Optimizing the Operating Temperature for an array of MOX Sensors on an Open Sampling System

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Summary

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 sampling system, i.e. directly exposed to the environment to be monitored, are exposed to low concentrations of gases with many fluctuations making, as a consequence, the identification and monitoring of the gases even more complicated and challenging than in a controlled laboratory setting. Therefore, tuning the value of the operating temperature becomes crucial for successfully identifying and monitoring the pollutant gases, particularly in applications such as exploration of hazardous areas, air pollution monitoring, and search and rescue[1]. In this study we demonstrate the benefit of optimizing the sensor's operating temperature when the sensors are deployed in an open sampling system, i.e. directly exposed to the environment to be monitored.

Methods and Results

A series of experiments have been carried out in a 2.5x1.2x0.4 m^3 wind tunnel (Fig. 1). A set of 9 portable arrays of 8 Figaro TGS sensors (Tab. 1) have been positioned at 6 different lines orthogonal to the wind direction for a total of 54 different measurement points distributed on a uniform grid that covers the entire wind tunnel (Fig. 1). An artificial air flow with 3 different average speeds of 0.10, 0.21 and 0.34 m/s has been induced. Two analytes have been used in the experiments, CO at 4000 ppmv and NH_3 at 10000 ppmv (the concentration reported is at the outlet of the gas source). Five different heating voltages were considered in these experiments, $V_H \in \{4.0, 4.5, \ldots, 6\ V\}$. We do not have access to the actual surface temperatures due to packaging, but a look-up table relating them to the heater voltage can be found in[2]. Each measurement consisted of 10 seconds of baseline recording, 3 minutes of recording with the active gas source and 3 minutes of recording during which the sensors recover to the baseline value. During an experimental run not all the boards were responding since some of them were not hit by the gas plume. We consider a board as being responding when the measured resistance change of one or more of the 8 sensors is at least the 20% of the baseline value. Figure 2 shows the number of boards responding as a function of the operating temperature. We can observe that for the two analytes evaluated, the number of responding boards decreases when the operating temperature increases and that NH_3 is easier to detect than CO with the sensor array we considered since the number of responding boards to NH_3 is larger across the entire operating temperature spectrum. For evaluating the discrimination capability of the array, we both calculate a Linear Discriminant Analysis and perform a Leave One Out (LOO) cross validation using a linear SVM as classifier. Figure 3 shows the histograms of the two classes for different operating temperature values, while Fig. 4 displays both the LDA separability index and the LOO performance of the SVM. According to both criteria, a heater voltage of 4.5V is the one which provides the best discriminative performance for the problem at hand. For estimating the response time of the sensors, a series of measurements with the sensors in a chamber have been performed. In this case the concentration of CO and NH_3 was 200ppmv. Ten replicates for each analyte-operating temperature combination have been performed. The sensors have been modeled as a first order system and an exponential has been fit to the response for estimating the time constant. Figure 5 displays the average time constants for each temperature value. We can observe that the response time of the TGS2600, 2602, 2620 decreases with increasing operating temperature, while for the TGS2610, 2611, 2612 it increases. Summarizing, the optimal operating temperature is a result of a trade-off among discriminative capability, sensitivity to the target analytes and speed of the response. For this particular problem the temperature corresponding to 4.5V voltage heater gives the best overall result. Future directions of research will investigate the optimization of the operating temperature of the sensors individually and the introduction of a modulation waveform on the operating temperature.

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[1] A. Vergara, et al., "Information-theoretic optimization of chemical sensors", Sens. Actuators B 148, 298-306, 2010.

[2] Figaro Engineering Inc., Japan, http://www.figaro.co.jp.

Figures

Table 1. Model type and number of sensors included in the array.

Sensor	TGS 2611	TGS 2612	TGS 2610	TGS 2602	TGS 2600	TGS 2620
Quantity	1	1	1	1	2	2

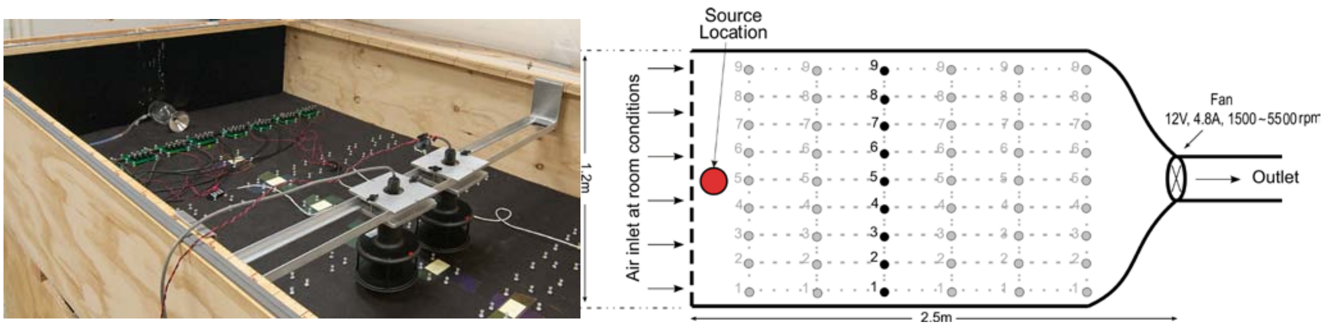

Fig. 1. Left: picture of the wind tunnel where the gas source, the sensor boards and two ultrasonic anemometers that have been used to measure the airflow are visible. Right: Sketch of the wind tunnel where the 6 lines of 9 measurement points are drawn.

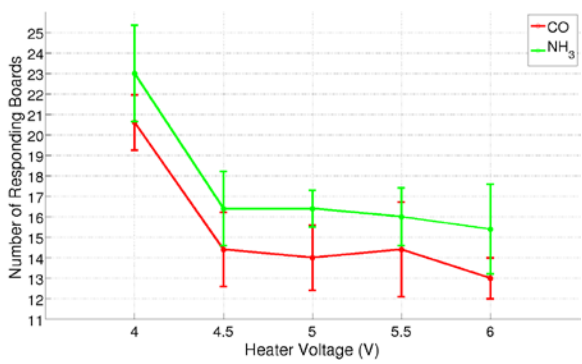

Fig. 2. Number of measurement points that respond as a function of the voltage applied to the heater of the sensor. The line represents the mean across five experiments, while the error bars stand for the standard deviation.

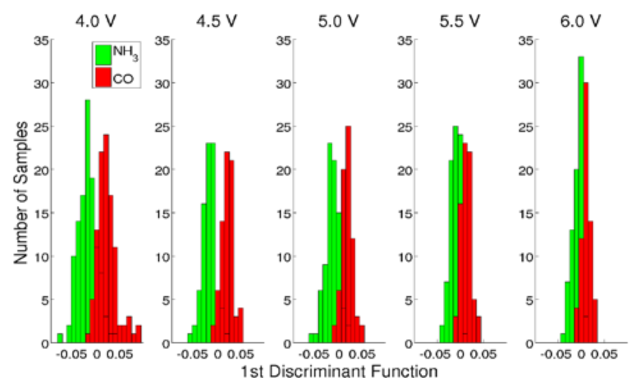

Fig. 3. Histograms showing the first discriminant function. Notice that since the problem has 2 classes the LDA can extract only one discriminant function.

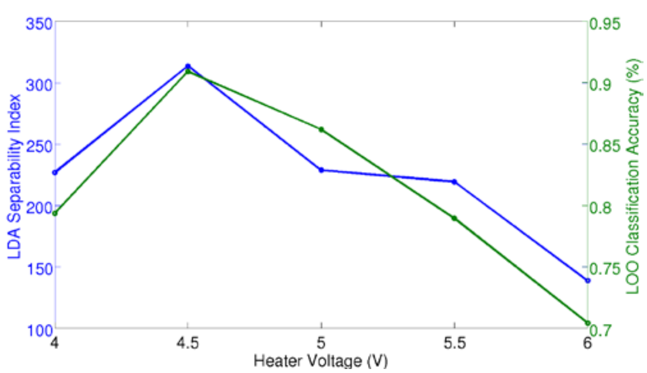

Fig. 4. Discrimination capability of the sensor array as a function of the voltage applied to the heater of the sensor. Notice how both criteria agree on the same optimal value of the operating temperature.

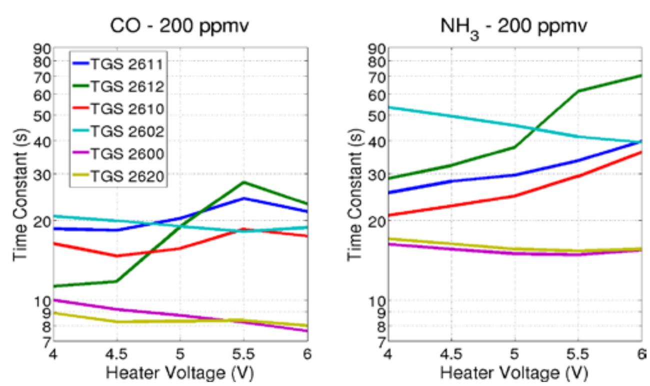

Fig. 5. Time constant of the sensors as a function of the heating voltage applied to the sensors. Notice that the time constant is drawn in logarithmic scale.