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Field Calibration Strategies for Methane Monitoring with Electronic Noses

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Summary:

The practical application of chemoresistive gas sensors is hindered by expensive calibration equipment and uncertainty about their performance under non-steady-state conditions outside laboratory facilities. To address this situation, we have developed a calibration method that reduces costs and, tailored for field applications, reports concentration with low error measures. We focus on methane case studies, although the method can be extrapolated to other scenarios, detailing how the type and amount of available data affect outcomes and reliability.

Keywords: field calibration, chemical sensors, metal oxide, electronic nose, machine learning

Headlines

Chemoresistive sensors can monitor specific gases thanks to advanced data processing techniques. However, these techniques usually rely on laboratory calibrations under controlled conditions, which can be quite different from real-world scenarios. This mismatch poses a challenge for users who need reliable sensor performance in everyday situations. To tackle this, we have developed a new method that cuts down on calibration costs while ensuring the sensors work well in the field, even under varying conditions.

Background, Motivation and Objective

In recent years, we have seen an increase in the use of machine learning to solve problems that would otherwise be practically impossible. One of these problems is the cross-sensitivity of chemoresistive sensors, which is their major drawback. It has been shown that these sensors can achieve high selectivity if an extensive number of calibration measurements are carried out followed by intensive data processing tailored to the needs of the studied case [1]. Most of these measurements are done in laboratories, under steady-state conditions and controlled atmospheres, what cannot guarantee their performance in practical cases under dynamic conditions and uncontrolled atmospheres. Moreover, despite the low cost of chemoresistive sensors, the equipment needed to carry out these calibrations is very expensive, which unfortunately hinders the widespread use of these sensors.

The few studies that consider using the sensors for field applications mainly find two solutions: (1) assume the concentration(s) will be correctly predicted [3]; or (2) conduct a study of e.g. odours [4] when individual gas concentrations are not necessary. With our method we present another option that can reduce the costly laboratory calibration and decrease the computational power from high to middle values, that can enable portable microcontrollers to support such models in real-time.

Description of the New Method

Low-cost sensor systems, presented in detail elsewhere [5], were equipped with an in-house C code, a tailor-made printed circuit board that powered and controlled four TGS Figaro sensors, and a pressure, temperature, and humidity BME680 sensor. The sensor system housing allowed direct exposure to air through different openings and convective air circulation to ensure the correct exposure to gases. Approximately 20 of these electronic noses where calibrated in situ under different field and weather conditions to evaluate the amount of data necessary to obtain well-performing models. The calibration process allowed tracking the concentration of the target gas in the relevant measurement atmospheric gas mixture without the need of the typical gas mixing systems available in laboratories, equipped with mass flow controllers, regulators, gas standards, safety cabinets, and test chambers. Thus, the cost is considerably lower. More importantly, this opens for the possibility of performing initial field calibrations adapted to the case studied ensuring better final performance and allows periodical reviews on-site to ensure long-term reliability. After the field calibration, the data collected from different sensors goes through a process of pre-processing, feature extraction, and consequent multivariate statistics quantification technique, what reports methane concentrations between atmospheric values and up to two orders of magnitude higher without the need of computational power-hungry algorithms such as neural network or support vector regression. This range of concentrations covers most practical cases where sources of methane emission have been tedious to evaluate until now but can be easily adapted to the needs of other cases.

Results

As a representative example, the concentration of methane predicted from our model for unseen data including certain variety of concentration ranges is shown in Figure 1 together with the data from a reference system. We can observe that for both atmospheric and much higher concentration values the trends agree. Figure 2 shows how the error evolves with points and highlights that after certain amount of time, the RMSE converges to a stable value. Additionally, results from the different systems and the evolution of the mean absolute error, mean absolute percent error, root mean squared error (RMSE) metrics as a function of the number and type of points used will be presented.

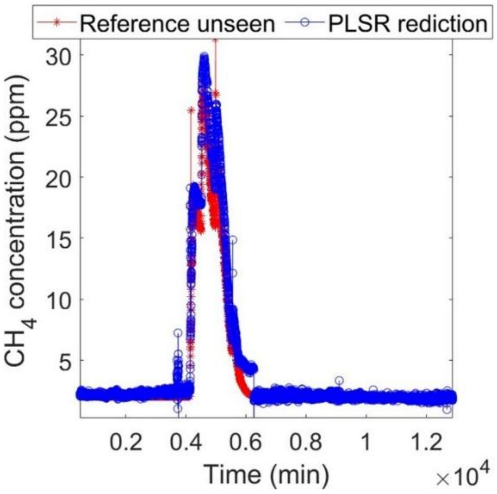

Fig. 1. Unseen concentration as a function of time reported by a reference system and the results of the partial least squares regression performed with data from our electronic nose using a novel field calibration strategy.

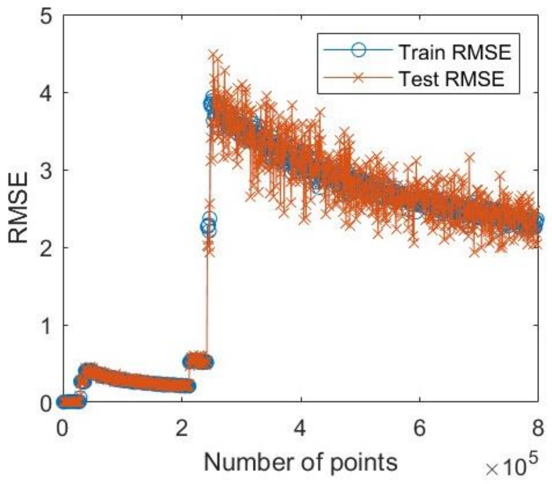

Fig. 2. Evolution of root mean squared error as a function of number of points.

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