minutes reference air flew inside the sensor chamber in order to clean the sensor active layer and bring their response back to the base line (recovery time). After the monitoring, the data registered by the electronic noses both during the training and the monitoring phase could be analyzed.

3. Results And Discussion

3.1 Exploratory data analysis

Exploratory data analysis (Pardo et al., 2000, p. 397) was used in order to preliminarly evaluate the sensor responses and get a feel of data structure.

First, the sensor response curves were explored, with the aim of analyzing the behaviour of both reference air humidity regulation systems, especially on field, i.e. during the monitoring phase. As far as the electronic nose EOS1 is concerned, the system capability of adjusting the reference air RH and make it equal to the sample air RH had to be verified, whereas in the case of EOS2, it was important to evaluate the system capability of partially dehydrating the reference air and keeping ΔRH constant.

By analyzing the sensor response curves relevant to EOS 1 it was possible to observe that the trend of the RH inside the sensor chamber follows the trend of the RH of the external ambient air RH. The absence of significant peaks in the responses of the sensor measuring the RH inside the sensor chamber (RH_CH) between the measurement and the recovery phase proves the capability of the humidity regulation system to keep reference and sample air at the same RH value. The good functioning of the humidity regulation system positively affects the sensor responses, which turn out to be more stable, repeatable and reproducible.

As far as the electronic nose EOS2 is concerned, pronounced peaks are visible in the responses of RH_CH between the measurement and the recovery phase, due to the different humidity content of sample and reference air, the latter being partially dehumidified. It can be seen that the external ambient air RH variations affect the trend of the base line of sensor RH_CH, but they do not have a significant effect on the amplitude of the sensor responses, thus proving the capability of the humidity regulation system to stabilize ΔRH by dehydrating the reference air proportionally to the humidity content of the sample air. Also in this case, the good functioning of the humidity regulation system has positive repercussions on the sensor responses, enhancing their stability, repeatability and reproducibility. Nonetheless, it must be highlighted that the highest stability, repeatability and reproducibility were observed in the sensor responses of EOS1, where reference air and sample air have the same humidity content.

The second step of exploratory data analysis was the evaluation of the graphs obtained by application of PCA to the sensor responses.

The PCA relevant to the training of both electronic noses EOS 1 and EOS 2 show a good separation between the different olfactory classes. Moreover, plotting the points relevant to the monitoring measurements on the PCA of the training data, it is possible to observe a partial overlapping of monitoring and training. This proves the capability of the humidity regulation system of making the sensor responses more repeatable and reproducible.

3.2 Qualitative classification of monitoring data

Once the effectiveness of both humidity regulation systems was verified through exploratory data analysis, a qualitative classification of the data registered during the monitoring period was performed, and the results of the qualitative classification relevant to both electronic noses were compared.

Given that the primary aim of this study wasn't the qualitative classification of the analyzed ambient air itself, but rather the comparison of the performances of the two instruments working with two different reference air conditions, the qualitative classification was limited to the discrimination of the olfactory class "neutral air", corresponding to a condition of non-odour, from the olfactory class "wastewater treatment plant", indicating the presence of odours from the plant at issue.

The results of the qualitative classification performed with the two electronic noses, EOS1 and EOS2, are represented graphically in Figure 1.

Based on the classification results the relative recognition frequency of each olfactory class can be determined by dividing the measurements attributed to each class by the total number of measurements carried out during the monitoring period (Table 1).

Based on the results reported in Figure 1 and in Table 1 it is possible to observe that the results obtained with the two instruments are similar, although presenting some differences. The electronic nose EOS1 detected the presence of odours from the wastewater treatment plant for a higher time percentage than the electronic nose EOS2 (26.5% against 21.6%). This could mean that eliminating the humidity differences between sample and reference air slightly increases the instrument sensitivity to odours.

The periods during which the electronic noses EOS1 and EOS2 detected the presence of odours from the wastewater treatment plant can be compared by means of a confusion matrix (Kohavi and Provost, 1998, p. 271) (Table 2).

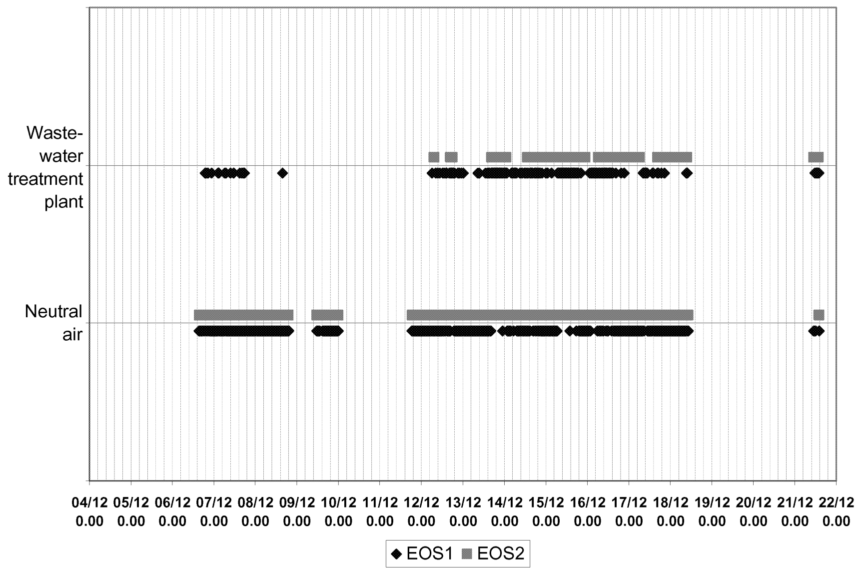

Figure 1. Results of the qualitative classification performed by electronic noses EOS1 and EOS2, respectively

Table 1. Relative recognition of the olfactory classes "neutral air" and "wastewater treatment plant" by electronic noses EOS1 and EOS2

Recognition frequency of the different olfactory classes				
	EOS1		*EOS2*	
Olfactory class	*Number of measurements*	*Relative recognition frequency (%)*	*Number of measurements*	*Relative recognition frequency (%)*
Neutral air	659	73.5%	703	78.4%
Wastewater treatment plant	238	26.5%	194	21.6%

Table 2. Confusion matrix relevant to the qualitative classification performed by electronic noses EOS1 and EOS2

Confusion matrix			
		EOS1	
		Neutral air	***Wastewater treatment plant***
EOS2	***Neutral air***	546	157
	Wastewater treatment plant	113	81

Table 2 shows that there is a certain agreement between the results of the qualitative classification performed by the two electronic noses. This can be quantified by determining the accuracy index, calculated as the ratio between the sum of the terms on the matrix diagonal, representing the measures in correspondence of which the electronic nose outputs coincide, and the sum of all the terms of the matrix, representing the totality of the measures:

$$AC = \frac{546 + 81}{546 + 157 + 113 + 81} = 69.9\% \quad (1)$$

In this case, the comparison of the results of the qualitative classification performed by the two electronic noses EOS1 and EOS2 gives an accuracy of 69.9%.

4. Conclusions

The exploratory analysis of the training and monitoring data, i.e. the critical evaluation of the sensor response curves and of the PCA, enabled to verify that both tested humidity management solutions are effective in improving the sensor responses, by enhancing their stability, repeatibility and reproducibility. Though, the most evident improvements were observed for the sensor responses of EOS1, working with the humidity regulation system that adjusts the reference air RH making it equal to the sample air RH.

As far as the qualitative classification results are concerned, the electronic nose outputs turned out to be similar, though with some interesting differences. More in detail, The electronic nose EOS1, working with a reference air with the same RH as the sample air, detected the presence of odours from the wastewater treatment plant for a higher time percentage than the electronic nose EOS2, working with the humidity regulation system for the partial dehumidification of the reference air (26.5% against 21.6%), thus showing that the elimination of the humidity differences between sample and reference air slightly increases the instrument sensitivity to odours.

Based on these considerations, the best humidity management system seems to be represented by the adjustment of the reference air RH to the sample air RH, though further studies are certainly needed in order to thoroughly investigate the performance of electronic noses working with a reference air with the same humidity content as the sample air.

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