

Direct Comparison between an Analog MOS Sensor Array and a Single Temperature-Modulated Digital MOS Sensor for Food Spoilage Status Classification

Lucia Corrà¹, Christian Ratti¹, Sara Bettinaglio¹, Emanuele Zanni², Francesca Pianca³, Raffaele Del-lacà², Laura Capelli¹

¹ *Department of Chemistry, Materials and Chemical Engineering "Giulio Natta", Politecnico di Milano, Piazza Leonardo da Vinci 32, Milan, Italy*

² *Department of Electronics, Information, and Bioengineering, Politecnico di Milano, Via Giuseppe Colombo 40, 20133 Milan, Italy*

³ *Electrolux Italia s.p.a., 31025, Treviso, Italy*
lucia.corra@polimi.it

Summary:

The integration of electronic nose (e-noses) in home appliances is limited by the cost of the hardware. In this study, food spoilage status has been assessed by comparing the performances of a single digital MOS sensor with an array of analog MOS sensors. To carry out this study, an experimental setup has been designed to measure the food sample headspace simultaneously with the two configuration settings. The single digital MOS sensor has shown comparable classification performance across three different machine learning models, demonstrating the potential of substituting sensor arrays.

Keywords: Digital sensor, MOS, Food spoilage, Home appliance, Temperature-Cycle Operation

Background, Motivation and Objective

E-noses based on metal oxide semiconductor (MOS) sensors have been successful in predicting food spoilage status [1]. However, the integration of such systems into home appliances remains limited in real-world applications [2]. One of the key constraints is the cost of the sensing hardware, along with its power consumption and compactness, which must be minimized to ensure their commercial viability [3]. Temperature-cycled operation (TCO) of digital MOS sensors has been proposed as an effective approach to emulate a virtual multi-sensor array using a single sensing element [4]. The TCO determines higher selectivity as the interaction of the sensitive layer with the Volatile Organic Compounds (VOCs) is temperature dependent, as they have different oxidation temperatures [5]. Furthermore, the instantaneous temperature changes from high to low temperatures determine a non-equilibrium condition in which trace amounts of reducing gases can react with the sensitive layer [6]. These features make TCO-operated digital sensors a promising low-cost alternative to analog sensor arrays. Therefore, this study aims to compare the classification performance in predicting food spoilage status using a single digital TCO MOS sensor, and an array of six analog MOS sensors operated at constant temperature.

Description of the New Method or System

The experimental setup (Fig. 1) was designed with four custom-made airtight containers connected to a single e-nose measurement core, consisting of a PCB designed to read six analog MOS sensors and one digital MOS sensor operated under TCO. With a frequency of 12 hours, headspace was drawn sequentially from each container by a diaphragm pump (NMP820KPDC-B, KNF) and routed to the measurement core via a custom PEEK flow distributor controlled by on-off valves (LVM09, SMC, JP). Due to the low headspace volume of the container (~1.5 L), a recirculation mechanism was implemented by adding a return path at the pump outlet via a second flow distributor. Finally, to allow for reference baseline measurement, a clean air inlet was installed at the e-nose measurement core.

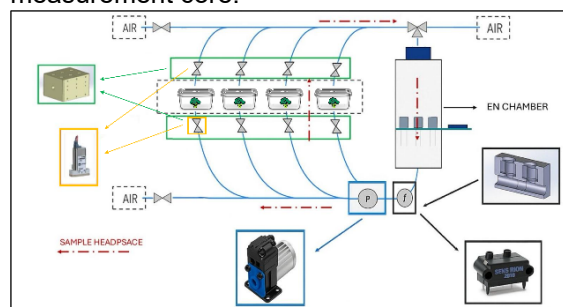


Fig. 1. Experimental setup.

To label the spoilage status of food samples, an internal microbiological method was carried out every 24 hours on a dedicated extra container kept under the same conditions as the head-space samples. Based on the microbiological results, three spoilage labels were defined: “fresh”, “eat it soon”, and “spoiled”. A total of three test sessions were carried out, each including four food samples for the e-nose and one sample for spoilage assessment, all taken from the same production lot.

Raw sensor resistances were pre-processed to remove undesired signal spikes and normalized using reference air. Subsequently, features extraction has been conducted on the sensors' resistance curve, resulting in a total of 102 features from the analog sensors (17 per sensor) and 99 features from the single digital sensor, including transient-dependent resistance changes. Feature selection was then carried out by removing zero-variance and highly correlated features, followed by application of Boruta algorithm to select the most informative features for classification.

Results

The subset of selected features, 7 for the analog sensor and 9 for the digital sensor, was used as input for Principal Component Analysis (PCA).

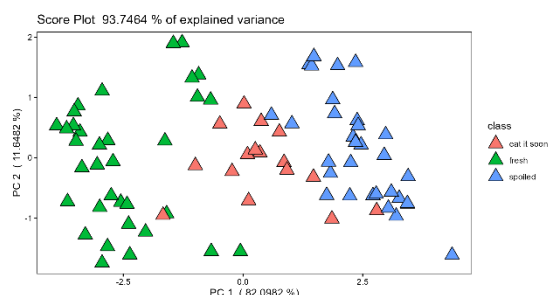


Fig. 2. PCA score-plot for analog sensors array.

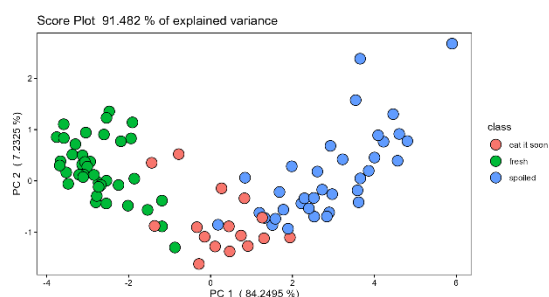


Fig. 3. PCA score-plot for digital sensor.

Both score plots (Fig. 2 and 3) reveal a visually similar distribution of samples, with the three spoilage labels showing comparable clusters along PC1. To quantitatively assess the classification performance, three machine learning models, Random Forest, Linear Discriminant Analysis (LDA), and XGBoost, were developed. Across the three independent test sessions, three containers were used as training and the

remaining one as test. Accuracy has been used as figure of merit for model classification performance (Fig. 4). The digital sensor showed similar performance compared to the analog sensor array across all three models yielding the highest accuracy with Random Forest.

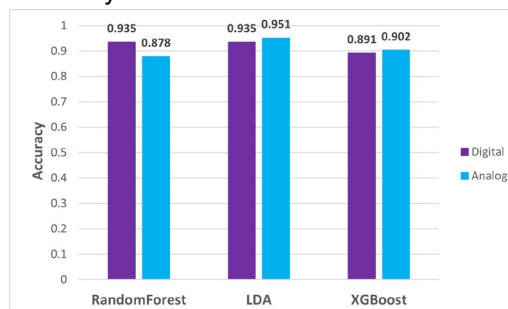


Fig. 4. Classification model accuracy.

These preliminary results indicate that the single TCO-operated digital sensor achieves classification accuracy comparable to the analog array, supporting its potential as a low-cost alternative for food spoilage classification. Further experiments will be conducted applying more advanced data processing techniques.

References

- [1] M. Falasconi, I. Concina, E. Gobbi, V. Sberveglieri, A. Pulvirenti, G. Sberveglieri, Electronic nose for microbiological quality control of food products, *International Journal of Electrochemistry*, (2012); doi: 10.1155/2012/715763
- [2] F. Röck, N. Barsan, U. Weimar, Electronic nose: current status and future trends, *Chemical reviews* 108, 705-725 (2008); doi:10.1021/cr068121q
- [3] GC. Green, AD. Chan, RA Goubran, Monitoring of food spoilage with electronic nose: potential applications for smart homes, *3rd International Conference on Pervasive Computing Technologies for Healthcare*, 1-7 (2009); doi: 10.1109/PCTHEALTH.2009.5291419
- [4] C. Schultealbert, T. Baur, A. Schütze, T. Sauerwald, Facile quantification and identification techniques for reducing gases over a wide concentration range using a MOS sensor in temperature-cycled operation, *Sensors* 18, 744 (2018); doi: 10.3390/s18030744
- [5] JM. Smulko, M. Trawka, CG. Granqvist, R. Ionescu, F. Annanouch, E. Llobet, LB. Kish, New approaches for improving selectivity and sensitivity of resistive gas sensors: a review, *International Journal on Smart Sensing and Intelligent Systems* 7, 1-6 (2020); doi: 10.21307/ijssis-2019-027
- [6] T. Baur, C. Schultealbert, A. Schütze, T. Sauerwald, Novel method for the detection of short trace gas pulses with metal oxide semiconductor gas sensors, *Journal of Sensors and Sensor Systems* 7, 411-419 (2018); doi: 10.5194/jss-7-411-2018