ENVIRONMENTAL ODOUR MONITORING BY MEANS OF ELECTRONIC NOSES: DEFINITION OF INSTRUMENTAL MINIMUM PERFORMANCE REQUIREMENTS

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ABSTRACT

The aim of this work is the definition of a specific protocol for the standardization of electronic nose performances for instruments to be considered suitable for environmental odour monitoring applications. The proposed protocol includes the definition of the procedures to evaluate such performances and the minimum criteria. The performances considered are the invariability of responses to atmospheric parameters (i.e., temperature and humidity), the instrumental detection limit, and the odour classification accuracy. The first phase of the work involved the identification of a limited number of pure compounds representative of a wide range of emissions, to make the procedure generalizable and reproducible. The second phase was based on laboratory tests to define reasonable performance requirements and their verification procedures.

Index terms– environmental monitoring, electronic nose, standardization, procedure

1. INTRODUCTION

The application of electronic noses to environmental odour monitoring is becoming more and more interesting, especially in cases where dispersion modelling is hardly applicable, in order to determine the exposure to odours directly where complained [1]. An electronic nose for environmental odour monitoring shall be able to continuously analyse the ambient air thereby detecting the presence of odours and classifying them, as well. The application of electronic noses to environmental odour monitoring entails some specific problematic issues, mainly associated with sensor stability and reliability, which is particularly critical when exposed to variable atmospheric conditions. One of the most critical limiting factors for the diffusion of electronic noses as environmental monitoring tools is the lack of specific regulation and procedures for the standardization both of the instruments and of their way of use. A first attempt of standardization of the instruments is proposed in this paper. Given the intrinsic complexity of electronic noses, standardization of the instrument hardware is less important than the standardization of the instrument performances, instead.

The aim of this work is to propose a standard procedure for the evaluation of the instrument performances, and further to propose a set of minimum requirements that an electronic nose to be used for environmental odour monitoring should comply with.

2. MATERIALS AND METHODS

2.1 General principles

Following performance characteristics shall be considered for the definition of requirements for an electronic nose for environmental monitoring:

- Invariability of responses to atmospheric parameters such as temperature and humidity;
- Instrumental detection limit;
- Classification accuracy.

It is fundamental both to define in detail the procedures for the verification of the instrument performances and to set minimum criteria for each characteristic. In order to evaluate the electronic nose performances, for each of the above mentioned characteristics specific tests shall be ran, each of them including the following three phases: (I) acquisition of a training data set; (II) acquisition of a test data set; (III) execution of specific recognition tests, thereby opportunely relating the test set to the training set for each requirement studied.

In general, a recognition test involves to perform the classification of a match set based on a suitable training set, giving that one recognition value, i.e. in the case of qualitative recognition an olfactory class, is attributed to every measurement of the match set. The attributed value (i.e. olfactory class) can then be compared with the effective olfactory class relevant to each measure.

Performance evaluation can then be based on the determination of a so called "Accuracy Index" (AI), calculated as the ratio between the number of measurements that were correctly classified and the number of total measurements. Minimum performance requirements can thus be established as minimum values of AI to be obtained in the recognition tests.

2.2 Identification of target compounds and sample preparation

The choice of the pure compounds is not trivial, since they must be representative of a wide number of plant typologies. The families of compounds that were identified as representative of environmental odour emissions based on an in-depth literature study (e.g., [2-3]) are: alcohols, aldehydes, ketones, terpenes, sulphur and nitrogen compounds. Table 1 shows the compounds suggested in the present procedure, including their chemical family, a description of their odour characteristics, and the type of emissions in which these compounds are typically present.

Table 1. Suggested compounds for the electronic nose performance evaluation

Compound	Family	Odour	Emission typology
Ethanol	Alcohols	Alcohols	Composting, Waste treatment, Biogas
Acetone	Ketones	Pungent	Composting, Waste treatment, Biogas
Limonene	Terpenes	Citrusy	Composting, Waste treatment, Decomposition of plants, Water treatment
Hydrogen sulfide (H_2S)	Sulfur compounds	Rotten eggs, Persistent	Landfills, Sugar mills, Water treatment, Sludge treatment, Anaerobic decomposition, Anaerobic digestion
Trimethylamine (TMA)	Nitrogen compounds	Rotten fish, Persistent	Water treatment, Rendering, Feed production

The methods for sample preparation are related to the nature of the compound, i.e. if the compound is liquid or gaseous. When dealing with liquids, samples are prepared by head-space technique. Reproducible samples can be obtained by controlling the temperature and considering the vapour pressure – temperature relation of the compound. When dealing with gaseous compounds, the samples are obtained by dilution of the original sample using an olfactometer or a pre-dilution pump.

3. RESULTS

3.1 Invariability of responses to atmospheric parameters

The training set (TS) shall comprise a minimum of 5 and a maximum of 15 different measurements for each compound. The odour concentration of the samples shall be comprised in a range between 80 and 1500 ou/m^3. The sample temperature (T) shall be fixed between 20°C and 30°C, while the relative humidity (RH) content shall be comprised between 50% and 70%.

The match set (MS) shall comprise a minimum of 10 and a maximum of 30 different measurements for each compound and for each different condition tested. The odour concentration of the samples shall be comprised in a range between 80 and 1500 ou/m^3.

A minimum of 4 different conditions shall be tested, considering two different test types: tests at fixed RH and variable T, and tests at fixed T and variable RH.

- Tests at fixed humidity and variable temperature:

$RH_{MS} = RH_{TS}$; $T_{MS} = T_{TS} \cdot (1 \pm y)$ with $0.1 < y < 0.25$

- Tests at fixed temperature and variable humidity:

$T_{MS} = T_{TS}$; $RH_{MS} = RH_{TS} \cdot (1 \pm y)$ with $0.1 < y < 0.5$

The recognition tests for the evaluation of the invariability of responses to temperature and humidity shall involve two different kind of tests. A first test considering the complete TS and a MS considering the measurements made at the same relative humidity as the TS, but at varying temperature, and a second test considering the complete TS and a MS considering the measurements made at the same temperature as the TS, but at varying relative humidity.

Two different result sets will be obtained, one for the tests at fixed RH and variable T, and one for the tests at fixed T and variable RH. This means that two different AI values will be determined, one for each test type. The minimum requirement entails that both AI values shall be at least 70%:

3.2 Instrumental detection limit and classification accuracy

The TS shall comprise a minimum of 10 and a maximum of 30 different measurements for each compound. The odour concentration of the samples to be analysed for the creation of the training set shall be distributed in a range between 30 and 1000 ou/m^3. This odour concentration range shall be divided into 5 intervals: 30-100; 100-200; 200-350; 350-600; and 600-1000 ou/m^3. Each interval shall comprise a minimum of 2 and a maximum of 6 measurements.

The MS shall comprise a minimum of 10 and a maximum of 30 different measurements for each compound. The odour concentration of the samples shall be comprised in a range between 15 and 250 ou/m^3. Also in this case, some indications are given regarding the odour concentration distribution of the samples analysed for the creation of the match set: at least 20% shall be comprised in the range 15-50 ou/m^3, and at least 20% shall be comprised in the range 50-100 ou/m^3.

The recognition tests for the evaluation of the instrumental detection limit shall involve one test for each compound considered. Each test shall relate the TS relevant to one given compound i to the MS relevant to the same compound i. This gives that, for each compound considered, the electronic nose shall classify the "low concentration" (15-250 ou/m^3) measures of compound i based on the "higher concentration" (30-1000 ou/m^3) measures of the same compound *i*. This means that, for each test, the electronic nose will attribute each measure of the MS either to the olfactory class *i* or to neutral air. The minimum requirement relevant to the instrument detection limit entails that for each compound, for c_{od}> 60ou/m^3, AI_{min}≥95%.

The recognition tests for the evaluation of the instrumental detection limit shall involve one single test relevant to all compounds considered. The test shall relate a "complete" TS comprising the TS relevant to all tested compounds to a "complete" MS comprising the MS relevant to all tested compounds. This gives that the electronic nose shall classify the "low concentration" (15-250 ou/m^3) measures of any of the compounds tested based on the "higher concentration" (30-1000 ou/m^3) measures of all the compounds tested. This means that the electronic nose will attribute each measure of the complete MS to neutral air or to any other compound considered. As an example, if considering the compounds suggested in Table 1, then the attribution of an Ethanol measure at 20 ou/m^3 may be recognized as Ethanol (correct recognition) or misclassified, i.e. attributed to any other olfactory class (neutral air, Acetone, Limonene, H_2S or TMA). One unique AI value will result from the recognition test relevant to the evaluation of the classification accuracy, representing the number of measurements that were correctly classified divided by the number of total recognitions. The minimum requirement relevant to the classification accuracy entails that this AI value shall be at least 75%:

4. CONCLUSIONS

This work gives a first attempt of a standard procedure for the evaluation of electronic nose performances specific for instruments to be used for environmental odour monitoring. The proposed procedure defines both the test methods and the minimum requirements in terms of invariability of responses to atmospheric parameters, instrumental detection limit, and odour classification accuracy,

5. FUTURE WORK

Further work will be required in order to verify the proposed method with different instruments. Other aspects could be introduced, as for instance the capability of electronic noses to quantify odour concentrations, and the capability of recognizing odour mixtures, for instance by quantifying mixing percentages. Also the effectiveness of the proposed minimum requirements will have to be further investigated.

6. REFERENCES

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