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Odour monitoring with e-noses in the Port of Rotterdan

Simon Bootsma*, Bianca Milan**
*Comon Invent BV
PO Box 39, 2600 AA Delft, The Neterlands
**DCMR Environmental Protection Agency
PO Box 843, 3100 AV Schiedam, The Netherlands

In the heavily industrialized and densely populated Port of Rotterdam odour nuisance is the second largest reason for complains. 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 from residents. One of the tasks of DCMR EPA is to investigate the cause of odour complaints by field inspection with the human nose. Comon Invent has developed an online e-nose technology for the evaluation of odour plumes in the field. DCMR EPA has employed this technology during an one year pilot study in order to investigate its feasibility to evaluate odour emissions originating from several petrochemical industries in the Port of Rotterdam. The technology has demonstrated a good potential to become a proactive Odour Management System. This presentation details the outline and some results of a research project that was carried out in the port of Rotterdam for one year. The project involved a temporarily installation of networks of electronic noses in the Rijnmond area which carried out continuous measurements under ambient air conditions. The electronic sensor data was evaluated in relation to odour complaints which are reported at the EPA control room and metrological information. A numerical data analysis was carried on electronic sensor data, metrological data and residential odour complaints. The main research questions of such a data-analyses reads: can a network of electronic noses be used for the automated detection and distribution of odour plumes? The analysis showed promising results. DCMR and Comon Invent have therefore decided to start a second pilot project in 2010. The first pilot project was performed with a coarse network of 10 online e-noses in an area of 50 km^2. In the second pilot project a dense network of 30 e-noses will observe an industrial area of 10 km^2.

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.

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Inevitably the cluster of oil and chemical activities leads to odorous emissions. Since the petrochemical 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 complaint 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 annum. Therefore, further reduction of industrial odour is still high on the agenda of all stakeholders in the Port of Rotterdam, authorities and industry.
In a further attempt to reduce the number of odour complaints in the Rotterdam Region the DCMR EPA has investigated the possibilities of online odour monitoring technology. The research on online e-nose monitoring in the Rotterdam Region is focused on primarily immission monitoring. The main research target was to investigate if Artificial Olfaction with a large number of distributed network of e-noses is a viable option for the establishment of an early warning system for malodours. Ideally the system will be adopted by the industry as a tool to nip in the bud accidental odour emissions.

1.1 Online odour monitoring

The approach of online odour monitoring allows for continuous measurement of airborne chemicals and other environmental parameters such as wind direction and speed. Online monitoring can be a promising tool for real-time odour nuisance monitoring. The online monitoring technology that Comon Invent has developed is based on the principle of Artificial Olfaction (AO). An array of broad spectrum gas sensors are continuously exposed to the ambient air. The electrical output signals of all the sensors in the array are simultaneously read-out and converted to a digital signal. This sensor array and the instrumentation electronics are mounted in an enclosure which is called the e-nose. The input-data for the AO-system is mainly provided by e-noses, weather stations and olfactive data such as odour complaints. This input-data is transferred to a remote back-office server via a wireless GPRS-link. Next, the input-data is processed on the server and transferred to human interpretable information about the odour situation at the monitored location. All the input-data and real-time processed information is online accessible.

The applied e-nose comprises four semiconductor gas sensors. This standard array of four semiconductors sensors has been shown to be well suited for continuously monitoring different types of industrial odours like landfills, waste water treatment plants, petrol stations, refineries and a oil terminals. The principle of operation of a semiconductor gas sensor is based on a surface reaction. A thin layer of stannic oxide is deposited on a alumina substrate with an embedded heater. A change in the sensor resistance is a measure for a change in the air composition around the e-nose. The sensor resistance is non-linear and is very sensitive in very low concentration ranges.

The semiconductor gas sensor is able to detect chemical airborne concentrations from ppb level. Each sensor reacts differently to a certain gas or gas mixture. Together the four sensor signals create a finger print of the gas sensed by the e-nose. Pattern recognition techniques can be used to compare an unknown finger print with known finger prints stored in a database. In this way the e-noses can be "learned" to distinguish odorous petrochemical vapours from manure or sewage gas or from toluene.
The research on online e-nose monitoring in the Rijnmond is focused on immission monitoring. It is founded on the endeavor of the DCMR EPA and Industries in the Port of Rotterdam to reduce the number of odour complaints in the Rijnmond. The main research target was to investigate if Artificial Olfaction with a large number of distributed network of e-noses is a viable option for the establishment of an early warning system for malodours. Ideally the system will be adopted by the industry as a tool to nip in the bud accidental odour emissions.

2. E-nose projects in the Rotterdam region

From 2005 DCMR EPA and Comon Invent have co-operated in projects where the applicability of the e-noses has been demonstrated. One of the applications was a monitoring campaign of a petrol station in the Rotterdam Region in order to find the cause of a 18-years lasting hindrance situation. For a period of three months a network of 6 e-noses was installed on and around the station to investigate the emissions to the neighborhood. The residents were given the opportunity to fill in their (mal)odour observations via internet webpage The results showed a clear relations between the hindrance of the residents and the emission of the petrol station. However, it was also noticed that e-nose network observed passing odour plumes that were clearly emitted from other sources in the region. All these findings aroused the interest for an area covering network of online e-noses that monitors the raise and spread of industrial emissions in the whole Rotterdam Region.
In September 2008 an important milestone was established by the start of a 3 months pilot project. The aim of the pilot project was 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. The network comprised ten fixed and two mobile e-noses. The fixed systems were installed on to the Air Quality Monitoring (AQM) stations of DCMR EPA which are located in the Rijnmond region where most of the complains are registered. The network covers a total area of 50 km^2. This includes the urban area of the Rotterdam Region that is located at the prevailing wind direction below of a large area of the petrochemical complex of the Port of Rotterdam. The mobile e-nose could be placed on the car of a DCMR EPA team which undertook field investigations in case of odour incidents. During the pilot project odour nuisance complaints registered by the control room of DCMR EPA were compared with observations of the e-nose network. The results showed, amongst others, clear "visual" correlations between the sensor readings and perceives odour by residents. From the 3-months pilot it was concluded that the online odour monitoring system has potential to become an Early Warning

System. Because of the high potential and to facilitate the subsequent statistical data-analyses step it was decided to continue the online odour monitoring with e-noses.

The next milestone was the start a desktop study for a statistical data-analyses in Q4 2009. For more than one year a database was filled with unverified recordings of all ten e-noses with an interval period of three minutes. Next to the e-nose data the meteorological data of five weather stations is stored in this database. Thirdly all complaints that are recorded by the control room of the DCMR are stored in the database. In Q4 of 2009 an intensive data mining process has been performed on this large dataset. Below the findings of this data-analyses step are discussed further.

The latest milestone was the start of new pilot project in April 2010. During this project 30 additional e-noses were installed around an industrial site as well in the surrounding residential area. The industrial site involved comprises a large oil refinery. A significant difference between the 2008 and the 2010 project is that in the latter the human correlation is predominantly from the DCMR experts whereas in 2008 the human input came mainly from annoyed residents.

3. Statistical data analysis

The statistical data analysis started with data mining process has been performed on this large dataset. The goal was to investigate the e-nose observations and the human correlation. The mining was performed on the dataset of all ten e-noses over a period of one year. With an interval of 3 minutes the database holds 60,000 e-nose records per month and almost 6,000 odour complaints.

The events where e-nose observations and human correlation can be investigated are relevant. Therefore the first step was to filter the dataset. The picture below demonstrates the filter mechanism including the empirical filter settings. The assumption was that the emission source was located in a circle with a range of 1 km having its origin 5 km upwind from the e-nose. The relationship between the e-nose observations and the complaints found in the area between two borderlines starting in the centre of the alleged source circle with an angle of 22.5° towards the wind axis was investigated. In the picture the red bar represents an e-nose that recorded an event. The phones are the locations of the callers reporting a complaint to the DCMR EPA.

The result was that with this e-nose network 77% of the reported odour nuisance had a positive match.

3.1 The training of e-noses with residential odour complaints

The next step was to train the e-noses to the complaints. Therefore the raw data of a part dataset of the e-nose recordings around positive results were analyzed using a numerical pattern recognition algorithm.

The numerical data processing results in distinctive e-nose patterns calculated by a component analysis. These patterns are compared to the description of the odour complaints. If a e-nose pattern matches to the typical description of the complaints, for example ‘oil based odour’ then this pattern will be stored in the knowledge base. This knowledge base is part of the olfactive memory of the AO-system.

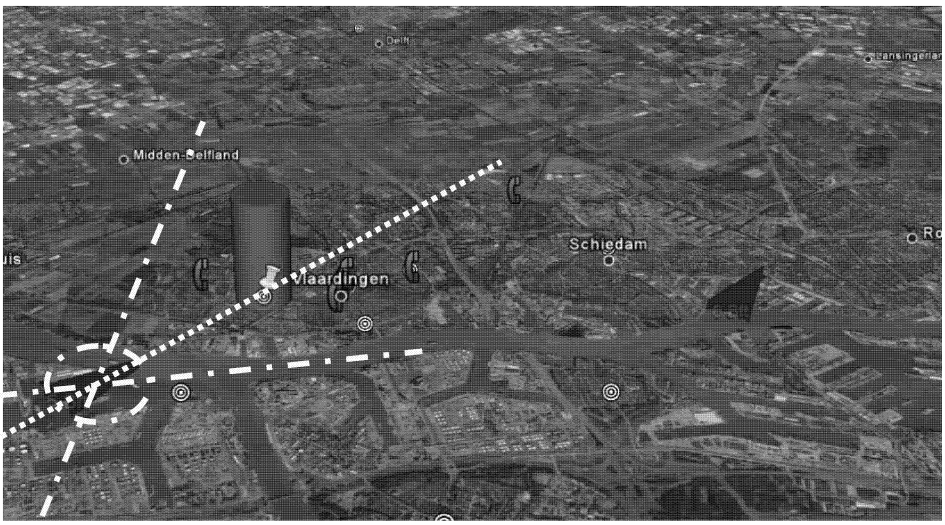

Figure 1. An e-nose observed a certain pattern when residents complain.

The e-nose pattern demonstrated in the picture above was labeled to an odour. The pattern is stored in the knowledge base. When other e-noses observe the same pattern they probably also ‘smell’ the same odour. Hence they can trigger an alert in the case they sense a malodour. This is plotted in the screenshot below.

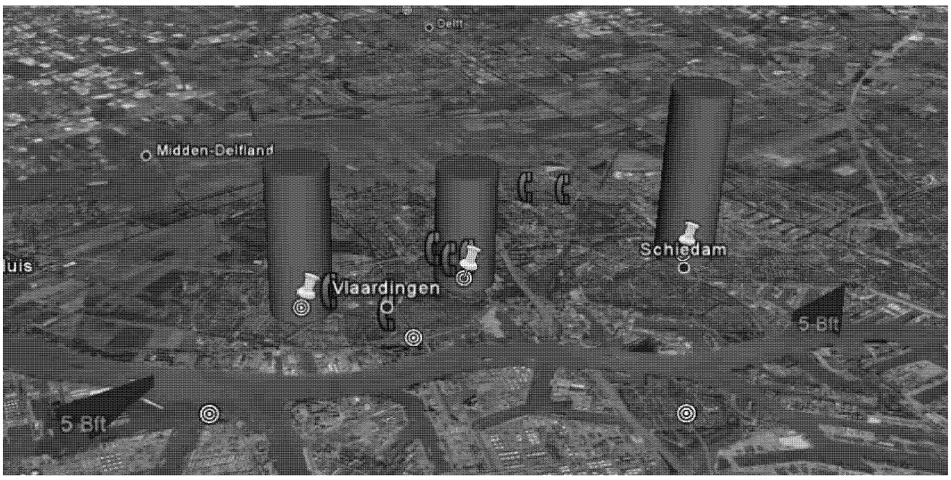

Figure 2. Malodour observed by three e-noses in a plume .

4. Conclusions and future work

The proof-of-principle with online e-noses in relation to odour complaints has been demonstrated in the project that was carried out in 2008/2009. A large area of 50 km^2 was observed with 10 e-noses which formed a coarse grid. The relation between e-nose recordings and human input came mainly from annoyed citizens.

In 2010 a second stage of the e-nose project was started. Now 30 e-noses are installed in an area of 10 km^2. Also 3 mobile e-noses are used by field inspectors of the DCMR. Now the human correlation will come from the DCMR experts as well from citizens.

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