

Development and Comparison of Innovative Sensing Modules to Support Pneumonia Diagnosis

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Summary:

In this work we developed an add-on system for expanding the sensing capabilities of an existing commercial E-Nose used for breath analysis aiming at pneumonia diagnosis. The system integrates three sensing modules with analog fixed-temperature metal-oxide gas sensors and temperature-modulated digital sensors. Module-specific machine-learning models were developed to compare their ability to discriminate pneumonia from healthy controls. The platform enables breath measurements with different sensing modules and future data fusion studies.

Keywords: electronic nose, breath analysis, temperature modulation, pneumonia, medical diagnostics

Background, Motivation and Objective

Pneumonia remains a major cause of morbidity and mortality, and its diagnosis often requires integrating clinical history, imaging, microbiology, and response to therapy [1]. Breath analysis using electronic noses (E-Nose) offers a rapid, non-invasive alternative, but performance is still limited by low volatile compounds concentrations, humidity interference, and poor sensor selectivity [2]. In addition, many commercial instruments provide limited sensor diversity and flexibility for testing new sensing strategies, and were not specifically developed for medical applications.

To address these limitations, we developed an add-on system to expand the sensing capabilities of an existing commercial E-Nose, enabling multiple measurements. The aim is to compare the ability of the sensing modules to support the diagnosis of pneumonia when compared to the commercial E-Nose. In this preliminary study, we assessed the potential of the two add-on sensing modules to discriminate between breath samples from patients with pneumonia and healthy controls by developing module-specific data processing pipelines.

Description of the New Method or System

The measurement platform comprised three sensing modules (Fig. 1-A). The commercial

sensing module was an EOS-AROMA (Sacmi, Italy) containing six fixed-temperature semiconductor metal-oxide (SMOX) gas sensors: four custom sensors based on ZnO, TiO₂, and SnO, and two commercial sensors (TGS2611 and TGS2610, Figaro Engineering), all operated at 400 °C.

Sensing Module 1 (SM 1) was integrated in series and included a digital gas-sensor module based on two temperature-modulated SGP40 sensors (Sensirion AG, Switzerland; STZ AO Action, Germany). Its operation mode was previously described in [3]. For the EOS-Aroma and SM 1, each analysis consisted of 20 min of sampling followed by 20 min of cleaning at 50 mL/min, with 1:1 dilution by carbon-filtered air.

Sensing Module 2 (SM 2) (Fig. 1-B) was developed as a complete E-Nose module with an independent flow system. It comprised an innovative sensing chamber designed to optimize flow distribution across all the sensors and a regulated pump for flow generation. SM 2 was operated in parallel with the commercial device and included an array of seven SMOX sensors from the TGS26XX line (Figaro Inc., Japan), a temperature and relative humidity sensor (SHT40, Sensirion, Switzerland) and one digital sensor operated under temperature modulation;

detailed specifications are intentionally omitted due to confidentiality agreements and non-disclosure obligations. SM 2 operated in parallel with the commercial E-Nose at 300 mL/min, with 6 min of sampling followed by 10 min of cleaning. Its operation was synchronized with that of the commercial E-Nose to ensure that the two systems never drew samples from the same line at the same time.

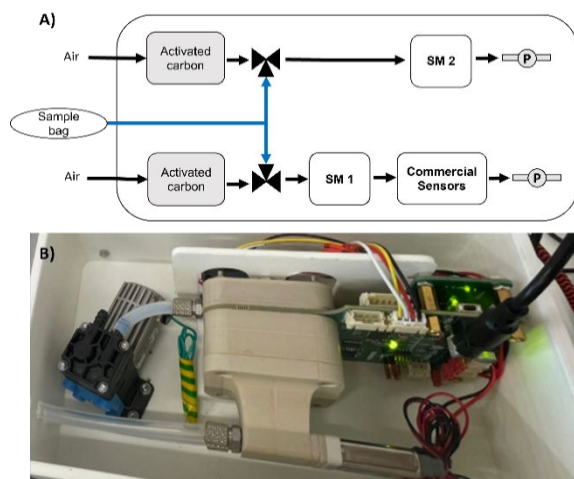


Fig. 1. (A) Illustration of the setup; (B) Prototype SM 2 installed inside the commercial E-Nose.

Breath samples were collected at ASST Papa Giovanni XXIII Hospital in Bergamo, Italy, under ethics approval no. 223/20. The present analysis focuses on the common subset of samples measured using all three sensing modules, currently consisting of 15 pneumonia cases and 11 healthy controls from an ongoing cohort. Exhaled breath was collected offline after a 3 min lung washout using a two-way non-rebreathing valve and medical air, as previously described in [2]. Samples were stored in Nalophan™ bags for 4-24 h in the E-Nose room to reduce humidity interference before analysis.

Different data processing pipelines were adopted for each sensing module. For the commercial E-Nose, the resistance curves were normalized with respect to clean air, and 12 features from the sampling phase were extracted for each fixed-temperature sensor. For the temperature-modulated sensors in SM 1, one steady-state temperature cycle was selected, log-transformed, and 6 features were extracted for each temperature modulation step, such as the mean value, maximum and minimum derivative and area under that temperature step. For the SM 2, the fixed-temperature sensors were processed as for the commercial E-Nose, whereas the temperature modulated sensor was processed as SM 1. Features of both sensing approaches were combined in a table before feature selection.

Boruta algorithm was used to select the top 15 most important features for each dataset, and the resulting feature table was used to train a linear SVM. Leave one out cross validation (LOOCV) was used to validate all models.

Results

Preliminary functional tests with acetone and ethanol (results not shown) indicated that the response time and sensitivity of TGS26XX sensors were improved for the SM 2 compared with the commercial E-Nose.

Breath analysis on the common subset provided a first indication of the diagnostic potential of the multi-module sensing system. Fig. 2 shows the PCA score plot obtained from SM 2, in which good separation between pneumonia and control samples is visible. Table 1 summarizes the LOOCV performance of the three module-specific models. Overall, the add-on modules performed better than the commercial E-Nose, suggesting that increase sensor diversity, temperature-modulated sensing, and optimized chamber fluid dynamics may improve information that can be extracted from the samples.

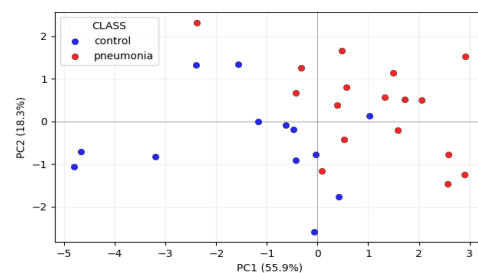


Fig. 2. PCA of breath samples from pneumonia (red) and control (blue) cases analyzed with SM 2.

Tab. 1: Performance of E-Nose in LOOCV in the discriminating pneumonia vs control breath samples.

Sensing Module	Accuracy (%)	CI95%
Commercial	72.7	54.9 – 85.4
SM 1	86.2	69.8 – 94.4
SM 2	90.0	74.4 – 96.5

References

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