

Abstract

Efficient Methods for Training and Validation of Odor Sensors [†]

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[†] Presented at the XXXV EUROSENSORS Conference, Lecce, Italy, 10–13 September 2023.

Abstract: The correlation between a gas sensor pattern and its corresponding odor impression on human noses remains a scientific challenge for the development of technical odor detection systems. Small, inexpensive gas sensors, for example, those based on a metal oxide semiconductor (MOS), offer a versatile platform for the development of application-specific sensor systems for odor detection or monitoring. The training of MOS sensors for odor detection remains a challenging task that has been addressed by recent advances. We hereby present a comprehensive method and instrumentation for the characterization and validation of MOS sensors using a gas chromatograph with a mass spectrometer and odor detection port.

Keywords: sensor characterization; volatile organic compounds; VOCs; gas chromatography; odor analysis; odorants; gas sensors; gas sensor systems; mini-GC

1. Introduction

The detection of a characteristic pattern of gases and volatiles plays an important role in fast and non-destructive analyses, with numerous applications. In medicine, specific volatiles are used as markers for emerging diseases; in indoor and outdoor air quality analyses, volatiles give insights into health risks; in the food industry, volatile organic compounds (VOCs) can be used to monitor the storage and production processes of food and feed. A multitude of scientific reports, demonstrators and even ready-to-market sensor systems are available for many of these applications. For an especially challenging subtask, the mimicking of the human nose, however, research seems to have stagnated. The idea of transferring the human olfactory system to a technical sensor (array) has fueled sensor research since the early 90s [1]. Among many promising detection principles, metal oxide semiconductor (MOS) gas sensors have stood out for their small size, low-cost mass production and wide applicability, with high sensitivity for broadband VOC detection.

However, even a reliable, application-specific detection of VOC patterns for describing an odor is still a very challenging venture that requires high-effort training. Recent advances in miniaturized sensor arrays [2], in the increase in their sensitivity and selectivity due to their dynamic operation [3], and in methods for the determination of a minimal set of training data [4] herald an era of the new generation of VOC sensors.

Until present, these methods did not allow for an efficient correlation between odor impression and VOC-pattern variability. Herein, we present a comprehensive method and instrumentation for the sensor characterization and sensor validation of on-site odorant detection applications.



Citation: Zeh, G.; Koehne, M.; Sauerwald, T. Efficient Methods for Training and Validation of Odor Sensors. *Proceedings* **2024**, *97*, 37. <https://doi.org/10.3390/proceedings2024097037>

Academic Editors: Pietro Siciliano and Luca Francioso

Published: 18 March 2024



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2. MOS Sensor Signals, Single Compound Identification and Odor Impressions—Sensor Characterization and Validation

The overall odor impression of a product or material usually consists of several chemical compounds in varying concentrations that are embedded in other volatiles emerging from the matrix.

A qualitative and quantitative description of the overall odor impression can be given by analysis techniques that amplify the human nose as a sensor, e.g., the sensory profiling of odorants, or olfactometry. With a laboratory analysis performed using a gas chromatograph coupled to a mass spectrometer and an odorant detection port (GC-MS/O), a correlation between the individual compounds of a gas mixture, their specific odor impressions and the impact of a single compound on the overall odor impression can be made. Thereby, key odorant compounds are identified that are unique to the underlying chemical or biological processes (e.g., spoilage, fatty acid oxidation) or correlate with product changes. Once the minimal subset of VOCs that contain the application-specific information about an odor impression is identified, the sensor's training can be minimized by specifying the training to the identified subset of key compounds.

Therefore, the GC-MS/O instrument can be equipped for sensor characterization using three synchronized ports at the outlet. The first port is for the mass spectrometer, for the identification of compounds; the second one is for the odorant detection port (a heated outlet for sniffing single compounds with the human nose); and the last one is for the gas sensor [5,6]. This instrumentation allows for simulating the sensor's performance with different system configurations.

In order for sensors to learn to detect these key odor compounds, even in difficult gas compositions, it is important to validate these key compounds in different concentrations and compositions, on the one hand, but also to test them with typical interfering gases from the application, on the other. For this purpose, suitable sensitive sensors are tested using a gas-mixing apparatus with varying conditions (e.g., humidity).

In a proof-of-concept test we demonstrated a GC sensor system with a traditional gas chromatographic separation column and a MOS sensor for the detection of the plant ripening hormone ethene [7].

Author Contributions: Conceptualization, G.Z. and T.S.; methodology, T.S.; validation, G.Z.; investigation, M.K. and G.Z.; writing—original draft preparation, G.Z.; writing—review and editing, M.K. and T.S.; supervision, T.S.; All authors have read and agreed to the published version of the manuscript.

Funding: This research and the APC were funded by the Bavarian State Ministry of Economic Affairs, Regional Development and Energy (StMWi), within the project “Campus of the Senses” (grant no. 20-3410-2-14-3).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Acknowledgments: The authors thank Michael Czerny for his administrative and technical support.

Conflicts of Interest: The authors declare no conflicts of interest.

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