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Abstract

Machine Learning for Enhanced Operation of Underperforming Sensors in Humid Conditions †

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Abstract: Using a single sensor as a virtual electronic nose, we demonstrate the possibility of obtaining good results with underperforming sensors that, at first glance, would be discarded. For this aim, we characterized chemical gas sensors with low repeatability and random drift towards both dangerous and innocuous volatile organic compounds (VOCs) under different levels of relative humidity. Our results show classification accuracies higher than 90% when differentiating harmful from harmless VOCs and coefficients of determination, R^2, higher than 80% when determining their concentration in the parts per billion to parts per million range.

Keywords: air quality monitoring; indoor; electronic nose; virtual sensor; machine learning

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1. Introduction

It is common practice among researchers to obtain the best possible results by using the best-performing sensors and discarding defective ones. In this work, we performed the opposite. We selected underperforming sensors and applied machine learning algorithms to demonstrate the powerful contribution of these data treatment techniques to overcome device manufacturing issues on sensor performance. Our sensors presented an unstable and non-reproducible baseline, response drift, and unexpected conduction behaviours, inducing low repeatability.

An electronic nose (e-nose) is a chemical gas sensor system that uses the signal patterns of several gas sensors to distinguish gases among mixtures and quantify their concentration via intensive data treatment [1]. However, despite the large benefits of e-noses in terms of enhanced selectivity compared to single sensors, there are limitations and issues associated with sensor arrays, which include calibration, maintenance, costs, complexity, and cross-sensitivity [2]. Thus, innovative techniques to obtain the benefits of e-noses while overcoming their flaws must be investigated. In this work, we approach this challenge using the so-called virtual sensor array [3,4] as a simple, flexible, and cost-effective alternative for gas-sensing applications. We demonstrate that data treatment can overcome the influence of relative humidity in the signal of an underperforming sensor and discriminate among similar volatile organic compounds (VOCs).

2. Materials and Methods

We implemented virtual e-noses by operating a single silicon-carbide-based field-effect transistor (SiCFET) with periodical temperature changes from 240 to 360 °C, using 22 s—30 °C steps, and extracting the sensor signal at each temperature to obtain five sensor signals. The different response patterns obtained at each temperature were used to implement the following: (i) 10-fold cross-validated support vector machines (SVMs) to classify between harmful (formaldehyde) and harmless (acetic acid) VOCs, and (ii) principal component regression (PCR) to quantify the studied VOCs under different levels of humidity. The studied gas concentrations ranged from 0.25 to 15 ppm and were diluted in humid synthetic air with relative humidity values from 20 to 50%.

3. Discussion

The results of the SVM classification and PCR quantification are shown in Figure 1. Data treatment was performed considering all data points for each specific gas as one group, irrespective of the background humidity level. In this way, we can observe that the influence of water vapor in ambient conditions can be overcome because we obtained a total accuracy of 0.93 when classifying gases and concentrations with SVM while, for the formaldehyde quantification, a coefficient of determination, R^2, of 0.82 and a root mean square error of about 220 ppb were obtained.

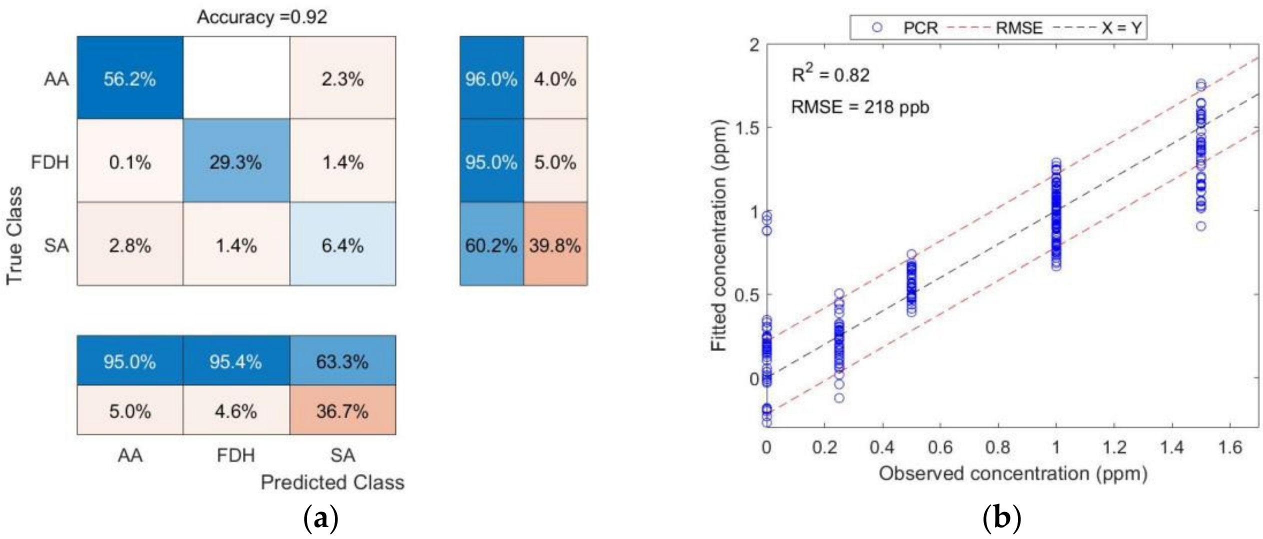

Figure 1. (**a**) Support vector machine classification results for formaldehyde (0.25 to 1.5 ppm), acetic acid (0.25 to 15 ppm), and synthetic air under relative humidity ranging from 20 to 50%; (**b**) principal component regression quantification results for formaldehyde under relative humidity ranging from 20 to 50%.

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