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Electronic Noses for the Qualitative and Quantitative Determination of Environmental Odours

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For odour impact assessment purposes it may be very useful to dispose of an instrument (electronic nose) capable of both qualifying and quantifying odours in ambient air. For this reason, in the last decade, at the Politecnico di Milano, in collaboration with Sacmi s.c. and Progress S.r.l., specific electronic noses for the continuous monitoring of environmental odours were developed. Since the first instrument developed (EOS 835), during the last years an innovative electronic nose was realized (EOS 507) with the aim of guaranteeing better performances on field. This paper reports the results of laboratory tests performed on different pure compounds, selected among compounds that are typical of environmental odour emissions, proving the capability of the new instrument EOS 507 of discriminating odours and to determine their concentrations up to very low odour concentration values (about 30 ou_E/m^3). Moreover, the two instruments (EOS 507 and EOS 835) were used on field, in order to verify their performances with real environmental odours.

1. Introduction

In recent years there has been a growing interest of population and environmental protection authorities towards the emission of odorous substances from industrial activities. For this reason, it is important to have suitable tools for monitoring odour nuisance. Especially where more industrial activities co-exist it may be useful to identify the cause of the odour nuisance directly at receptors, (Myrick et al., 2008), in order to be able to reduce citizens' discomfort due to the presence of odours at their homes.
For this purpose it is important to have an instrument capable of continuously monitoring ambient air quality which, besides detecting the presence of odours, should also attribute the analyzed air to a specific emission source (Capelli et al., 2009).
For this reason, in the last decade, at the Politecnico di Milano, in collaboration with Sacmi s.c. and Progress S.r.l., specific electronic noses for the continuous monitoring of environmental odours were developed. Since the first instrument developed (EOS 835) (Falasconi et al., 2003), during the last years an innovative electronic nose was realized (EOS 507) (Capelli et al., 2010) with the aim of guaranteeing better performances on field with variable meteorological conditions and diluted odours (Dentoni et al., 2011).

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In order to evaluate the performances of this new instrument, a set of laboratory tests and a field monitoring were run. Laboratory tests had the aim of discriminating the presence in air of different environmentally interesting odorous compounds. Moreover, preliminary test were run for evaluating the possibility of using the electronic nose for odour quantification, as well.
The experimental monitoring had the aim of evaluating and comparing the performances of both instruments (EOS 835 and EOS 507) directly on field, especially as far as the capability of discriminating different olfactory classes and thus identifying the provenance of the odour nuisance is concerned.

2. Materials and methods

2.1 Employed electronic noses

2.1.1. The electronic nose concept
The concept of electronic nose as an instrument consisting of a set of gas sensors for odour classification was first introduced by Persaud and Dodd (1982).
Both electronic noses used for this study are equipped with 6 MOS sensors (Yamazoe et al., 2003), which allow to extract features based on their resistance variations relative to reference conditions (obtained by fluxing a suitable reference substance into the sensor chamber), that are used for the recognition. The two electronic noses used for the study have different characteristics, which are detailed in the next paragraphs.

2.1.2. EOS 835
The electronic nose EOS 835 has two air inlets: the first is connected to a system for the realization of “neutral air”, obtained by means of filtration through activated carbon and silica gel and used as a reference by the instrument, whereas the second (“sample air” line) is connected to a valve regulating the sample air flow directed to the sensor chamber. When “neutral air” flows on the sensors, it produces a response in terms of sensor resistance. As the composition of the analyzed mixture changes, when the inlet is switched to the sample air, the sensor responses (resistances) change correspondingly, thus generating a response curve for each sensor, from which the desired features may be extracted.
The training phase requires the analysis of odour samples opportunely collected and diluted by means of the olfactometer at a suitable concentration range, which previous research has proved to be comprised between 100 - 200 ou_E/m^3 (Capelli et al., 2008). Moreover, the instrument shall be trained towards “neutral air” (i.e. non-odorous air), which is effectively considered to be an olfactory class.
During the monitoring period, the electronic nose EOS 835 analyzes the air every 15 min. At the end of this period the collected data must be processed in order to extract significant features from the sensor response curves (e.g., the difference between the sensor resistance in specific points of the curve compared with the reference conditions, or the area subtended by the response curve) to be used for odour recognition.
In order to optimize the sample air classification a feature selection was performed, as to use just the features accounting for the best discrimination of the considered olfactory classes (Sironi et al., 2007). This operation is performed using data analysis techniques such as cross validation and PCA (Pardo et al., 2000).
Once the features are selected, the instrument performs the classification of the unknown measures using a KNN algorithm (Lavine B. K., 1999).

2.1.3. EOS 507
The electronic nose EOS507 has two innovative aspects with respect to commercial electronic noses: the use of a reference which is not “neutral air”, but a so called “standard”, different from neutral air, and a system for the adjustment of the sample air humidity to a fixed value, calculated as to optimize the instrument regulation capability. Such innovations were introduced in order to minimize the influence of the atmospheric conditions and of the sensor drift on the field measurements. The instrument has two inlets for the ambient air. The first inlet is connected to a system composed of an oxidizer and an activated carbon filter for the obtainment of “neutral air”, i.e. air that doesn’t cause a

sensor resistance variation, whereas the second (“sample air”) is connected to the measured sample air flow. The neutral air is drawn to a humidity regulator that brings the air stream to a set humidity value calculated as to keep the mixture to be analyzed, consisting in neutral and sample air, at a constant Dew Point (DPwk) relative to the one used for the standardization phase.
The EOS 507 has an internal system for the training sample dilution, which allows to analyze the samples at different dilutions, with various concentrations of the original sample. During the training phase, both odour samples and neutral air samples are analyzed.
The instrument extracts one feature for each measure, called “Eos Unit” (E.U.), calculated from the sensor resistance value during the measure with respect to the standard phase.
The system performs the recognition of unknown measures based on the training measures. The attribution of the analyzed air to an olfactory class requires the use of a “threshold”, calculated based on the E.U. values relevant to the neutral air. If the sensor responses are below this threshold, these are automatically classified as “neutral air”. Otherwise, the classification takes place.
During the monitoring phase the air is analyzed and data are recorded once per second.

2.2 Laboratory tests

2.2.1. Aims
The laboratory tests had the aim to verify the instrument capability to discriminate between odour samples of pure compounds, chosen as to be representative of industrial odour emissions. Preliminary tests were run in order to evaluate the possibility of quantifying odour, as well.

2.2.2. Tested compounds
The compounds to be tested were selected among typical compounds that can be found in environmental odour emissions, and include different functional groups. The compounds used were limonene, ethanol and dimethylsulfide.
The samples were prepared from the liquid compounds, by inserting the liquid into a sampling bag and then filling the bag with neutral air. The obtained samples were stored at fixed temperature and pressure, in order to guarantee measurement repeatability.
The samples were then analyzed by dynamic olfactometry for odour concentration determination, in order to make it possible to dilute them as to obtain samples at a concentration of about 300 ou_E/m^3.

2.2.3. Test method
The laboratory tests involved the training of the electronic nose EOS 507 with the samples of pure compounds and with neutral air.
The data relevant to such measures where analyzed by PCA in order to evaluate the instrument capability to discriminate the analyzed samples. Then, samples of pure compounds with a given concentration were analyzed by electronic nose. The classification and quantification of those samples performed by the instrument were evaluated.

2.3 Field test

2.3.1. Field test aim
The monitoring had the aim to evaluate the performances of both instruments on field. The instruments were employed in order to determine the odour exposure in ambient air in an area where several industrial activities are present. More in detail, an oil mill and two waste treatment plants were considered as possible odour sources.
After a specific olfactometric campaign, the electronic noses (four EOS 507 and one EOS 835) were trained with samples collected at the above mentioned plants as to be representative of their odour emissions.
These instruments were then positioned on field, at the boundaries of the plants being studied and at specific receptors, for a 10 days period (Figure 1).
The data collected by the electronic noses were opportunely processed and, together with the meteorological data relevant to the monitoring period, analyzed in order to determine the source of odour nuisance in the monitored zone.

2.3.2. Comparison EOS 835 vs. EOS 507

The comparison of the two different electronic noses involved the comparison of the different characteristics and functions, such as the training typologies, measurement frequency and the time required for data analysis. Then, the two electronic nose typologies were evaluated based on their capability to discriminate the odours tested, through application of PCA to the training data.

Moreover, cross validation was performed in order to verify the capability of correctly classifying unknown measures.

3. Results and discussion

3.1 Laboratory tests

The training analyses of the samples of pure compounds at different concentrations were analyzed by PCA. This analysis proved the EOS 507 to effectively discriminate the samples containing the three different compounds.

Then, specific tests were run in order to verify the electronic nose capability to quantify the odour concentrations of these samples. These tests were limited to limonene and ethanol, because the instruments turned out to be scarcely sensitive to dimethylsulfide.

As an example, Table 1 reports the results obtained with the limonene samples. In general, the system is able to estimate the odour concentration of the tested samples, with an error of about 10 % for samples with a concentration of about 300 ou_E/m^3. These results seem promising, and further experiments will be run for verifying the instrument capability of accurately estimating the odour concentration of extremely diluted samples (i.e. low odour concentrations) as well as for evaluating the influence of the training typology on the quality of the estimation.

Table 1: Real concentration and estimated concentration of the limonene samples

Real concentration [ou_E/m^3]	Estimated concentration [ou_E/m^3]
60	51
116	108
232	237
290	298

3.2 Field tests

3.2.1. Monitoring results

The results of the monitoring, for each of the electronic noses used, are reported in Table 2.

Table 2: Percentage of measures attributed to the different olfactory classes during the monitoring period

Air quality	EOS 835_25 Measures (%)	EOS 507_05 Measures (%)	EOS 507_12 Measures (%)	EOS 507_11 Measures (%)	EOS 507_13 Measures (%)
Neutral Air	80,6%	90,0%	91,9%	72,7%	70,9%
Unknown	--	2,2%	0,3%	24,6%	25,5%
Oil Mill	1,6%	6,1%	0,8%	1,4%	2,2%
WTP 1	17,2%	0,4%	0,1%	0,9%	0,2%
WTP 2	0,6%	1,3%	6,8%	0,5%	1,3%

Based on the monitoring results reported in Table 2 it is not possible to identify the plant that mostly contributes to odour nuisance in the monitored zone. This may be due to the meteorological conditions of the monitoring period, for which the prevailing wind direction was from South-East to North-West, i.e. in a direction unfavourable to the diffusion of the emitted odour towards the receptors where the electronic noses were installed (Figure 2).

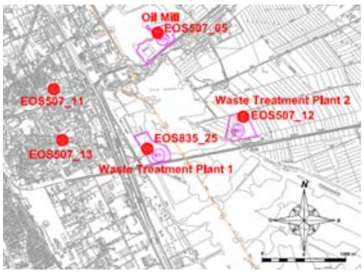

Figure 1: Position of the electronic noses

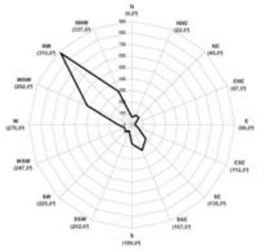

Figure 2: Rose of wind direction vectors relevant to the monitoring period

Moreover, it is possible to observe that a significant percentage of the measured recognized as different from neutral air weren't attributed to the considered olfactory classes, but they were classified as "unknown". This result indicates the presence, in the studied area, of other sources of odour nuisance than the ones considered during the training phase.

3.2.2. Comparison EOS 835 vs. EOS 507

It is possible to make some general considerations about the functioning of the different instruments used for the study.

First, as far as the instrument training is concerned, the possibility of analysing samples at different concentrations with the automatic dilution system of the EOS 507 significantly reduces the sample preparation times and therefore turns out to be very useful from the operational point of view.

As far as the features to be extracted from the sensor responses are concerned, the EOS 835 requires the calculation of several features and a feature selection for recognition optimization. This operation, which has to be done by an operator, makes the entire recognition process more complicated and subject to the operator's decisions.

Instead, the EOS 507 calculates only one feature for each sensor and directly performs the recognition of the sample air, thus reducing the times required for data processing and the influence of the operator on the recognitions.

Regarding the monitoring phase, an important difference is given by the frequency of the analyses: the EOS 835 performs a measures every 15 minutes, whereas the EOS 507 performs one record per second.

Moreover, the EOS 835 doesn't include the option to classify the measures as "unknown", and therefore always attributes an unknown measure to one of the olfactory classes considered during training. The EOS 507 has therefore improved the reliability of the recognition procedure.

In order to evaluate the recognition performances of the two instruments, the training data were analyzed by PCA (Figure 3 and Figure 4).

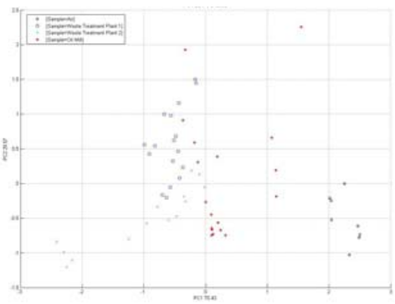

Figure 3: PCA of the EOS 835 training data

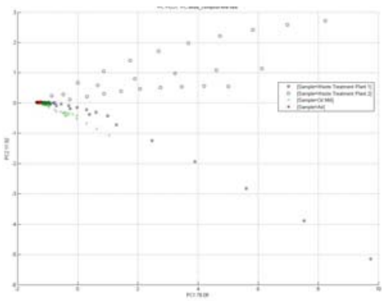

Figure 4: PCA of the EOS 507 training data

The reported PCAs proves the EOS 507 to be more effective in the discrimination of the olfactory classes being considered.
Moreover, cross validation of the training data of the two instruments was performed, whose results show a percent error of about 15-20 % depending on the analyzed data.
The observations resulting from this study prove that the innovations introduced in the EOS 507 improve the instrument characteristics in terms of easiness of use and odour discrimination capability with respect to the old EOS 835, thus making it more suitable for the continuous monitoring of environmental odours.

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