Advanced on-line monitoring at wastewater treatment plants: Coupling e-nose technology and modelling techniques

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Abstract: In this paper a novel on-line monitoring e-nose system for online monitoring of environmental odours at a wastewater treatment plant (WWTP) is presented, that combines a multi-chemical sensors array and a processing statistical and modelling tool for estimation of the odour level. Dynamic olfactometry analyses are used for model calibration, training and validation purposes in real field conditions. With the in-site implementation of the proposed system at the outlet of a deodorization unit a very satisfactory performance of the model was obtained being able to explain more than 90% of the variance of the data with a satisfactory fitting of the model. The results showed the potential of this novel measurement system for the on-line monitoring of odour emissions with different further applications including the identification of different gaseous atmospheres, odour events and finally for decision making purposes within WWTPs facilities.

Keywords: Odour prediction, on-line odour monitoring, wastewater

INTRODUCTION

Odours emitted by wastewater treatment plants (WWTP) are considered as the main source of complaints for local authorities due to the annoyance generate in the neighbourhoods. However, the complex nature and high variability of odours emissions from WWTPs, driven by operational and meteorological conditions, have made difficult to continuously characterize and quantify such emissions, evaluate nuisance odours and take remedial actions (Zarra et al., 2014; Gebicki et al., 2016).

Monitoring of air quality at higher temporal resolution is taking a key place in the new environmental regulations for air quality control objectives. Odour impact assessment should imply the quantification of the presence of odours: the time frequency with which the odour is perceived or when a given odour concentration is exceeded. From the techniques currently available for odour characterization and quantification (analytical, sensorial and mixed methods), special attention has been paid to mixed methods based on artificial noses (e-nose technology), which perform instrumentally the functions of human olfaction and have the potential to combine “the odour perception” and the “field monitoring” (Giuliani et al. 2013).

The e-nose technology is a multisensorial array system already mature in the food and cosmetic industry. The promising results obtained recently with e-noses in the industrial area, together with their low cost, encourage the application of this technology to the environmental field (Nicolas et al., 2012). Still, only few references are found concerning the continuous odour monitoring in the wastewater field needing to face important limitations associated with the properties of chemical sensors, the complexity and dynamics of the measurement environment, the signal processing performance and the real operating conditions in in-situ applications (Carrera-Chapela et al., 2014; Gebicki et al., 2016; Romain et al., 2016).

In this paper a novel monitoring e-nose system for online monitoring of environmental odours at a wastewater treatment facility is presented. The complete in-site implementation approach includes a multi-chemical sensors array combined with a signal processing tool to provide an estimation of the odour concentration and potential of odour nuisance. Regression and statistical techniques are used for quantitative odour level prediction and dynamic olfactometry analyses are used for model calibration, training and validation purposes. The overall aim of this study is to provide a fast, reliable and practical on-line monitoring system for detection of odour events, anticipate odour annoyance in the neighbourhoods and finally for decision making purposes within WWTPs facilities.

MATERIALS AND METHODS

Electronic Nose

The sensors-array developed by Odometric (www.odometric.com) is composed of six metal oxide semiconductor (MOS) gas sensors (Figaro inc., Japan) differing in selectivity and sensitivity. Specific solid state sensors have been selected for their cross-sensitivities, their preconized applications and the characteristics of the measurement environment. The sensors are placed inside a cylindrical PTFE chamber where a temperature and humidity sensors are also included. The continuously sampled air is passed through a gas conditioning system before being pumped to the chamber to reduce humidity negative effects. Specific software developed by Odometric is used to control the hardware and the acquisition of the raw sensor signals. Data are either processed on-line to provide an estimation of the odour concentration or downloaded for off-line processing. Figure 1 shows a simplified schematic representation of the e-nose system.

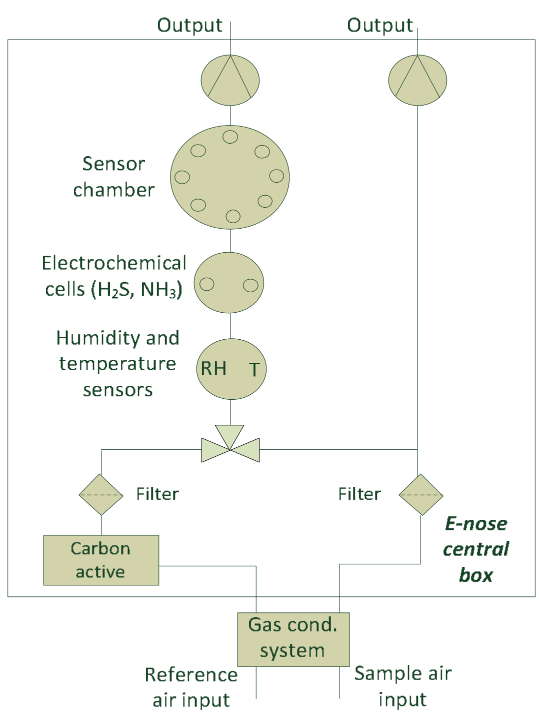

Figure 1. Schematic representation of the e-nose system

Several tests were carried out in a preliminary phase to evaluate the characteristics of the gas to be measured and select the suitable set of MOS sensors within the e-nose system. Such tests included gas samples for semi-quantitative measurement of NH_3, mercaptans, H_2S and odour concentration. A lab-scale e-nose system was also used to analyse different gas samples taken at different locations within the selected WWTP with the aim of characterizing the gas composition. Table 1 summarizes the final set of sensors included in the e-nose system. Two electrochemical cells sensitive to NH_3 and H_2S were also included.

Table 1. Set of selected sensors within the e-nose system

Sensor	**Type of sensor**	**Preconized application**
S1	MOS*	Detection of LPG gas, hydrocarbons, H_2, Alcohols
S2	MOS*	Detection of H_2, CO, SO_2, COVs
S3	MOS*	Detection of H_2, CO, COVs
S4	MOS*	Detection of LPG gas
S5	MOS*	Detection of alcohols and organic solvents
S6	MOS*	Detection of Ammonia
H2S	EC**	Quantification of H_2S
NH3	EC**	Quantification of Ammonia

*MOS: metal oxide semiconductor sensor
**EC : electrochemical cell

Odour level prediction

The gas sensors in the e-nose provide a signal when they are exposed to a gas mixture or odour inducing a change in their electric resistance from a reference level. The combination of such responses is called a “gas fingerprint” and describes the characteristics of the measured gas. A statistical regression model is then used to estimate the “level” of odour at the e-nose location as a linear combination of the sensor signals. The model is built and calibrated against a set of gas samples, collected at the measurement location, for which the odour information is extracted thanks to dynamic olfactometry analyses. Figure 2 summarizes the calibration process.

Compared to traditional approaches where calibration is done in laboratory conditions, the calibration is done in real field conditions. The odour samples are collected in polymer bags and analyzed within the 30 hours after the sampling (to preserve the measured environment characteristics) by a certified laboratory (http://www.labaqua.com). Each sample is passed also thorough the e-nose system to acquire information about the gas fingerprint and odour pattern. An important number of samples over the overall range of expected values (low and high odour concentration values) is required to avoid over-fitting of the model, take into account the high sensitivity of the measured environment and compensate intrinsic uncertainty of the odour analyses.

Statistical measures such as the coefficient of determination (R^2) and the root mean squared error of prediction (RMSEP) are used to evaluate the goodness-of-fit of the model. The valid model is then applied for on-line processing of the e-nose measurements to continuously estimate the odour level. Extra gas samples are used to evaluate the performance of the model in the long term and under different operational conditions and if needed, recalibrate the model for a better estimation.

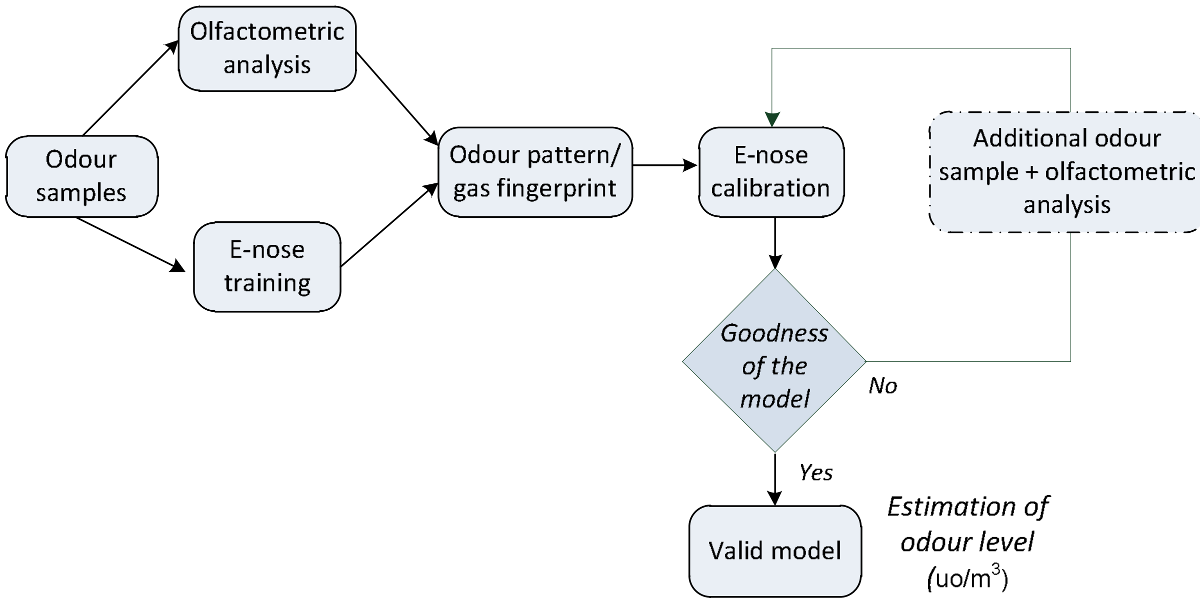

Figure 2. E-nose model calibration procedure

RESULTS AND CONCLUSIONS

The proposed approach has been implemented at the outlet of odour treatment unit (Figure 3) within an urban wastewater treatment plant with the objective of monitoring in real-time the odour emissions, anticipate possible nuisance odours periods and take corrective actions. The e-nose box was placed close to the deodorization outlet tower where two sampling point allowed to: (1) continuously measure the gas outlet within the e-nose system; and (2) take spot samples for dynamic olfactometry analyses used for calibration and validation of the model.

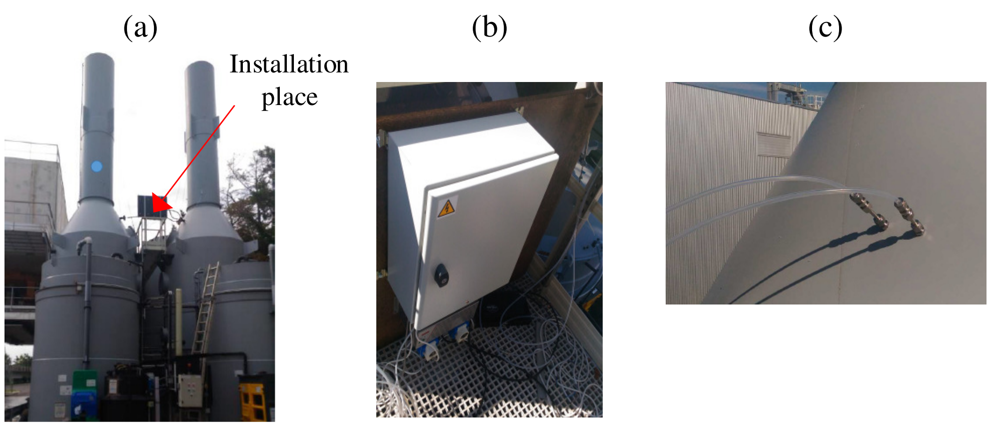

Figure 3. E-nose system in-situ installation: (a) Installation place at t, (b) e-nose equipment, (c) sampling points at the deodorization outlet tower.

The model building and calibration process needed to face different challenges including among others: the complexity of the compounds mixture encountered in the measured air, the variability of environmental factors (temperature, humidity, interfering gases, etc.) affecting the measurement system and the high variability of the odour concentration levels in function of the operational conditions at the WWTP. With the objective of covering a large range of odour level values and operational conditions a set of 18 samples, after removing of outlier samples, was used for model calibration purposes. Such set of samples included periods of high odour concentration values, due for example to a dysfunction of the deodorisation unit, and periods of low odour concentration values. Samples considered as outliers could answer to different reasons such as a mishandling of the gas sample, uncertainties within the olfactometry measurements, presence of interfering substances in the analysed gas, presence of highly odorous compounds at a concentration below the detection limit of the gas sensors in the e-nose system among others.

To improve the model representativeness, a signal pre-processing is applied to the raw data set to remove noise, possible outlier samples and standardise the response of each individual sensor. Each sensor signal is also corrected by the reference air to compensate the accumulative drift effect. Different criteria are used to evaluate the performance of the model and the goodness of the odour prediction including the coefficient of determination and the margin of error. Figure 4 shows the results obtained in the calibration phase and the quality of the prediction model for estimation of the odour level. An estimation of the odour level (ou/m3) is giving each 20 minutes in the current implementation. The error bars represent the 95% confidence interval of a measured olfactometry. A very satisfactory performance of the model was obtained, able to explain more than 90% of the variance of the calibration data, despite the inherent uncertainties of the dynamic olfactometry method used within the measured samples.

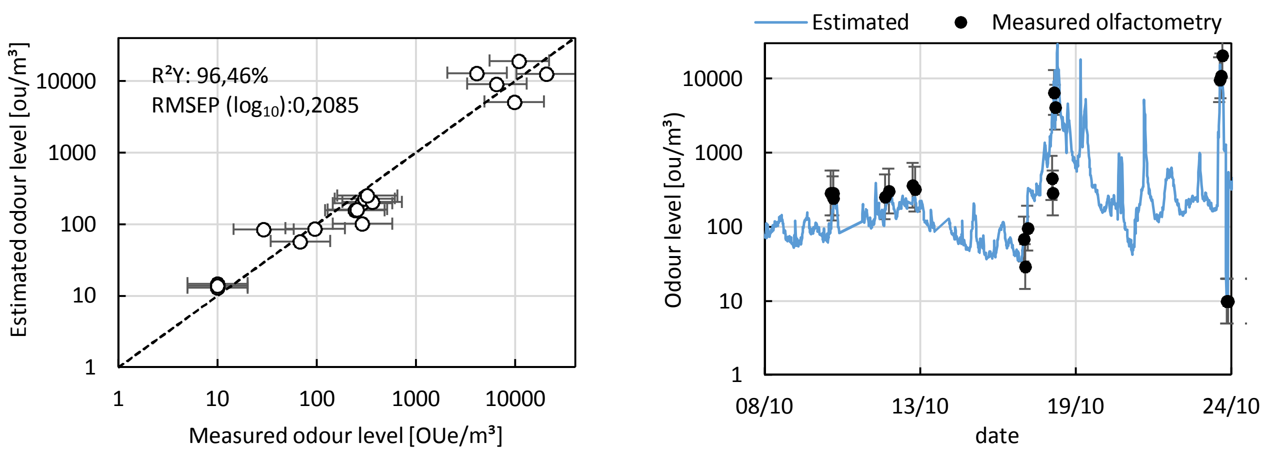

Figure 4. Model calibration phase. (a) Measured odour level vs estimated odour level, (b) Time series of the measured and estimated odour level

After the calibration phase the valid model was applied for on-line processing of the raw e-nose measurements for continuous estimation of the odour level. Additional samples were then used to evaluate the performance of the model in a longer term. Figure 5 shows the time series of the measured and estimated odour level for a representative five weeks period. A good fitting was also observed in relation to the validation samples with a satisfactory performance of the model. In general, the odour concentration values varied mainly between 100 and 500 ou/m^3 in normal conditions with periods of higher concentration values related to dysfunction of the deodorisation unit (episodes occurred on the periods October 24th – October 25th, November 13th – November 15th and December 13th – December 15th) or important changes in the operational conditions of the plant that generated higher odour concentrations (episodes occurred on October 26th and December 7th).

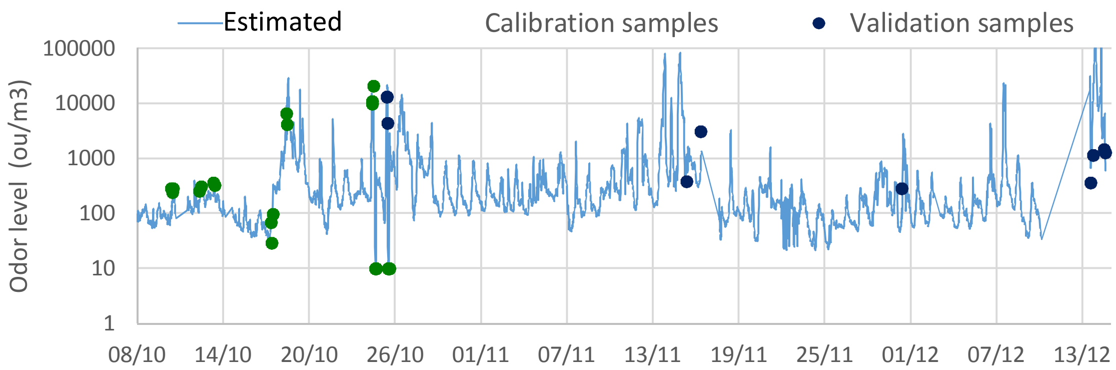

Figure 5. Time series of the measured and estimated odour level for a long period

The satisfactory results obtained with this first in-situ implementation show the potential of this novel measurement system that couples the use of a multisensorial array with statistical modelling techniques to provide a continuous estimation of the odour level. Further tests are envisaged to evaluate the behaviour of the system under different operational conditions and measurement locations, with the objective of, among others, analyse the effect of different gas fingerprints and the drift of the sensors response in a longer term operation. Several further applications within the WWTP operation can be envisaged such as the on-line monitoring of the odour emissions, the identification of different gaseous atmospheres, the detection of odour events, the detection of dysfunction of the odour treatment units and anticipation of nuisance odour episodes.

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