

Low-Cost Electronic Nose for Environmental Applications

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Summary:

Atmospheric methane (CH₄) concentrations are increasing rapidly for reasons that are not entirely clear. To understand the dynamics of this gas, we need a high number of CH₄ sensors widely distributed over the Earth's surface, what would only be possible if such sensors were inexpensive. Low-cost sensors (LCS) could fill this technological need. However, LCS suffer from cross-interference and thus show complications to measure CH₄. We have developed a platform that combines low-cost metal oxide CH₄ sensors with ambient temperature, humidity, and pressure sensors, and an algorithm that trains models enabling to compensate for interferences at low cost. Using mechanistically informed multivariate statistical models trained on reference equipment data, we manage to measure CH₄ changes at sufficient precision to track atmospheric changes. We compare laboratory and field calibrations and describe limitations and practical ways to improve this versatile approach for data from natural and anthropogenic sources.

Keywords: methane, electronic nose, metal-oxide sensors, calibration, machine learning.

Headlines

- Our electronic-nose combines several low-cost metal-oxide CH₄ sensors with temperature, humidity, and pressure sensors.
- Mechanistically informed multivariate statistics models trained against reference equipment are used to compensate cross-interferences and retrieve CH₄ concentrations.
- Laboratory and field calibrations show differences; we discuss limitations and routes to improve reliability for natural and anthropogenic source contexts.

to better understand concentration variability, support source attribution, and assess mitigation efforts. However, reliable use of LCSs remains limited due to their need for extensive periodical calibrations and the necessity to compensate for cross-interferences and environmental influences to ensure data quality [3].

Description of the New Method or System

Our system is a multi-sensor platform that integrates various low-cost metal-oxide CH₄ sensors with co-located environmental sensors (temperature, humidity, pressure). Thus, the platform generates multi-channel signals intended to capture both CH₄ response and confounding effects. We calibrated several platforms both in laboratory conditions and outdoors, close to the laboratory and in the final measurement site. Then, we deployed them outdoors close to known anthropogenic emission sources. During field measurements, we observe that these three environmental variables influence the sensor signal, both baseline and response, and are therefore important variables to compensate for during real-world operation if one targets absolute CH₄ accurate concentration. We then applied mechanistically informed multivariate statistics models trained against reference equipment and retrieved CH₄ concentration predictions. An important novelty is the algorithm of the multivariate statistic model, which is adaptative and can return models adapted to the sensor units and platforms. Because each sensor and system

Background, Motivation and Objective

CH₄ is a potent greenhouse gas with a 100-year global-warming potential of 28–34 relative to CO₂ by mass, and atmospheric concentrations are rising rapidly for reasons that are not totally clear [1]. Current ground-based monitoring systems used for national inventories and international reporting are costly and thus far too scarce to help resolve source-sink dynamics details at local scales, exactly where they could help reduce further emissions [2]. This strengthens the need for affordable and accessible CH₄ quantification techniques. In this sense, distributed LCS networks represent an appealing solution that could fairly complement reference approaches. LCS could potentially enable more spatially resolved measurements and support flux analyses

present particularities, the model returning gas concentration can be considerably different. With our data treatment architecture, we can improve the interpretability and reliability of LCS outputs under variable environmental conditions.

Results

By implementing our algorithm to data from electronic noses calibrated with reference instruments, we compensate enough for cross-interferences to resolve CH₄ environmental variability even if the metal-oxide sensors are meant for CH₄ leakage detection at much higher concentration values. In Fig. 1 one can see the results of the model for one of the LCS systems trained with our algorithm. The graph shows only test data, i.e., data that was not used to train the model (unseen). This is an approximation to how the system will perform after being calibrated and operating in the deployed field as the measurement shown is when operating outdoors and exposed to uncontrolled atmospheric variable changes. The predicted signal is compared to data collected with the reference instrument that was located next to the LCS system to validate the results. In this way, one can understand the level of accuracy we can reach with a ~500€ system compared to what one obtains with a reference system of with a cost of ~60 times higher. Besides, we observed that one metal-oxide sensor is not enough to track atmospheric concentration changes but that three achieve convenient accuracy. Moreover, we also observed that more than three sensors do not relevantly improve the resolution and thus we keep three sensors as cost-accuracy compromise. We present results that highlight differences between laboratory calibrations and field calibrations, and we discuss what these differences imply for deployment strategies and calibration transferability.

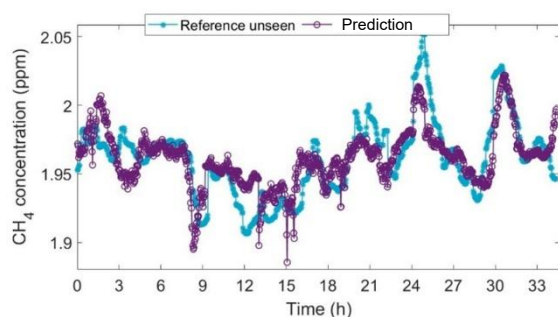


Fig. 1. Comparison between the signal of unseen reference methane data over time (test set, not used during model training) and predictions extracted from a low-cost electronic nose dataset operated during the same time period.

Finally, we outline limitations of the current calibration strategies, machine learning approaches for data treatment, and practical pathways for improvement based on tests using data associated with both natural and anthropogenic sources. This work aims to support the use of CH₄ LCS networks to complement reference-grade instruments and help assess mitigation strategies efficiency.

References

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