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Orthogonal Decomposition of Chemo-Sensory Signals: Discriminating Odorants in a Turbulent Ambient

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Abstract

Chemo-resistive transduction is essential for capturing the spatio-temporal structure of chemical compounds dispersed in different environments. Due to gas dispersion mechanisms, namely diffusion, turbulence and advection, the sensors in an open environment condition, are exposed to low concentrations of gases with many fluctuations making, as a consequence, the identification and monitoring of the gases even more challenging than in a tightly-controlled sampling system. Consequently, extracting proper features becomes crucial to successfully identify and monitor the pollutant gases, particularly in applications such as exploration of hazardous areas, air pollution monitoring, and search and rescue. In this context, we explore the benefit of decomposing the chemo-receptor signal responses in an alternative space, spanned by a set of orthogonal functions, namely the Bessel functions' space. We claim that by expressing the sensor signal responses in this alternative space may be beneficial for the identification of the distinct odorants in open environments.

Keywords: Metal-oxide chemical sensors; turbulent ambient; Bessel fucntions; feature extraction.

1. Introduction

Numerous applications reported in the sensors literature have established metal-oxide gas sensors as effective devices for detecting and quantifying chemical analytes in a broad range of events [1, 2]. However, despite the promising results obtained in these previously cited attempts, there is still a standing critical question that could substantially expand the usage of metal oxide sensors: given a gas plume

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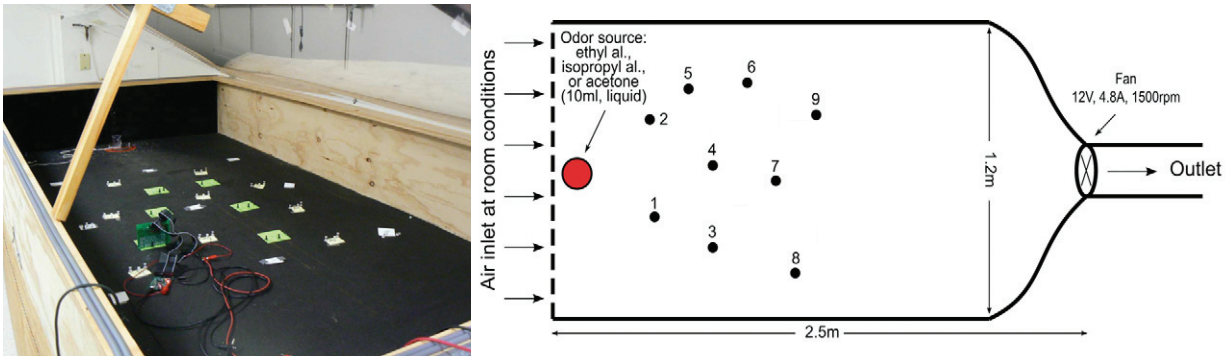
emitted from a fixed location within an in-door space, can metal-oxide gas sensors characterize the spatio-temporal structure of the chemical compounds dispersed in different environments for recognizing or predicting their odor identity? In an attempt to address this issue, in this paper we consider an odor identification phenomenon affected by different non-predictable environmental parameters changing with time. Our goal then is to design a consistent procedure that will effectively represent the information contained in the sensor signal response subjected to the turbulent ambient and simultaneously fulfill time and accuracy constraints in the pattern recognition task. The method consists of decomposing the chemo-sensor signal responses in an alternative space, spanned by a set of orthogonal oscillatory functions, namely the Bessel functions' space [3, 4]. Our hypothesis suggests that this novel representation will become a more consistent procedure to capture the spatio-temporal information in metal-oxide gas sensor measurements made at fixed locations within the plume, thereby boosting up the potentiality of the sensors to predict the odor identity in an open sampling system.

2. Experimental details

We carried out a series of experiments in a 2.5×1.2×0.4 m^3 wind-tunnel as shown in Fig. 1. We selected 9 random land-mark locations in the wind-tunnel at various distances and angles from the odor source, in which a stand-alone portable array of metal-oxide gas sensors was located. Then, we made 7 independent measurements at each landmark location for each of the 3 analytes considered, namely ethyl-alcohol, isopropyl-alcohol, and acetone, dosed at a single concentration.



(a) (b)

Fig. 1. (a) Picture of the wind tunnel where the gas source, the sensor board and measurement points that have been used to collect the data are visible. (b) A sketch of the wind-tunnel with the measurement landmark locations. Seven independent recordings from each landmark location and analyte considered were taken for training and test our feature extraction approach in a random order.

Each measurement consisted of an 8-channel time series, representing the time profile of sensor resistances for 3 minutes in response to each analyte as shown in Fig 2. The order of these 189 recordings was randomized with respect to the analyte and the location. Thus, the idea is to test the discrimination capabilities of the sensory system at the different locations.

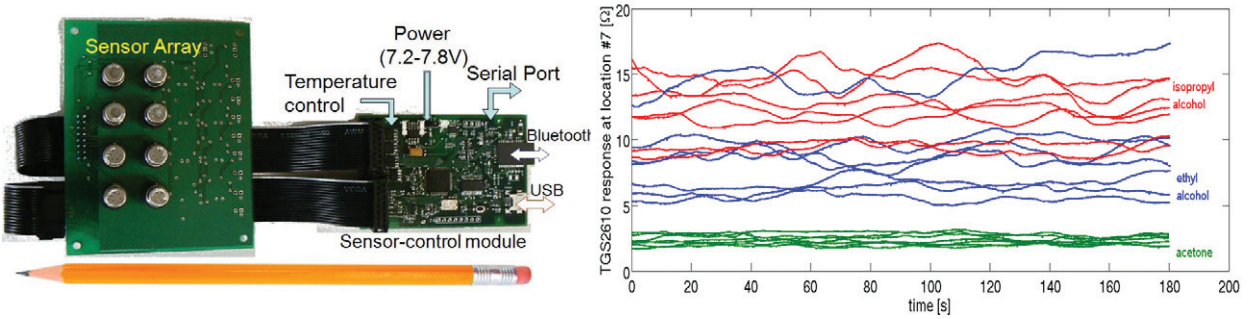
2.1. The sensory signal decomposition

In processing the sensor responses, we utilize a new set of features consisting of decomposing the original sensory cues, subjected to the turbulent ambient changes, into an alternative space, spanned by a set of orthogonal functions, namely the Bessel functions' space [3]. The key-point of this method is to express

alternatively the sensor response information by L of these orthogonal Bessel functions, preserving the meaningful part of the original information of the odor identity, thus,

$$r(t) = \sum_{m=1}^{L} c_m \varphi_m(t) \tag{1}$$

in which $\varphi_m(t)$ represents one of the L basis functions (i.e., a zero-order Bessel functions $J_o(\cdot)$) and c_m are the coefficients of expansion that describes the sensor response $r(t)$. In the context of our experiment, it is expected that the orthogonality nature of the selected basis functions will facilitate the extraction of the parameters of expansion, and yet it will capture better the fundamental nature of the sensor waveform, thereby promoting the distinguishability of the three compounds measured in the open sampling system. In what follows we will present the results obtained.



(a) (b)

Fig. 2. The custom-design portable tin-oxide gas sensor array used as the sensing layer for the identification task in the open sampling system facility considered in this study (a). A three-minute parallel read-out from the array when subjected to the three analytes considered at a certain location in a wind-tunnel. Each record consisted of 8 parallel time series, one from each sensor. All 21 responses recorded from a particular sensor at training location #7 are shown in panel (b). Note how acetone clearly separates from the other two odorant classes, whereas the remaining 2 classes (i.e., Isopropyl alcohol and Ethyl-alcohol) constitute a more challenging discrimination problem.

3. Results

To demonstrate the consistency and robustness of our novel feature extraction scheme, we address the three-gas classification problem shown in Fig. 1, in which the goal is to discriminate the three different analytes regardless of the measurement landmark where the chemo-sensory array within the wind-tunnel test-bed. In doing so, we conducted a validation process, in which the resulting Bessel expansion coefficients are used to build the discrimination models to be interfaced to the desired classifier. We then quantified the performance of each created model in the classifier by applying the following training/validation procedure. For every landmark location we divided the resulting dataset in 70% of the measurements for training and then applied the remaining 30 % of the measurements for validations. We repeated this training/test process 100 times to evaluate the classification performance, ensuring to a certain degree that each measurement is held out at least once for validation. The average identification success rate (with these features) over the 100 runs, using a support vector machine classifier with radial-basis function kernel, is shown in Table 1. As the results illustrate, we managed to accurately identify the distinct analytes on the different locations considered. Note how acetone separates perfectly from the other two odorants, whereas the remaining 2 classes (i.e., Isopropyl-alcohol and Ethyl-alcohol) present a more challenging problem. Although the overall discrimination performance worsened in landmarks 4, 5, and 8, the errors in the rest of landmarks never were larger than 20%, which is promising that our feature extractor for open sampling systems is generalizable.

Table 1. Identification performances conditioned on the measurement location. The results are obtained by a Support Vector Machine classifier with Radial-Basis Function kernel and were jackknifed at each location (i.e., each entry is the average of 100 train-test episodes, performed by holding out each measurement of the corresponding analyte for test and using the remaining measurements at that location as the training set).

Landmark Location	Identification performances in (%)			
	Acetone	Ethyl-alcohol	Isopropyl-alcohol	Overall
1	100	87	93	80.91
2	100	93	100	93.00
3	100	93	93	86.49
4	100	73	87	63.51
5	100	80	77	61.60
6	100	93	87	80.91
7	100	93	87	80.91
8	100	87	67	58.29
9	100	73	73	73.00

4. Conclusions

We have reported the significant benefits of using an orthogonal signal decomposition scheme as a feature extractor for chemo-sensory response cues. The method consisted of decomposing the sensor response signal using a set of orthogonal Bessel functions. As we have demonstrated using metal oxide gas sensors as a sensing layer, this approach boosts the identification performance in an open sampling system. Therefore, whenever feasible, our feature extraction scheme should be preferred over other conventional feature extraction methods. Finally, the suggested signal decomposition based feature extraction scheme is easily expandable to other type of environmental condition (e.g., outdoor environments) and could be applied to odor localization tasks. These analyses, nonetheless, could be the object of a completely new piece of research that we seek to address in further works.

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