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MOX Sensor Platform in Outdoor Odor Nuisance Monitoring

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Abstract

Citizens of the Warndt region, part of the Saarland, Germany, have been complaining about odor nuisances for years. However, the source could never clearly be identified as several sources are possible. In a current project, several gas sensor systems based on highly sensitive but low cost metal oxide gas sensors have been deployed in the region to assess their potential for odor nuisance monitoring. Temperature cycled operation mode allows the use of pattern recognition for identification of specific odors. In parallel, a citizens' network has been established to provide reference data for training of the sensor network.

Results from a first monitoring period covering three months indicate that the sensor systems might be a suitable solution. However, further improvements in sensor sensitivity and calibration of the sensor systems with the citizens feedback are required for routine application.

Key words: metal oxide gas sensor, temperature cycled operation, outdoor air quality, odor nuisance monitoring, citizens network

Introduction

Entering the outdoor odor monitoring domain was motivated by sustained complaints from residents of the Warndt region, which is a large wooded area with a number of small villages on the German-French border. Recurring odor nuisance problems were reported and attributed to a petrochemical plant in Carling/France. As pollutant monitoring by the public authorities shows that the annual average limit values are not exceeded, efforts to objectify the situation were realigned to assess odor nuisance by technical means. As there is currently no technology available to monitor and identify general odors in a spatio-temporal manner, the nature and severity of the exposure is difficult to evaluate by the authorities. In a current project, a number of sensor systems based on highly sensitive but low-cost metal oxide (MOX) sensors were deployed in the region. In parallel, a citizens network has been established to provide an online human odor reference via a website where registered volunteers were invited to report observed odors twice a day. The first goal of the project is to establish if the sensor system which has been tested in the lab at (sub-)ppb VOC concentrations [1] is sufficiently sensitive to detect relevant odor events. Based on advanced signal analysis of the sensor response patter obtained from temperature cycled operation (TCO), the partners plan to map observed odor exposures and verify them by additional environmental data, especially wind direction and speed for source attribution. MOX sensors operated in TCO mode [2] have previously proven their suitability for odor monitoring allowing good correlation with human sensory panels [3] and multisensor systems have been used for environmental monitoring [4]. This report covers the first three-month monitoring period from October 2014 to January 2015. The project was performed on behalf of Saarland's Ministry of Environment and Consumer Protection and was supported by various Warndt municipalities and the citizens initiative "Saubere Luft für die Warndtgemeinden e. V.".

Sensor system setup

As previous experience of the partners mainly covers equipment for laboratory use, industrial applications and indoor air quality, the particular requirements for stand-alone outdoor systems had to be assessed in the beginning of this project. In order to achieve maximum flexibility in MOX sensor operation, electronics from the MNT-ERA.net project VOC-IDS were adapted. This platform – developed for indoor air quality field test experiments – allows for independent control and read-out of two MOX sensors, both of which are mounted separately on a sensor-specific carrier PCB that also hold calibration information so that they can be easily exchanged in the modular system. The main PCB contains all necessary control circuitry – microcontroller with SD card for configuration and data collection, real-time clock, power supply, heater control – as well as interfaces to a CO_2 NDIR module and a combined temperature and humidity sensor [5].

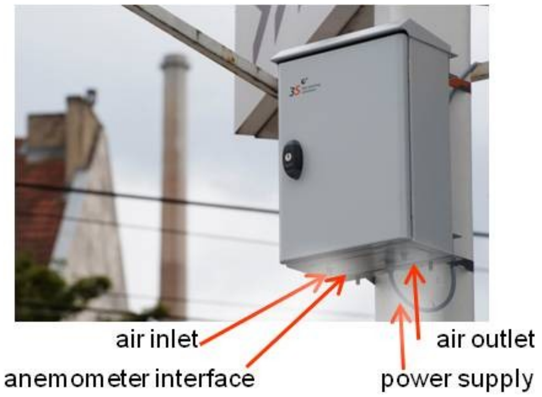

Fig. 1. Sensor platform for outdoor monitoring

The electronics part is enclosed in a double metal housing to withstand influences of weather and vandalism (cf. Fig. 1). Therefore, a pump had to be introduced for active gas transport to the sensors whereas the systems for indoor air quality monitoring are based on gas diffusion only. A fiberglass tissue filter is attached to the air inlet to keep out dust, insects and water droplets, cf. Fig. 2. Along with an interface option for a local anemometer with wind vane as well as battery backup for intermittent power supplies (including street lights and solar panel operation), all technical requirements for the field test of TCO MOX sensors are met.

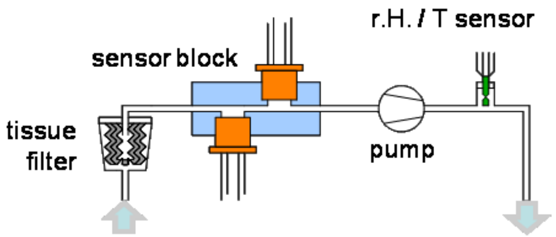

Fig. 2. Pneumatic diagram of sensor system

Sensor system setup and data evaluation

The sensor platforms are equipped with two sensor boards each, with an AS-MLV (ams Sensor Solutions GmbH, Reutlingen, Germany) and a GGS 1330 (Umweltsensortechnik GmbH, Gschwenda, Germany) sensor, respectively. Temperature cycles have durations of 20 s (AS-MLV) and 120 s (GGS 1330) covering temperature ranges from 150–350 °C and 200-350 °C, respectively, in discrete temperature steps. Sensor conductance is recorded every 10 ms.

Based on previous experience, in the current approach of the data analysis, 14 features are extracted from each temperature cycle by dividing the cycle into 5 sections, cf. Fig. 3, and determining the mean and slope of each section as well as the relative differences between sections. These feature vectors can be plotted, e. g. using Linear Discriminant Analysis (LDA) for classification of different odor events identified by the citizens network. For further analysis, the sensor data can also be evaluated without using the panel reference, e. g. using non-supervised techniques like Principal Component Analysis (PCA) or by simply plotting the sensor signal at various temperatures over time to detect high and low gas concentrations.

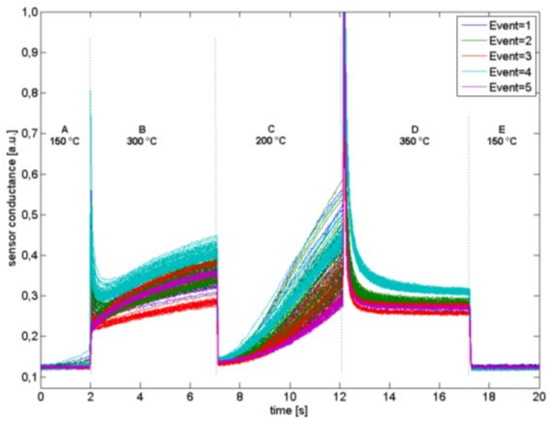

Fig. 3. Sensor response of an AS-MLV type MOX sensor during 5 reference events

Sensor deployment

The sensor systems were deployed in the Warndt region at six locations as shown in Fig. 4. These locations were chosen so that there are several members of the citizens network in the immediate neighbourhood. This allows for “training” the sensor systems according to odor observations of the local residents. All sensor systems are mounted on building walls or posts at approx. 2 m height with an clear area around and distant from local odor sources, i. e. roads. The distance from the suspected odor source is approx. 3–8 km.

Citizens network

In an initial poll which also assessed the nuisance situation in the targeted area, citizens of the Warndt region were asked for their willingness provide odor observations twice a day over a period of at least three months. For those volunteers, a website was set up allowing the participants to provide their observations online by noting the observed odor character, nuisance and intensity along with the observation time. Locations are provided implicitly as the participants log into the website with individual accounts and only report from their place of residence as defined during registration. In an information event, all 50 residents who had expressed their interest were informed about the project and its goals and trained in the use of the website. Eventually, 35 residents participated in the survey, but their activity decreased somewhat over the project period. By mid-January a total of 3105 observations were recorded over a period of 103 days; ideally, 7210 observations would have been expected.

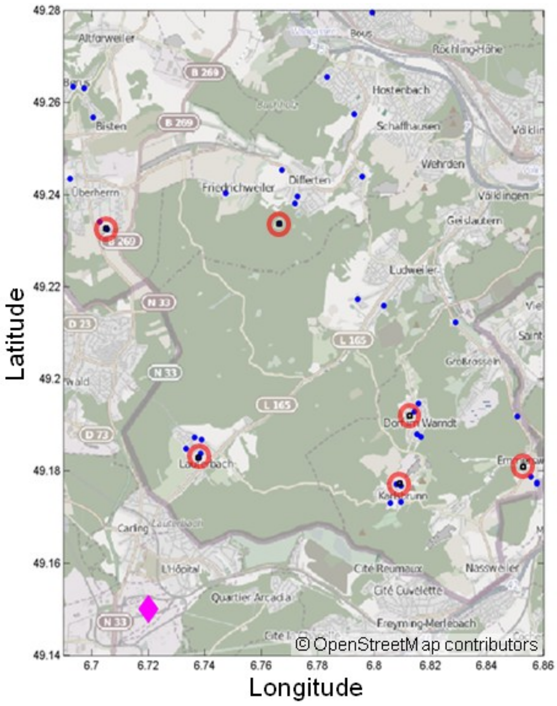

Fig. 4. Map of the Warndt region showing the installation sites of the sensor systems (red circles), residences of citizens network participant (blue dots) and alleged odor source (pink diamond), the maps shows a region of approx 11 by 14 km²

Data analysis

As a first step of the data analysis, the reports from the citizens network were screened in respect of plausibility. Wind direction was taken into account as an ancillary criterion, i. e. wind at considerable speed coming from north or east should rule out the suspected odor source in the south-west for the related period of time. With this approach, about 155 reports were left with odors of a character – “pungent sweet”, “pungent chemical”, “burned plastic” – that could stem from the Carling source. The next step was to look at temporal clusters in the relevant odor reports, along with their spatial distribution to identify “target odor events”. In order to obtain a training data base, consistent reports of no perceptible odor over the whole area were identified as “no odor events”. Taking into account the possibility of other relevant odor sources, the data was also screened for significant “other odor events”.

For all three types of event, sensor data were selected from the relevant periods of time. The sensor response features were extracted and processed by a LDA to check if a separation of the different events was feasible.

First Results

In total, only two consistent “target odor events” could be identified from the citizens network data. They were contrasted by two “no odor” events selected with proximity of time as well as one distinct “other odor” event for the subsequent LDA processing.

Fig. 5 shows a LDA plot for all five events, each circle represents one 120 s temperature cycle of the GGS 1330 sensor. Overall separation of the events is found to be insufficient. This can be attributed to two main reasons: Firstly, 120 s is quite a long sampling time for a passing odor plume; secondly, the large thermal time constant of the GGS1330 limits the application of fast TCO in order to increase selectivity and sensitivity.

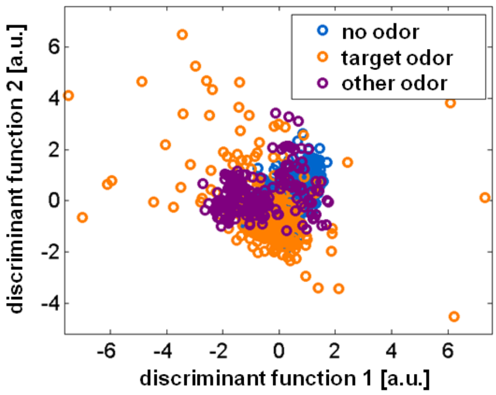

Fig. 5. LDA plot with insufficient separation of zero, target and other odor events obtained from the response of a GGS 1330 sensor at installation site “Dorf im Warndt”

However, results derived from the micro-hotplate based AS-MLV as shown in Fig. 6 appear much more promising. A fair separation of one “target odor” and one “no odor” event can be found, in combination with a distribution along discriminant function 1 (DF1). Although separation of the three events around DF1 = 0 is not as clear as with the others, a consistent tendency can be found from DF1 = 2 (no odor) to DF1 = −4 (target odor). Although the same tendency is also found in the AS-MLV sensor responses from other measurement sites (cf. Fig. 7), speculation about further correlations and implications has to be put aside until additional data with a sufficient number of odor events will be available for evaluation.

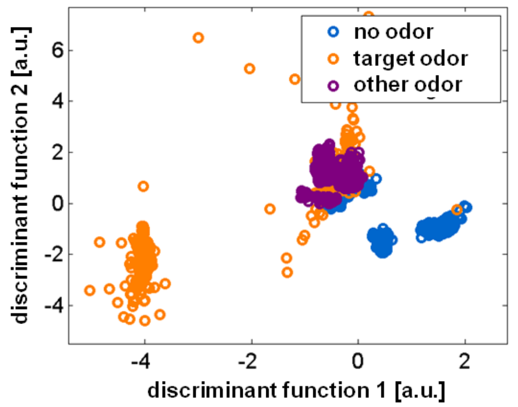

Fig. 6. LDA plot with fair separation of zero, target and other odor events obtained from the response of an AS-MLV sensor at installation site "Dorf im Warndt"

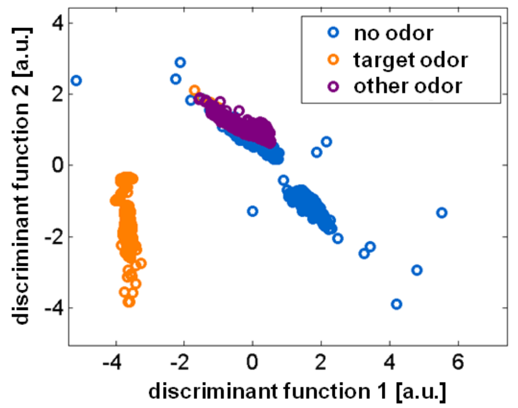

Fig. 7. LDA plot with fair separation of zero, target and other odor events obtained from the response of an AS-MLV sensor at installation site "Karlsbrunn"

Conclusion and outlook

In the context of this specific odor monitoring project, results from a first evaluation show that it is feasible to separate odor events from general background air even in remote residential areas. In order to set up a stable method and algorithm that could be used for continuous technical odor monitoring purposes – let alone odor quantification – too few reference events were reported by the citizens network. Therefore, a second observation and measurement phase was started in April 2015 with stronger participation from the citizens network and two additional sensor installation sites, one of which is on French territory near the petrochemical plant that is the suspected odor source.

Regarding the sensor systems, no severe technical issues have been encountered since the start of the deployment in October 2014 throughout the seasons. The modular approach has proven to provide easy maintainability, although this feature has only been used once for a planned checkup on calibration. Filter replacement, data collection and TCO reconfiguration via SD card change is a matter of minutes on-site. Due to the proven reliability, the sensor systems will shortly be updated with a wireless data interface for online data collection.

Planned projects include use of this online data interface for real-time odor monitoring, augmented by pertinent graphic representation. Data interfacing with a geographic informational system is considered to be a valuable tool for providing integrated services.

Other ongoing projects exploit the experience gained in outdoor odor assessment for emission control purposes. For those applications, the systems are equipped with dilution and sampling units to cope with special process atmosphere issues like saturated humid air at high temperatures, large concentration peaks and acidic components.

Acknowledgements

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