Classification of Optical-Sensor Response Cues with a Bi-dimensional Wavelet-Transform Approach

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Abstract. In this work is used the two-dimensional discrete wavelet transform as a feature extractor of time responses from a porous silicon optical gas sensor for gas identification. The wavelet decomposition allows us to have a more in-deep sight of the sensor response. In addition, using a linear support vector machine (SVM) as classifier we evaluate our approach for a six-analyte discrimination problem.

Keywords: Classification; Feature, extraction; Porous silicon optical gas sensor; Two-dimensional wavelet transform; Support vector machine.
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INTRODUCTION

In the last years there has been a growing demand for and rapid increase in the quality/variety of chemo-sensing technologies, in which optical-based sensors, in general, and porous silicon film-based chemical sensor, in particular, is gaining more and more importance[1]. Both, the high surface sensing area available and the nano-scale size of the porous have contributed to such a preference. The detection of chemical agents is usually performed by monitoring shifts in the porous silicon reflectance (wavelength) spectrum generated during exposure to parts-per-million levels of airborne chemicals. However, due to the aspects of the raw signal of the sensor response, there is some valuable information that such a general feature may be overlooking. In this direction, we propose an alternative way to extract more useful attributes for optical-based sensors, based on the 2D-discrete wavelet transform (2D-DWT)[2], that will allow us to have a more in-deep sight of the sensor response. Using a linear support vector machine (SVM) as classifier, we evaluate our approach for a six-analyte discrimination problem.

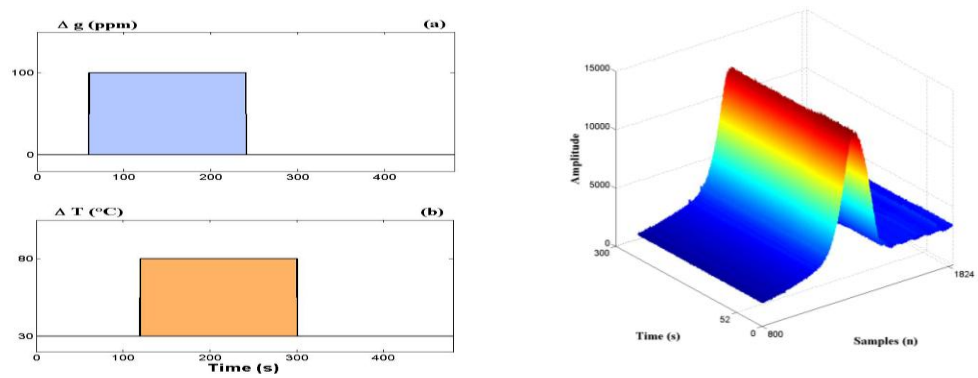
RESULTS AND DISCUSSION

A database of a single optical-based porous silicon sensor with different surface chemical modifications, acquired from a computer-supervised continuous flow system

(CSCFS), was analyzed. The optical sensor was placed in an air-tight test chamber connected to CSCFS that allows us to obtain the desired concentrations of gases to be measured. The whole measurement process took 13 min to complete divided in 60 s baseline, 180 s gas/operating temperature-interaction phase and the remaining 9 min for cleaning. The different time intervals for the gas/temperature-interaction phase are shown in Fig. 1 (a). Eventually, six different gases dosed at different concentrations (10 replicates each) were considered in this study (see Table 1).

TABLE 1. Data set considered.

Gas	**Concentration in ppm**
Acetone	50,75,100,125,150,175,200,225,250,275,300
Ammonia	50,75,100,125,150,175,200,225,250,275,300
Acetaldehyde	10, 20, 30, 40, 50, 60, 70, 80, 90, 100
Benzene	10, 20, 30, 40, 50, 60, 70, 80, 90, 100
Isopropyl	10, 20, 30, 40, 50, 60, 70, 80, 90, 100
Toluene	10, 20, 30, 40, 50, 60, 70, 80, 90, 100

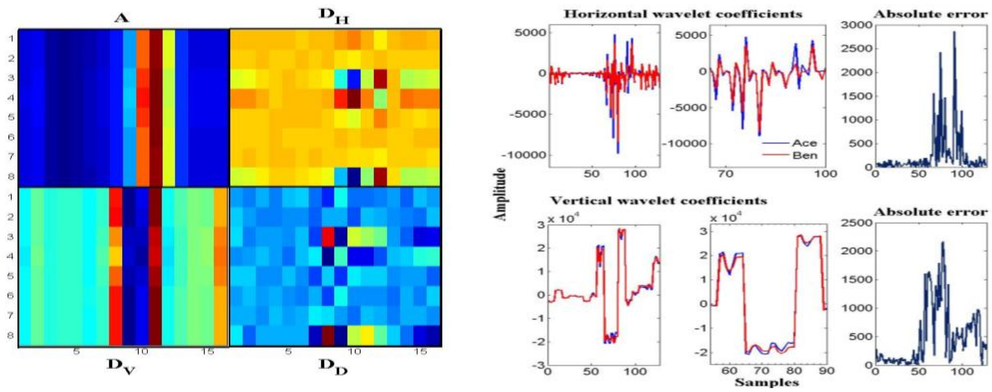


(a) (b)

FIGURE 1. (a) The time intervals of gas injection and changing working temperature. (b) The time response of the optical sensor in the presence of 50 ppm of acetaldehyde.

Due to the bi-dimensional nature of the optical sensor cue in response to a single analyte (a 2-D image wavelength signal shown in Fig. 1 (b)), we considered the 2D-DWT as a feature extractor; method amply known for its feasibility to handle non-stationary and transient signals in signals of different dimensions[2].

Thus, we decompose the sensor response into different levels of decomposition, in which each of these decomposition levels provides four pieces of information that we call sub-images: one image-approximation and three image-details. In this work these details are the ones that we consider as being descriptive of the shifting behavior of the wavelength. This shifting is specific to each odor or concentration. In particular, we selected the wavelet coefficients at the sixth level of decomposition because we found that the wavelet coefficients at such level capture the significant differences due to the response to the chemical analyte. In Figure 2(a) is illustrated the wavelet decomposition at sixth level in the presence of 100 ppm of acetaldehyde vapor. Figure 2 (b) shows the comparison at the sixth level between the wavelet coefficients of the horizontal and vertical directions in the presence of 100 ppm of acetone and 100 ppm of benzene. A close-up version of the transformed responses is shown in the middle column, in which the absolute difference between the two signals (i.e., the two gases) is observable from left to right (see the right column of Fig. 2 (b)).



(a) (b)

FIGURE 2. (a) The transformed response corresponding to the 6 wavelet level decomposition of the optical sensor response in the presence of 100 ppm of acetaldehyde vapor (db1 wavelet function considered). (b) (Left column) Wavelet coefficients of the horizontal and vertical directions corresponding to the sixth wavelet level decomposition in the presence of 100 ppm of acetone (Ace) and 100 ppm of benzene (Ben), using the db4 wavelet function. (Middle column) A close-up version of the two signals, where the maximum difference between these signals is shown. (Right column) The respective absolute error of the signals in both horizontal and vertical directions.

Finally, to evaluate the discrimination capabilities of the features extracted using our approach, a linear SVM (leave-one-out cross-validated) was used. The results using three different wavelet functions over the six classes are summarized in Table 2. We can observe that the wavelet information in both horizontal and vertical directions yield an outstanding performance irrespective of the type of wavelet function used, which demonstrates the potentiality of our approach to analyze sensor responses of optical gas sensors.

TABLE 2. Success rate in gas discrimination in %.

Wavelet subimage → **Wavelet function ↓**	**D-H**	**D-V**	**D-D**
db1	97.80	97.90	87.21
db2	94.67	97.58	78.03
db4	91.28	98.71	65.48

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