Quantitative Measurements and Qualitative Assessments in Air Quality Monitoring

Sorin Nicolae Cociorva [1]

[1] *Technical University of Civil Engineering, Faculty of Building Services and Equipments, Bulevardul Pache Protopopescu, nr. 66, sect. 2, Bucharest, Romania, (40)21 252 42 80 /130,* *cociorvs@instalatii.utcb.ro*.

Abstract- The present paper sets out an intelligent instrument for a *quantitative measurement* of air quality, consisting of a some gas sensors, each of them being embedded into a adaptation module, an data processing and acquisition module provided with a microcontroller and a decision making, display and alarm system. An *electronic nose* composed of a high-sensitivity and low selectivity micro-sensors array, a data measurement, transmittal and normalization system and an intelligent decision making system is presented of an example of a *qualitative assessment* in air quality monitoring.

I. Introduction

There are two approaches in assessing air quality: *air quality monitoring with quantitative measurements* and *qualitative assessments with electronic noses*.
The ***quantitative approach*** measures, in real time, the concentrations of air pollutants: carbon monoxide (CO), methane, propane, VOC, hydrogen sulphide, alcohol and other flammable and toxic gases (NO_2, SO_2) in a determination location under given temperature, humidity and wind speed. These measurements are strongly influenced and depend on the location of the pollutant sources, the time of the measurement, the working schedule of pollutant and operators, dispersion time, car traffic etc.
The present paper sets out an intelligent instrument to monitor air quality, consisting of a some semiconductor sensors, each of them being embedded into a adaptation module, an data processing and acquisition module provided with a microcontroller and a decision making, display and alarm system.
The ***qualitative approach*** classifies some subjective, immeasurable magnitudes, as environmental quality and air pollution, by way of its qualitative features into various categories. Inspired from the operation of human smelling, an *electronic nose* is proposed for a new approach to assessing the environmental quality in working spaces. 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 block and an intelligent decision making system.

II. Air Pollution Monitoring System

With the view of monitoring the air quality inside a closed or semi-closed space (inner courtyards, stadium, storage spaces etc.) the paper propose a dedicated instrument, an intelligent system of monitoring the air pollution, able to determine in a fast manner the pollutant concentrations, for a number of gases of interest: carbon monoxide, methane, propane, VOC, hydrogen sulphide, alcohol and other flammable or toxic gases.
The Air Pollution Monitoring System (APMS) is build-up base of the principle of multiprocessor electronic measure and control apparatus. A tell apparatus comprise two microprocessors, notably one to control the analogical circuits inside the protected housing, and the other one to ensure linkage with the human operator.
The bloc diagram of an electronic system for measuring the air quality is shown in figure 1.
The system consists of 6 – 12 specialized gas sensors included into measurements modules, supervised by a controlling device with a microcontroller.
Gas sensors can be: electrochemical cells, semiconductor sensors or explosimetric cells.
Depending on the requirements imposed to the (air pollution monitoring system), APMS electrochemical gas sensors are used to detect toxic gases like: NO2, NO3, H2S, SO2, CO, in case

pollution caused by burning fossil fuel or car traffic is to be monitored or combustion gas catalytic sensors (explosimetric cells) n case fire or explosion hazards are to be identified.
The main issues in connection to these sensors are their short life cycle and the relatively easy "empoisoning" by other volatile substances, most frequently organic solvents. Moreover, their high "inertia" impedes identification of short duration pollution peaks.
The infrared absorption sensors are highly sensitive and have a long life cycle, fast responsive, empoisoning and air speed proof yet are expensive and exceedingly specialized, for one gas type only (mostly CO2).
The semiconductor-metallic-oxide-sensors for combustible gases, display the advantage of a good sensitivity, along with a long life cycle and low selectivity. The costs of such devices are close to the electrochemical sensors' ones. In addition to this, the measuring and adjusting circuits are relatively simple. However, these sensors too display a high inertia, their de-empoisoning being quite difficult.
Consequently, for long duration monitoring the use of semiconductor sensors is recommended.

Data acquisition and control unit makes communication with the interfacing blocks of the gas sensors.

The microcontroller facilitates, in the same time, communication through an interfaces circuit with the external data bus of the data acquisition system. The control device establishes the operational status of the signal conditioning blocks performs the measurement and triggers the analogue-digital conversion cycle.

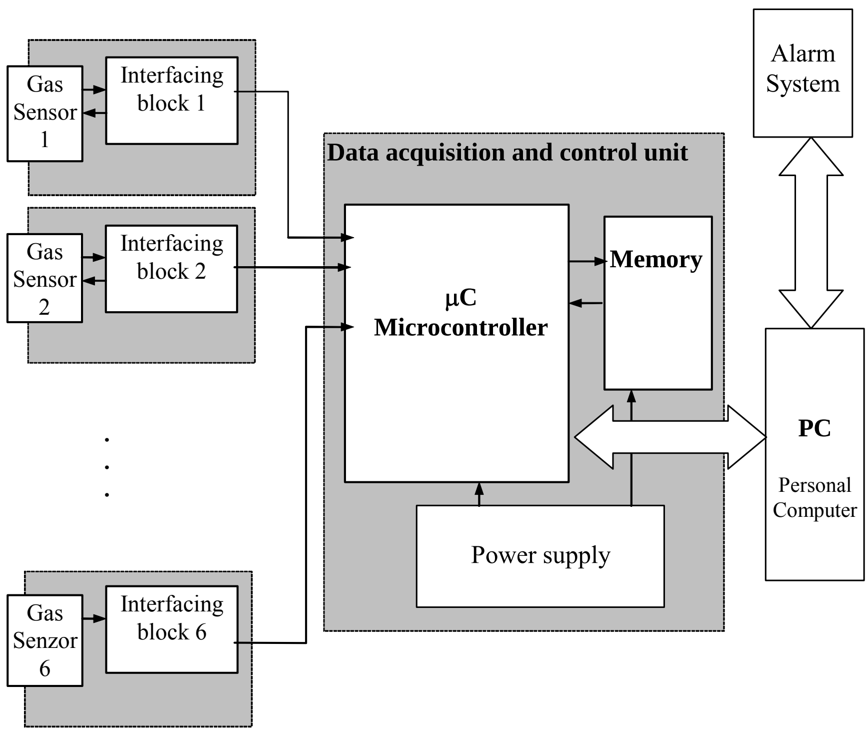

Figure 1. Diagram of the Air Pollution Monitoring System.

The measured magnitudes are transferred to an IT system (work station, PC) taking over, ordering and acquiring the data.
The system may operate either in real time and local alarming mode or in monitoring mode through taking over and conveying data to an outer system, in order to be subsequently analyzed.
Depending on the system storage capacity, measurements can be done every 5 minutes, 30 minutes, half day etc.
Interpretation of the measured data can be done automatically, by using specialized software.
To easy identification of the pollutant, the gas sensors present variable sensitivities to different pollutants, and are calibrated to certain pollutant the one to which it presents the highest sensitivity respectively.

Continuous monitoring is extremely costly from the economical perspective – involving specialized instrumentation, as part of high capacity informatics systems of measurement, acquisition and processing of lot of data.

Table 1
Gases types and concentration range detected with APMS.

Gas Type	Concentration range	Applications
methane, propane, butane	100 -10000 ppm	pollution detection , explosion risk
hydrogen	50 - 1000 ppm	pollution detection , explosion risk
carbon-monoxide	20 - 1000 ppm	incomplete combustion protection, health protection
alcohol organics solvencies	20 - 500 ppm	explosion risk, technological losses
hydrogen sulfide	2 - 200 ppm	pollution detection, health protection
ammoniac	10 - 300 ppm	pollution detection, health protection
Chlorofluorocarbons	30 - 3000 ppm	pollution detection, health protection, technological losses

The system thus presented enables a permanent monitoring or a monitoring within the period of interest (during productive activities, during traffic peaks, during the calmness periods of the atmosphere and whenever high temperatures arise – smog hazards) and enables further studying of the various phenomena as: dispersion of the pollutants, accumulation of the gases triggering greenhouse effect, assessment of the fire hazard, assessment of the effect of pollutants on people and over local, regional and global ecosystems.

III. Electronic nose

Most of the time, in assessing air quality inside a closed, semi-closed or even open 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 or semi-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 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.
Figure 2 shows the block diagram of an electronic nose.
The block SENSOR ARRAY contains some gas sensors and their supply circuits.
Likewise the olfactory mucous membrane, 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.

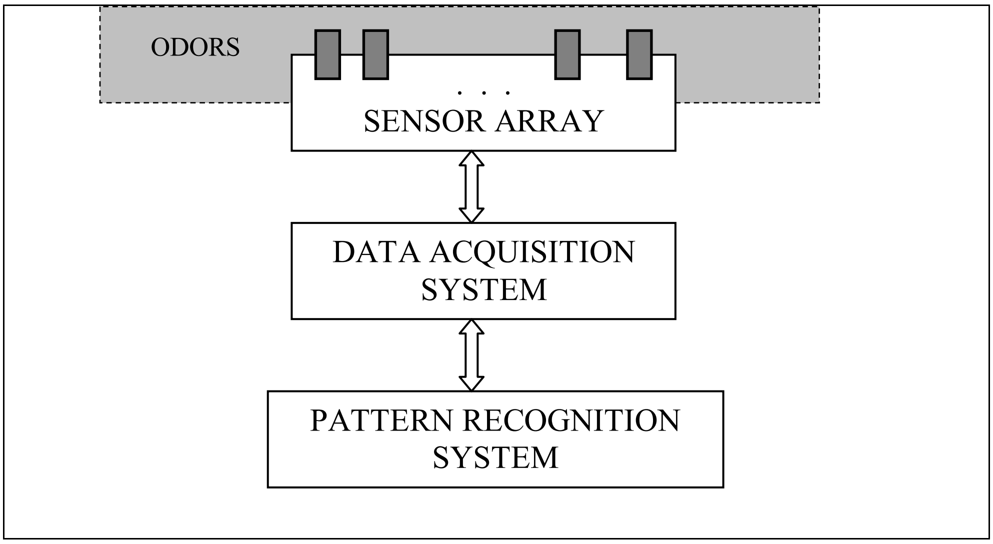

Figure 2. The block diagram of the electronic nose.

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 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.
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.
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 Feedforward Networks, Competitive and Feature Mapping Networks, "Fuzzy" Based Pattern Analysis and Neuro-Fuzzy Systems.
An Electronic Nose can be regarded as a modular system comprising a set of active materials which detect the odour, associated sensors which transduce the chemical quantity into electrical signals, followed by appropriate signal conditioning and processing to classify known odours or identify unknown odours.

For Air Quality Assessment there are proposed the following pattern classes:

- *a)* –very clean atmosphere;
- *b)* –clean atmosphere;
- *c)* –atmosphere slightly polluted by toxic gases (CO);
- *d)* – atmosphere slightly polluted by organic volatile compounds;
- *e)* – atmosphere polluted by combustion gases (methane, ethane,…);
- *f)* – toxic atmosphere;
- *g)* – dangerous atmosphere (polluted by combustion gases);
- *h)* – very dangerous atmosphere (blasting hazard).

The modelling of the network has been made by multilayer perceptron artificial neural networks, one entry level having n Units equal to the dimension of the input vectors (the number of sensors), a hidden level consisting of 3n neurons with a bipolar activation function and an output level with o decision neurons (equal to the number of classes) and a binary activation function.

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 is 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 (very clean air and blast hazard).
These performances of the electronic nose recommend its use for Environmental Quality Assessment indoor and outdoor of building and of the atmosphere in general. The ***qualitative approach*** is indicated to determine air quality inside and outside of working areas, to assess fire or explosion hazard.

IV. Conclusions

The ***Air Pollution Monitoring System*** is necessary to measure the extent of the atmospheric pollution by toxic gases, to identify the pollutants and pollution sources, where the use of the quantitative monitoring methods is absolutely needed. The solution is relatively costly and requires collection of a significant quantity of data, followed by the interpretation thereof.
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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