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Indoor Air Quality Measurement

Sorin Nicolae Cociorva[1],

[1.] *Technical University of Civil Engineering, Faculty of Building Services and Equipments,*
66, Pache Protopopescu Blv., Bucharest, Romania, tel. (+40)21 252 42 80, cociorvs@instal.utcb.ro

Abstract- *A qualitative assessment of indoors air quality is presented, by the use of an electronic nose consisting of a gas sensor array, a data acquisition system and a pattern recognition system. The gas sensors are sensitive to gases polluting the indoors air but they are sensitive to indoors temperature and humidity as well. The data acquisition system overtakes the sensors specific response and outputs a characteristic pattern to the pattern recognition system. The latter, a logic neural network based system, classifies the results of the measurements on qualitative grounds and takes decisions in terms of meliorating comfort inside buildings, houses and work conditions.*

I. Introduction

The quality of the air inside a building is affected by a variety of comfort, physical, chemical and biological factors. Factors influencing the indoor air quality of a room or building include:

- Comfort issues (temperature, humidity)
- Supply of fresh air to the building,
- Accumulation of particulate, biological or chemical contaminants originating from within or outside the building.

The Indoor Air Quality Measurement (IAQM) aims to provide work areas where as many people as possible can work at their highest level of productivity and effectiveness. This goal is balanced against the physical and engineering constraints of the work areas. The occurrence of illnesses related with poor ventilation has driven an increasing attention towards indoor air quality monitoring. In buildings equipped with climate control systems, the diseases related to the air quality can be significantly reduced if smart intervening procedures, aiming to control the concentration of pollutants in the indoor air, can be implemented in the heating, ventilation air conditioning unit. When reliable information about both the indoor and outdoor air quality is made available, the climate control system can provide the most appropriate amount of ventilation, ensuring safe and comfortable living conditions. It is not possible to provide complete comfort to 100% of the population of every workspace due to individual sensitivities.

In this paper, a dedicated, miniaturized, low-cost electronic nose based on state-of-the-art metal oxide sensors and signal processing techniques was developed. The proposed device is targeted to estimate the concentrations of carbon monoxide, methane, alcohol and nitrogen dioxide in mixtures with relative humidity and volatile organic compounds by using an optimized gas sensor array and highly effective pattern recognition techniques.

II. Electronic Nose

Most of the time, in assessing air quality inside a closed space, a pure qualitative assessment of the air is needed. The qualitative assessment most resembles the use of human senses and instincts. In a closed working space, assessment of the environmental conditions outputs for instance: very good working conditions, good working conditions, ventilation system needed, pollutants present with no harmful action on the workers present, intoxication hazard upon long exposure to the environment, intoxication hazard upon short exposure to the environment, improper work conditions, fire hazard, explosion hazard, danger/death hazard.

For this kind of assessments no massive information storage is compulsory, respectively of the concentrations of atmospheric pollutants at different times, but the assessment can be done directly through evaluating the responses of the sensors in real time by making use of mathematical analysis methods, enabling the qualitative computation as: fuzzy logic and artificial neural networks.

Such intelligent system able to evaluate the indoor air quality inside a working space as well as in the environmental space is an ***electronic nose***.

Embodying the structure of the human olfactory sensor (olfactory mucus, olfactory nerve, olfactory brain) the electronic nose is composed of a high-sensitivity and low selectivity micro-sensors array, a data measurement, transmittal and normalization system and an intelligent decision making system. Fig. 1 shows the block diagram of an electronic nose.

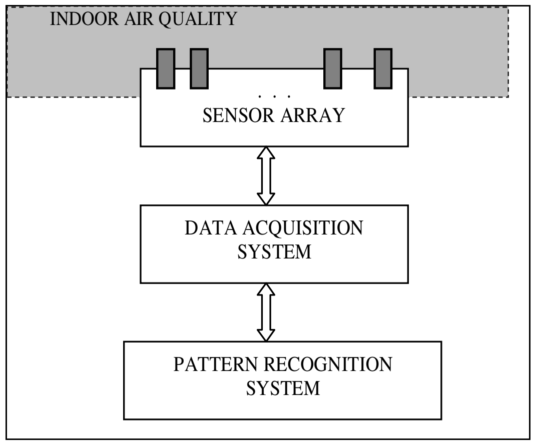

Figure 1. The block diagram of the electronic nose.

A. Sensor Array

The block SENSOR ARRAY contains some gas sensors and their supply circuits.
The sensor array has to ensure high sensitivity to gases of interest, along with low selectivity. This can be achieved at present through using semiconductor materials (organic or inorganic), for odour sensing.
Research effort is now centred upon the use of arrays of metal oxide and conducting polymer odour sensors.
A sensor arrays with semiconductor metal oxide displays the advantage of an easier integration of the sensor into the transducer functional box and ensures good signal repetitiveness.
Sensor arrays with conducting polymer request a more elaborated technology and adjusting circuits of a higher complexity, yet enables engineering their molecular structures for a particular odour-sensing application.
The gas sensors are sensitive to gases polluting the indoors air but they are sensitive to indoors temperature and humidity as well.
A miniaturized, low-cost electronic nose based on state-of-the-art metal oxide sensors and signal processing techniques was developed. The proposed device is targeted to estimate the concentrations of carbon monoxide, methane, alcohol and nitrogen dioxide in mixtures with relative humidity and volatile organic compounds by using an optimized gas sensor array.
The output of the sensor array is a pattern specific to each type of defined environmental quality, identifiable through a process of pattern recognition, namely a specific appliance of the currently produced artificial neural networks.

B. Data Acquisition System

The block DATA ACQUISITION SYSTEM stimulates electrically each sensor and collects the corresponding response. The response of the sensor array consists of an analogical vector, sized up by the actual number of sensors, each value equating the dimension the respective sensor measured at certain time. The data acquisition system multiplexes, samples, digitizes and stores the network response, along with the time the measurement was effected and supplies to the pattern recognition system a digital vector to be categorized.

C. Pattern Recognition System

The PATTERN RECOGNITION SYSTEM takes over this vector, compares it against the vectors already known and includes it into one of the categories defined. Several different data processing and pattern recognition techniques have been used in the literature to recognize signals produced by sensor arrays. These include linear pattern recognition techniques, such as Principal Component Analysis and Cluster Analysis, and non-linear pattern recognition techniques, such as Classical Multivariate Analysis and Artificial Neural Network

Algorithms. As the relationship between the signal produced by sensor and an odorant concentration is usually non–linear, non-linear pattern recognition techniques are generally more successful then linear ones.
The 'Intelligent' Pattern Analysis Techniques comprise: Multilayer Feed forward Networks, Competitive and Feature Mapping Networks, "Fuzzy" Based Pattern Analysis and Neuro-Fuzzy Systems.

III. Indoor Air Quality Assessment

An Electronic Nose can be regarded as a modular system comprising a set of active materials which detect the odour, associated sensors which transform the chemical quantity into electrical signals, followed by appropriate signal conditioning and processing to classify known odours or identify unknown odours. The gas sensors are sensitive to gases polluting the indoors air but they are sensitive to indoors temperature and humidity as well.
Metal oxide gas sensors are sensitive to various combustion and toxic gases, their sensitivity depending strongly upon air (environment) temperature and humidity. This triple-temperature, humidity and impurities concentration in air – sensor sensitivity allows use of these sensors in modeling Indoor Air Quality categories.
The response of the sensor arrays consists of a "characteristic pattern" that is to be classified. Classification is made according to the user's needs.
For Indoor Air Quality Assessment may be proposed the following pattern classes:
a) – cosy, clean air, nice for sleep;
b) – clean atmosphere, coolness, nice for study;
c) – warm atmosphere, slightly polluted, nice for party;
d) – cool atmosphere slightly polluted by organic volatile compounds;
e) – moist atmosphere, polluted by combustion gases;
f) – hot, dry, toxic atmosphere;
g) – cold, moisture, danger of ice;
h) – dry atmosphere, polluted by combustion gases, danger of fire;
i) – very dangerous atmosphere (blasting hazard).

An Electronic Nose for Indoor Air Quality Assessment was simulated. The modelling of the Pattern Recognition System has been made by a multilayer perceptron artificial neural network, presented in fig. 2.

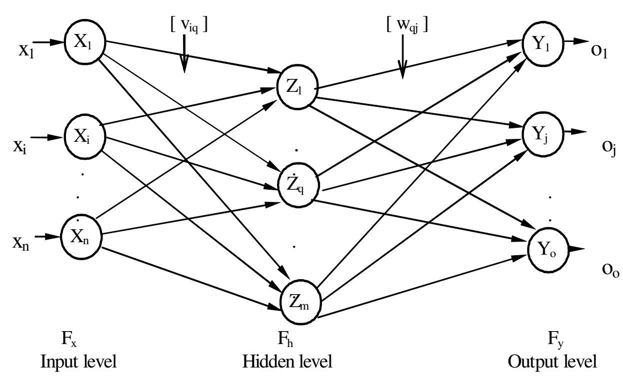

Figure 2. Multilayer perceptron artificial neural network.

The entry level has ***n*** Units equal to the dimension of the input vectors (the number of sensors).
The hidden level consists of **3*n*** neurons with a bipolar activation function, f(x) = *tanh(x)*.
The output level presents ***o*** decision neurons (equal to the number of classes) with a binary activation function: $f(x) = \frac{1}{1-e^{-x}}$.
The known data, measured under the terms of the pattern classes presented above, has been divided into two groups, the training set and the test set, by the rate of 80% to 20%. The training of the network is made using the back propagation method. One has found that a large number of epochs are required, normally over 2000, in order to establish the network weights with an acceptable error (10^{-1}).

By using the network as previously trained to classify the test set of data, one found out that an accurate classification has been made in over 85% of the cases corresponding to the intermediary classes and in over 95% corresponding to the extremity classes (clean air and blast hazard).

The electronic nose was tested in an environment reproducing real operating conditions. Exploiting the unique response patterns of the different sensors in the array and the capability of a simple multilayer perceptron artificial neural network it was possible to identify and discriminate concentrations as low as 25 ppm for CH_4 and 5 ppm for CO in the test gas environment, allowing to reach the necessary sensitivity towards the target pollutants together with the selectivity towards the typical interfering gas species.

These performances of the electronic nose recommend its use for Indoor Air Quality Measurement.
The decisions made by the electronic nose may be subsequently used in actuating heating and ventilation systems, in controlling air conditioning systems, methane supply of fire protection systems and security systems for buildings and personnel.

IV. Conclusions

The electronic nose described in this paper represents a first step toward the assessment of comfort quality in residential buildings and working spaces.
The occurrence of illnesses related with poor ventilation has driven an increasing attention towards indoor air quality monitoring. In buildings equipped with climate control systems, the diseases related to the air quality can be significantly reduced if smart intervening procedures, aiming to control the concentration of pollutants in the indoor air, can be implemented in the heating, ventilation air conditioning unit. When reliable information about both the indoor and outdoor air quality is made available, the climate control system can provide the most appropriate amount of ventilation, ensuring safe and comfortable living conditions.
To rapidly assess the air quality, identify the immediate hazards and unpleasant odours, it would be advisable to use the Electronic Nose, providing for a qualitative assessment of relatively low cost, relying state of the art in materials technology and signal processing. Last but not least, the “decisions” thus made are by far user-friendlier and matching the collective reasoning manner of the addressees.

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