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Advances in Odour Monitoring with E-Noses in the Port of Rotterdam

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In the heavily industrialized and densely populated Port of Rotterdam odour nuisance is the second largest reason for complaints. The DCMR EPA has a control room that is manned 24 hours, 7 days per week. It receives on a yearly basis about 5,000-6,000 odour complaints of residents. One of the tasks of DCMR EPA is to investigate the cause of odour nuisance by field inspection with the human nose. Comon Invent has developed an online E-nose technology. Various industries are using this technology to monitor odours emitted of their own operations. DCMR EPA and Comon Invent co-operate in a long-term program in the port of Rotterdam to explore the potential of this technology. The target is to establish a real-time monitoring system which provides situational awareness about odour and air safety related issues. The program involves networks of electronic noses in the port area and the neighbouring residential areas. The data gathered by the e-nose data is processed and related to other information sources. Among them are odour complaints of residents, field observations of DCMR-inspectors and results of olfactometer laboratory testing. The olfactometry testing is performed in collaboration with VITO. This paper details some results of the program.

1. Industrial Odour in the Rotterdam region

The Port of Rotterdam is one of the world's major centres for oil and chemicals. Many of the world's leading oil and chemical companies are active in Rotterdam. In the port there are four world-scale oil refineries and more than 40 chemical and petrochemical companies. Three producers of industrial gases have set up operations in Rotterdam, as well as 13 major tank storage and distribution companies.

Inevitably the cluster of oil and chemical activities leads to odorous emissions. Since the petro chemical cluster is located in a dense populated region of the Netherlands the risk of odour nuisance is obvious. In case of a passing odour episode in the region, residents can report their complaints to the control room of DCMR EPA which is manned 24 hours, 7 days per week. One of the tasks of DCMR EPA is to investigate the cause of odour complaints by field inspection with the human nose.

The industry has taken many technical measures to improve the air quality in the last decades. Although progress has been made and the odour situation in the Rotterdam Region has significantly improved, the DCMR EPA still receives 5,000 – 6,000 odour complaints per year. Therefore, further reduction of industrial odour is still high on the agenda of all stakeholders in the Port of Rotterdam, authorities and industry.

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2. E-NOSE Technology

Comon Invent has developed an online e-nose technology. The e-nose is an instrument comprising an array of gas sensitive sensors. The e-nose responds when it is exposed to oxidizing or reducing gas mixtures. The sensor signals of all e-noses in the field are transmitted via an online data communication link to a database on a remote computer system. This database stores all raw e-nose readings. Each incoming e-nose reading is compared with known fingerprints stored in a knowledge base. A matching pattern means that there is a probability that this e-nose reading holds human interpretable information since the reference pattern was entered in the knowledge base as a result of a defined classification process. Hence we call the patterns in the knowledge base classified finger prints. The classification of finger prints in the knowledge base is a learning process based on multivariate input. Among the input sources are human observations that are recorded in the same place and time as the e-nose reading. This can be a perceived odour or reading on a gas detection device or the result of a laboratory test. For the classification the different input sources are combined.

3. E-NOSE Program

From 2005 DCMR EPA and Comon Invent have co-operated in several projects where the applicability of the e-noses has been demonstrated (Bootsma and Milan 2011, Bootsma and Milan 2010). One of the applications was an e-nose monitoring campaign at a petrol station in the Rotterdam Region in order to find the cause of a 18-y lasting hindrance situation. Another was a 3 months pilot project, aiming in establishing whether e-nose networks are a viable option as a pro- and interactive odour management tool in the heavily industrialized and densely populated Port of Rotterdam.

As a direct outcome of all promising e-nose project results, a 3 y e-nose research program has started in 2010. This research program has two main objectives. Firstly to investigate further the e-nose potential as an odour management tool for the DCMR aiming in reducing odour exposure and thus odour impact. Secondly, to investigate whether the e-nose can also be used as a safety management tool for DCMR gasexpert through a fast recognition of accidental gasses resulting in incidents. The e-nose potential as an odour management tool is discussed in this paper.

The following topics are part of the E-nose program:

Support of the DCMR control room in establishing an early warning system and thus to assist in faster and more effective tracing and tracking of unknown odour sources when residential complaints are reported.

Conducting e-nose monitoring campaigns around known odour nuisance related companies in order to examine the nuisance situation and thus trying to establish the cause of hindrance more effectively.

Statistical data analyses in order to investigate the correlation between e-nose observations and odour complaints, thus to prove the feasibility of an e-nose early warning system for odour incidents

Training of e-noses using the human readable information and pattern recognition programs: human readable information such as odour observations, made in the field as well in the laboratory, together with pattern recognition are being used to classify the readings of e-noses in odour groups like mercaptans, aromatic hydrocarbons, naphtha and crude oils etc.

3.1 Support of the DCMR control room

One of the aims of the E-nose program is to establish whether e-nose networks are a viable option as a pro- and interactive odour management tool in the heavily industrialized and densely populated Port of Rotterdam. To achieve this aim an e-nose network was established to carry out continuous (24/7) odour measurements in the Rijnmond area for a 2 year period starting in 2010. The network comprises 40 fixed and four mobile e-noses. 30 fixed e-noses are installed on lampposts around an industrial site as well as in the surrounding residential areas. The industrial site involved comprises a large oil refinery. These 30 e-noses cover an area of 10 km^2. In addition, also a set of 10 fixed e-noses are installed on several Air Quality Monitoring (AQM) stations of DCMR EPA. The mobile e-noses can be placed on the car of a DCMR EPA team which undertakes field investigations in case of odour incidents. A special dashboard was constructed providing the real-time status of the e-noses. This dashboard is operational in the control room of DCMR EPEA. Figure 1 demonstrates a presentation method of the e-nose readings that is being applied here. The location of the fixed e-noses are marked by a circle plotted on a Google Earth map. Four alert levels were implemented, white, yellow, orange and red. After clicking on an e-nose circle a box appears showing a graph of the readings of the last hour by default as well additional information about the situation. In this case apparently a high concentration of an unknown gas has been detected by e-nose BU-02. Two other e-noses in the same area were also affected by the passing gas.

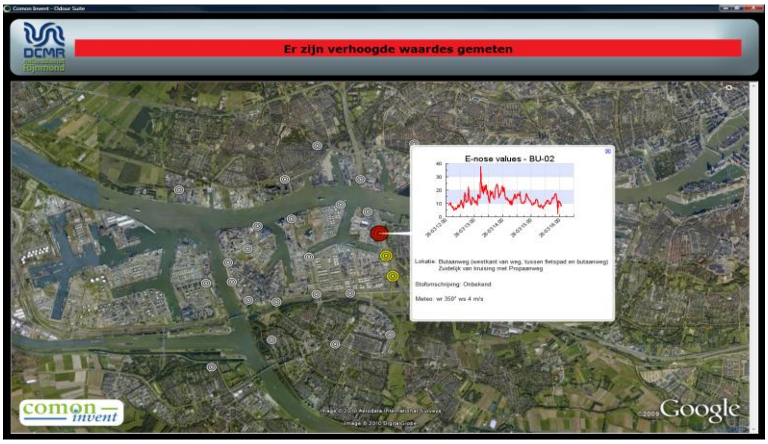

Figure 1: Dashboard implemented at the control room of the DCMR-EPA

At events where one or more e-noses went into alarm conditions, the system rendered a sound to alert the operators. In the case of red alerts inspectors of DCMR EPA undertook a field inspection at the suspected area. Relevant results of the field inspections are used in the classification process.

3.2 Conducting e-nose monitoring campaigns

In order to map the hindrance situation of specific companies with a long track record of odour complaints e-nose monitoring campaigns are being conducted by the DCMR EPA in collaboration with Comon Invent. For a period of usually 3 months a network of 6-10 e-noses is installed on and around a company to monitor 24/7 the emissions and the impact to the neighbourhood. The residents are given the opportunity to fill in their (mal)odour observations via a dedicated internet webpage. Continuous monitoring of odour emissions is an important advantage as it enables to find the specific cause of odour nuisance at the company.

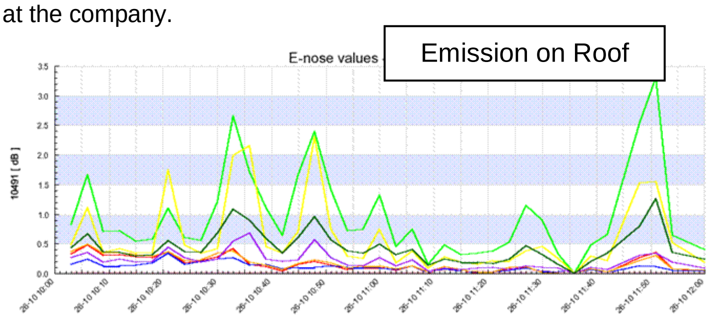

Figure 2: Emission recorded by an e-nose installed on the roof of the nut burner factory. Each line represents one sensor of the e-nose. The peaks correlated with odour observations made at the same time by a person standing on the roof

One of the monitoring campaigns, was performed in 2010 at a nut burner factory. The regular odour report, based on olfactometry and dispersion calculations, was not able to give a representative picture of the odour situation as it could not forecast the hindrance situation. A better representative picture was obtained by monitoring 24/7 the odour emissions of the nut burner factory. For this, e-noses readings had to be related to human odour observations of burned nuts. It turned out that a clear relationship was found on emission levels between odour observation on the roof of the factory and e-nose readings (see Figure 2). More important, also a clear relationship was found on emission levels between odour observations in the residential area and mobile e-nose readings (see Figure 3).

Figure 3: Emission recorded by a mobile e-nose in the residential area. Especially the green sensor reading correlated with human odour observation of burned nuts (red, orange, yellow, blue= intense, moderate, little and no smell).

3.3 Statistical data analyses

A second focus of the E-nose program is to identify if a reliable odour network can automatically warn when an odour incident might occur. A qualitative early warning system will alert the control room of the DCMR EPA so that the responsible company can take immediate action in order to keep the resulting complaints to a minimum. The public and private sector share a mutual interest in such a system: residents suffer less from odour nuisance in this heavily industrialized area, and companies can improve their public image where odour nuisance is concerned. Thus the goal of our statistical data analyses is to investigate correlation between the e-nose observations and the human observations.

The first statistical data analysis was performed on the “old”dataset of the 2008 network. The 2008 network comprised ten fixed noses installed on to the Air Quality Monitoring (AQM) stations of DCMR EPA which are located in the Rijnmond region where most of the complaints are registered. The network covers a total area of 50 km^2. All odour nuisance complaints registered by the control room of DCMR EPA were compared with observations of the e-nose network. Using several data filtering steps, the end results showed that with this coarse e-nose network 77 % of the reported odour complaints had a positive match. A second statistical data analysis was performed on a combined e-nose dataset for a 4 months period in 2009. The dataset consists of 10 DCMR EPA owned e-noses and 8 industrial owned e-noses around an oil tank terminal. This second analysis showed the advantage of a dense network with respect to a coarse network as more than 90 % of the reported odour complaints had a positive match with the e-nose readings.

3.4 Training of E-nose

Several methods are applied to optimize the sensitivity of the e-noses. The results of these methods are entered in the knowledge base.

Method 1 : **using reported odour complaints**

The first method is to compare the e-nose patterns or fingerprints with odour complaints. Figure 4 (left) shows the result of a typical e-nose reading that is stored in the knowledge base. It is the fingerprint that was assigned to odour complaints. It was found that in many cases the e-noses observed this pattern in odour nuisance events where people described the odour as unpleasant oil related odour. This pattern has been recorded in several similar events (see for example Figure 4 (right)).

Figure 4: Human perceived odour complaints assigned to e-nose readings (left) and proof-of-principle: All e-noses inside the complaint plot observe the same finger print. The others don't (right)

Method 2: using odour observations of experts
A second method to generate fingerprints is to use an e-nose with a GPS receiver. Experts can take the mobile e-nose on their odour inspection sessions. A smart phone is applied to enter the human odour perception. The previous shown Figure 3 gives a good example of this training method.
Method 3: using lab analysis of head spaces of liquid samples
A third method to generate fingerprints is to expose the e-noses to known gases under laboratory conditions. The graph in Figure 5 shows the raw e-nose data of an e-nose that was exposed to the headspace vapour of four petrochemical liquid samples.

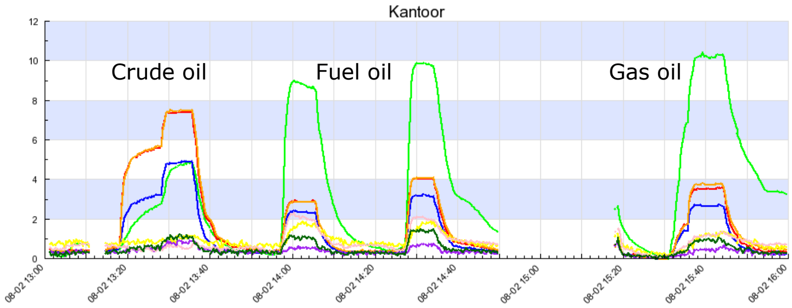

Figure 5: response of the e-nose to four petrochemicals. Each line represents one sensor of an e-nose.

A cluster analysis of this raw data of the e-nose resulted in the definition of three fingerprints (Figure 6):

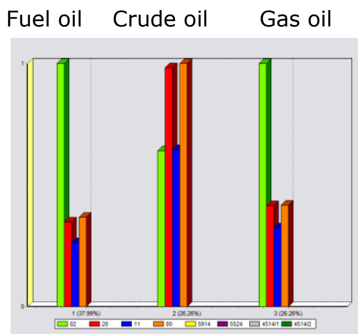

Figure 6: Fingerprints of Fuel oil, Crude oil and Gasoil

Method 4: using olfactometric analyses

A last training method is the laboratory training by means of olfactometric analyses. The picture and graph below (figure 7) show an experimental set-up where an e-nose replaced a panellist during an olfactometric measurement. The panel was exposed to different concentrations of H_2S and methyl mercaptan. In this experiment the e-nose demonstrated a stable and reproducible output signal for both gases. Sensor responses at lower concentrations were observed in this experiment, but at a very low signal-to-noise ratio of the e-nose. Similar tests were performed with field samples of different industrial plants.

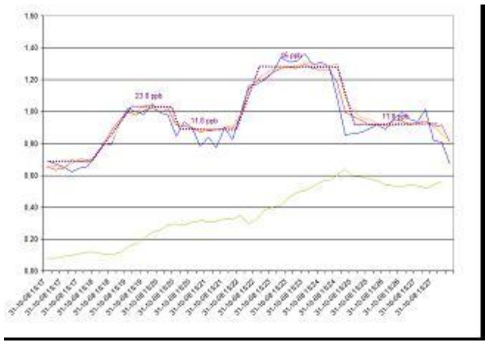

Figure 7: E-nose training with olfactometric analyses: e-nose replace one panellist during an olfactometric test (left), e-nose results for methyl mercaptan (right)

4. Conclusions

The results of the research program so far are promising. The machine learning process of the e-noses is growing. Appropriate matches between field observations, lab tests and human odour perceptions are found. In the coming years further development of the knowledge base and incremental improvements to the system will mature the e-nose technology as a toolbox for online odour and safety management

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