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Stationary Gas Sensor Networks for Continuous Leakage Detection

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Summary:

Continuous monitoring of Biogas installations is a means to improve safety and detect failures occurring only under specific operational conditions. Stationary methane sensor networks are able to perform this task by providing temporarily and spatially resolved data on methane concentrations. Therefore, the reliability and precision of the concentration data of individual nodes is paramount. This contribution presents the setting up of such a wireless gas sensor network based on a miniaturized, photoacoustic methane detection approach via multi-unit calibration. The results highlight the importance and potential of reliable calibration methods as basis for gas flux measurements using stationary sensor nodes.

Keywords: leakage detection; gas sensor network; photoacoustic-based NDIR

Introduction

Several conceptually different approaches for scalable monitoring of methane leakages are currently subject to intensive research and development efforts [1]. This high relevance is due to the ubiquitous use of methane in many industries and the associated high environmental and economic impact as well as the safety-related issues. While satellite-based methods are able to provide a global overview, the continuous detection of leaks on small and medium spatial scales is currently not solved in a techno-economic satisfactory way. The use of distributed gas sensor networks to determine gas flows from a 3D data point cloud of concentration measurements with adequate temporal and spatial resolution is a possible route, if combined with measurements of wind speed, wind direction, temperature, and pressure. Based on the gas flow determination one can then determine the location and strength of leaks. The use of stationary gas sensing networks in this scenario allows for a continuous monitoring at arbitrary sites.

Modeling gas dispersion has shown promise [2], offering the potential for using low-cost, miniaturized sensors to measure environmental factors. Indirect photoacoustic gas sensors offer promising features in terms selectivity and sensitivity in a smaller size as compared to standard non-dispersive infrared spectroscopy (NDIR) devices [3]. Yet, ensuring reliability and repeatability across a large-scale network is critical. This study delves into a calibration method for consistent data quality across sensor nodes based on custom-build, miniaturized indirect photoacoustic sensors using mid-infrared light emitting diodes (mid-ir LED) at 3.5 µm to excite photoacoutic waves.

Gas Sensor Network

The gas sensor network is based on individual nodes, each of which feature a GPS module NEO-6M for geolocalization and data synchronization, an integrated temperature, humidity, and pressure sensor BME280 from Bosch, a LoRaWAN module for wireless, long range data transfer. The determination of a leak's source and strength is possible by using stationary gas sensor networks and to this end a total of 10 sensor nodes with the same setup and particularly with the same optical path length for NDIR-type photoacoustic detection of methane have been built. As light source a mid-infrared light emitting diode (MID-IR LED) L15893-0330M from Hamamatsu Photonics K.K. with a central emission wavelength of 3.5 µm is employed. Its output is modulated with a sinusoidal current modulation at a frequency of ω_{mod} = 300 Hz. The photoacoustic detector consists of a hermetically sealed cell filled with pure methane at 1 bar pressure, and includes a microphone ICS-40720 from TDK-Invensense Inc. mounted onto a TO 5 socket and bonded to it, as well as 0.5 mm thick sapphire window for infrared radiation access. The probing light passes through an optical path length d_{opt} = 30 mm. The 10 sensor node have been exposed to varying levels of temperature, humidity, and methane concentrations at the same time and in the same environment. Figure 1 shows the variability between different units. To correct the slope, one needs another calibration measurement.

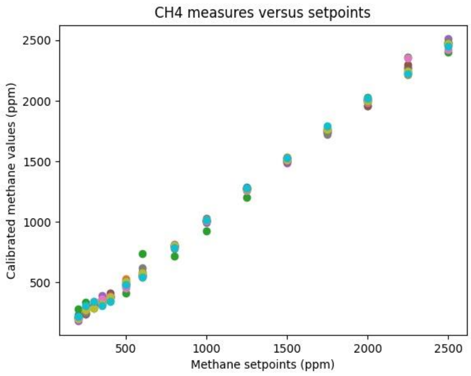

Figure 1: Sensitivity response for 10 sensing nodes at different concentration levels.

Figure 2 shows the corresponding errors in prediction for methane for the different models. The error in prediction can be as high as 1750 ppm, while the error when the calibration for the specific sensor is used remains in the order of tens of ppm.

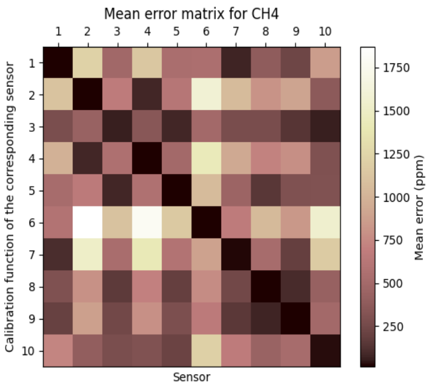

Figure 2: Error in prediction when the calibration models are applied to different sensing nodes.

The cross-sensitivity to temperature and humidity is shown in Figure 3 which highiights de dominance of the temperature coss-sensitivity. Finally, we evaluated the methane calibration models when transferred directly to the other units. In this scenario, the error in the predictions has an average of 1200 ppm.

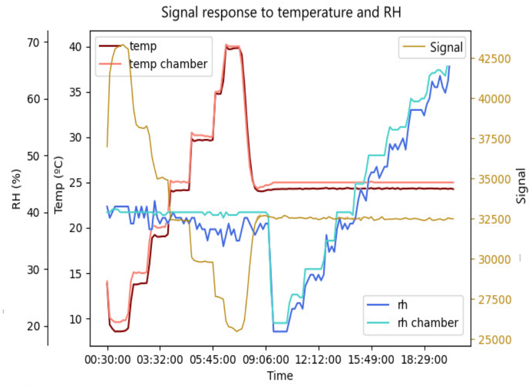

Figure 3: Sensing node exposed to different levels of humidity and temperature.

On the other hand, when performing a singular calibration for each unit the mean error decreases to 25 ppm. When the model incorporates calibration measurements from different sensing units, performing a multi-unit calibration, the average error is 400 ppm, which is a significant decrease with respect the use of models build with different units.

Discussion and Conclusions

In this contribution the development of sensing networks for methane leakage detection based on stationary, indirect photoacoustic spectroscopy is presented. While results of individual calibrations perfom with high accuracy, their cost is not affordable for the deployment of a dense network of sensors. Therefore, the possible to build a multi-unit calibration is demonstrated. This strategy is cost-effective and the performance decay is acceptable for the rapid detection of methane leakages.

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