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The Applications of the New Technologies "E-Sensing" in Hospitals

M. Cannistraro[1*] and E. Lorenzini[2]

[1]Research Fellow University of Ferrara, Italy
[2]University of Bologna, Alma Mater Studiorum, Italy

Email: mauro.cannistraro@unife.it

ABSTRACT

The technologies or techniques "e-sensing", in the past decade have had significant developments from the technical and commercial point of view. The term "e-sensing", refers to the ability to reproduce human senses by means of sensors and recognition systems. The proposed work has been developed within the doctoral thesis and is part of a larger research project about sensors underway at the Faculty of Engineering of Messina. The research, combining the knowledge of engineering methods and tools with medical and chemical competence, is oriented to the development of a system able of monitoring the exhaled air for diagnostic purposes, for the realization of electronic systems at a low cost, for the diagnostics in medicine. It was built an artificial olfactory system, known as "electronic nose", which allows monitoring the exhaled air components of patients undergoing a dialysis treatment. This diagnostic non-invasive method is able to provide at low cost, through the specific control of the markers of the exhaled air, some useful information to assess health of dialyzed patients. The realized device, was tested for biomedical applications and mainly for the specific monitoring of volatile biomarkers in the exhaled air, associated with certain medical conditions (eg. NH_3 for nephrological diseases). It will allow to obtain an effective early diagnosis of the disease reducing care times and, at the same time, reducing the invasiveness of diagnostic treatments.

Keywords: E-sensing, Electronic nose, Support vector machine, Safety monitoring.

1. INTRODUCTION

In everyday life, the importance of electronic sensors and biosensors is growing exponentially, and is directing the scientific community to increase the studies of versatile platforms that can be used for various mass applications and for the realization of low cost products.

Most applications of EAD technologies hitherto have been in industrial production, processing, and manufacturing.

Some of the more common manufacturing applications have been in quality control and grading, product uniformity and consistency, processing controls, gas leak detection and environmental effluents monitoring.

Applications are continuously being developed in many new areas of applied research such as for volatile emissions assessments, homeland security, environmental protection, biomedical diagnoses, personnel safety, and in product development research [1-11].

The tab.1, reported below, shows the list of the possible application of electronic nose in various fields and sectors.

The present work is part of a larger research project about sensors.

It combines the new instrumentation and the engineering knowledge with chemistry and medicine, and it is the attainment of a diagnostic monitoring for human diseases [12-26].

The intended goal is to use an artificial olfactory system, designed and built in a laboratory, and hereinafter referred to as "Electronic Nose", in order to analyze and monitor patients undergoing dialysis treatment.

2. ANALYSIS OF THE AIR EXHALED

In recent years the analysis of the expired air has been proposed as a diagnostic tool for a variety of lung diseases.

It is well known that the expired air contains hundreds of gases and volatile organic compounds (VOCs) from metabolic and inflammatory body pathways l [12].

2.1 Clinical diagnosis through breath testing

There are volatile organic compounds detected in human exhaled air that become dangerous if their concentration exceeds a certain range.

Among them:

- Ethanol: it makes possible, through exhaled air, the assessment of the legal alcohol limit in the human body's blood.

Table 1. List of the electronic nose applications in various sectors

SECTORS	APPLICATIONS / FUNCTIONS
Agribusiness/Zootecnic	• Traceability of food • No-adulteration • Environmental Monitoring in greenhouses • Environmental Monitoring in farms
Environmental	• Pollution Control in the city • Indoor air pollution control (IAQ) • Tests for harmful emissions and harassing • Surveillance volcanic areas • Control of drinking water and industrial water
Biomedical	• Early diagnosis of various diseases • Automatic control of health status in patients dependents
Industrial process control	• Product quality control and process of industrialization in industries: packaging, food and transport • The level of cleanliness control • Formulation of new products
Aerospace	• Air Control in the cabin and in space stations
Safety	• Monitoring of potentially risky places for humans • Detection of explosives • Detection of drugs

It was further established its presence in patients suffering from nonalcoholic fatty liver disease.

- Acetone: its concentration increases in a healthy human being, from 300-900 ppb to 1800 ppb in diabetic patients**.**

- Carbon Monoxide: it is used in the breath control of the smokers but also as CO poisoning tests. It is also a biomarker in pulmonary and systemic inflammatory diseases. In the breath of a nonsmoker, its concentration is 0.4-0.8 ppm, vice versa is 2-20 ppm.

- Ammonia: the permitted exposure limit is set to 35 ppm over 15 minutes. It is a useful indicator for the diagnosis of kidney diseases.

- Nitric oxide: nitric oxide (NO or more correctly nitrogen monoxide) is an endogen mediator of very important processes, such as the vasodilatation and the transmission of nerve impulses. It is important to diagnose serious diseases such as bronchial asthma.

- Carbonyl sulfide: it has been identified as a biomarker for liver diseases. High COS concentrations were also found in lung transplant patients who had acute transplant rejection. Exposure to COS may cause adverse effects on patients.

- Hydrogen sulfide: It is a powerful anti-inflammatory, antioxidant and anti-apoptotico5.

Its concentration in the breath is high if the range is 20-70ppb.

At high concentrations it paralyzes the olfactory nerve and can cause unconsciousness in a few minutes.

To learn more about the human exhaled air, first we must examine what a man inspires in order to know its characteristics.

The atmospheric composition of air at sea level, is reported in Tab.2, with values % refer to weight

- **Hydrogen**: it is a valid non-invasive tool to assess gastroenterological conditions.

Gas produced during the bacterial fermentation in the colon spreads into the blood and then in the breath.

Appreciable quantities of hydrogen are released when, for example, you ingest fermentable substrates, mainly carbohydrates**.**

- Hydrogen Peroxide: an increase of this human exhaled air component is present in patients suffering from various pulmonary inflammatory diseases and in uraemic patients undergoing regular hemodialysis.

From the foregoing description we realize how the blood can vehicular some harmful substances to our health and to the functionality of various organs.

The presence of the renal apparatus, whose job is the excretion of water, ions, and waste products, ensures the proper discharge of the body functions.

Table 2. Characteristics of atmospheric air components and exhaled air with value of the % in weight

Characteristics atmospheric air			Characteristics air exhaled		
Components	pressure	%	Components	pressure	%
- O_2 Oxygen	158 mmHg	20,9%	- O_2 Oxygen	116 mmHg	15,3%
- CO_2 Carbon Dioxide	0,3 mmHg	0,04%	- CO_2 Carbon Dioxide	32 mmHg	4,2%
- H_2O Water	5,7 mmHg	0,75%	- H_2O Water	47 mmHg	6,2%
- N_2 Nitrogen	596 mmHg	78,4%	- N_2 Nitrogen	565mmHg	74,3%
- Infinitesimal traces and other gases					

3. EXPERIMENTAL APPARATUS OF THE ELECTRONIC NOSE

The preliminary stage for the realization of the electronic nose is represented by the preparation of the circuit diagram which led to the design of the circuit.

It contains various electric components and connections in the mechanic container, where detecting sensors have been positioned. [14].

On the basis of what is described, the printed circuit board has been realized by assembling the various components on the same card, followed then by the assembly of the various sensors at appropriate points in the container.

Fig.1/s shows the sampling system box; Fig.1/b shows the chamber of sensors of the electronic nose.

Tab. 3 shows the sensors in the electronic nose.

To analyze the exhaled air components, you need to transfer the flow of air inside the chamber, as Fig.1/a and Fig.1/b show.

In the next section this aspect will be developed, by using the sampling circuit of the exhaled air.

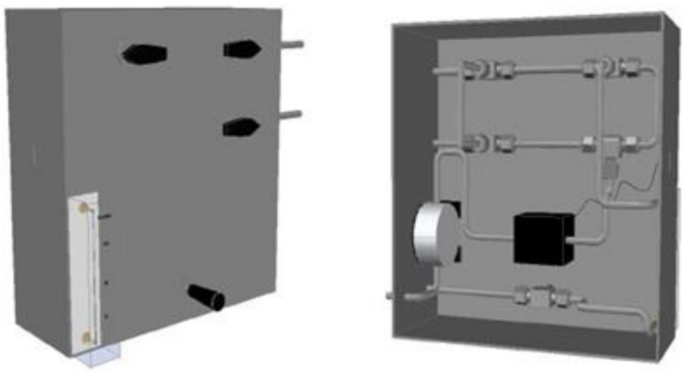

Figure 1/a. Sampling system box

Table 3. The sensors in the electronic nose

Sensors	Target	Operating range	Calibration range
TGS822	C_3H_6O	50-5000 ppm	1 - 100 ppm
TGS2600	CO	1 - 100 ppm	0, 5 - 50 ppm
TGS82602	H_2S	0, 1 - 3 ppm	20 - 500 ppm
TGS826	NH_3	30 - 300 ppm	1 - 10 ppm
TGS4161	CO_2	400-4500 ppm	400-50000 ppm

3.1 The sampling system of human exhaled air

The sampling system is designed to take a portion of the exhaled air to be analyzed.

The exhaled air through a small tube is placed within the sampling system.

Subsequently, through two three-way valves, it is conveyed in a sampler tube.

In order to transport the exhaled air, a line of compressed-air input is used to maintain the sensor under a reference gas flow at known volume.

A needle valve and a flow meter, regulates the flow speed.

Fig.2 shows the scheme of the sampling system described above.

To use the electronic-nose system in different environments from laboratory, it was made a 30×30×10 cm sized metal box containing the chamber of the electronic nose, the valves and the piping system.

In the previous phase it was described the realization of the electronic nose.

Its wiring diagram was analyzed with the individual components, the room of the six tensors housing the sensors and the sampling system used.

The sensors of the atmospheric parameters have been located within the chamber, for this purpose has been realized a small container of circular shape, of the same diameter of the chamber in which the sensors with its additional components (resistors and capacitors) are positioned.

The electronic nose, before being used for analyzing the various gas species components of the exhaled air, has been "trained" for the recognition of the various gaseous species.

In the embodiment of this first phase, developed in a laboratory, the instrument was supplied with the data base necessary for the next gas recognition.

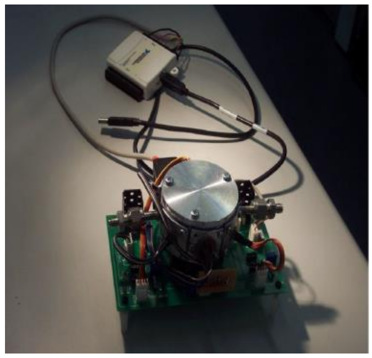

Figure 1/b. Chamber of sensors of the electronic nose

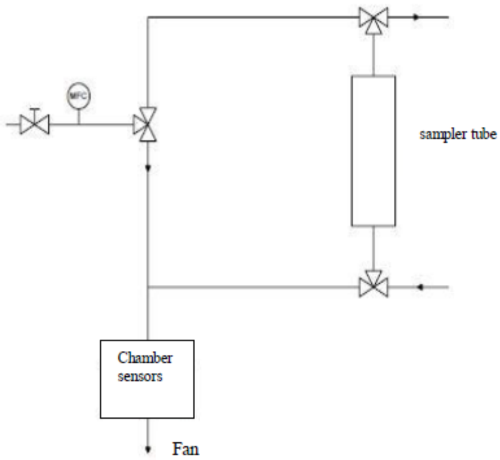

Figure 2. Scheme of the sampling procedure

For this purpose it was used an "Experimental setup".

As Fig.3 shows, the experimental apparatus with the purge gas system is under an extractor hood.

In Fig. 3 you can see the following main components of the experimental apparatus:

- Cylinders
- Flow control
- Flow permeation tubes Controller
-Bubbler
-Thermo cryostat

When a gas is present, each sensor reports an electrical signal.

The acquisition of the electrical signal is handled through a program created ad hoc by LabWindows/CVI software.

The main purpose of the software is to reprocess signals supplied from the USB-6009 card, representing the output voltage values of each sensor, and to show them graphically and numerically on the terminal monitor in real time.

In the training phase, the output signals of sensors have been stored, in order to obtain a useful database to various cases studies encountered during use.

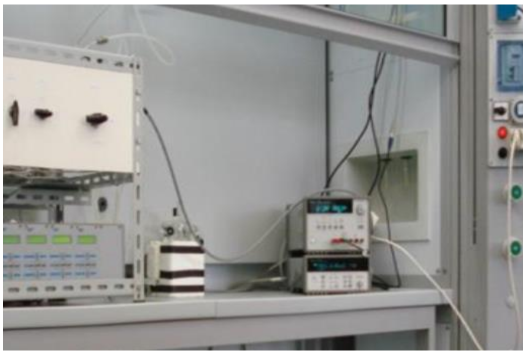

Figure 3. Experimental apparatus, with analogical controller "*BRONKHORST E7000*"

4. MEASUREMENTS AND RESULTS

The responses of each sensor belonging to the device, were compared in laboratory and then tested to evaluate the repeatability of the sensors: Carbon Dioxide, Carbon Monoxide and Ammonia. The baseline was obtained with a gas mixture of 20% of O_2 and 80% of N_2.

Three healthy subjects were tested. The answers provided by these patients made it possible to verify the truthfulness of the electronic nose results.

At the nephrology department of General Hospital of Messina, further tests of the device on dialysis patients has been performed to test the reliability of the equipment.

As far as the reliability of the sensors placed in the nose, preliminary tests at different concentrations were made, graphing the sensor response, in absence and presence of the gas target.

The results are shown in Fig.4.

You can see the sensor is highly sensitive to changes of CO_2 concentration, presenting an immediate response.

It is interesting to notice that the baseline is quickly recovered as soon as the carbon dioxide is removed from the gaseous mixture.

The calibration curve, shown in Fig.5, has been obtained through these measures.

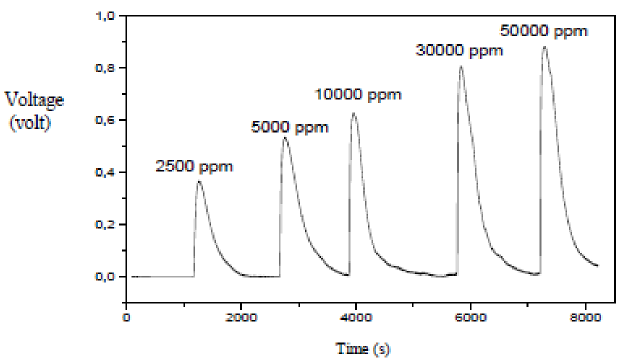

Figure 4. Sensor TGS4161 response CO_2 concentrations

In order to check the repeatability of the sensor response, we sent more times CO_2 at a concentration of 2500 ppm.

As it is observed in Fig.6, the sensor shows an excellent reproducibility of the response and a stability of the device with time. Also the other gas sensors react to detection of Carbon Dioxide.

Although they show an increased stabilization time after the removal of gas to return then to the basic value.

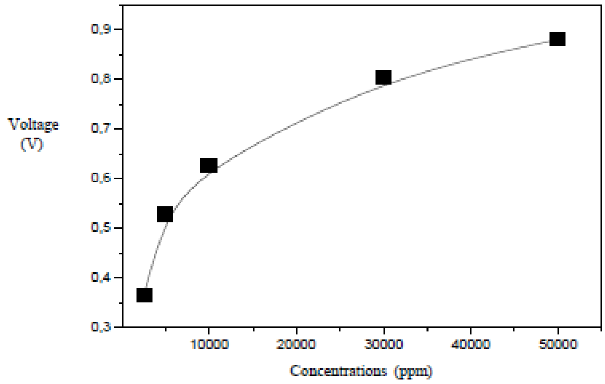

Figure 5. Calibration curve of the sensor TGS4161

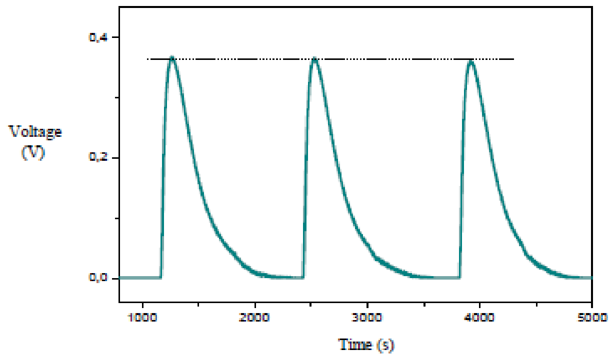

Figure 6. Repeatability sensor TGS4161 in CO_2 presence

Fig.7 shows the dynamic response obtained at a concentration of 800 ppb.

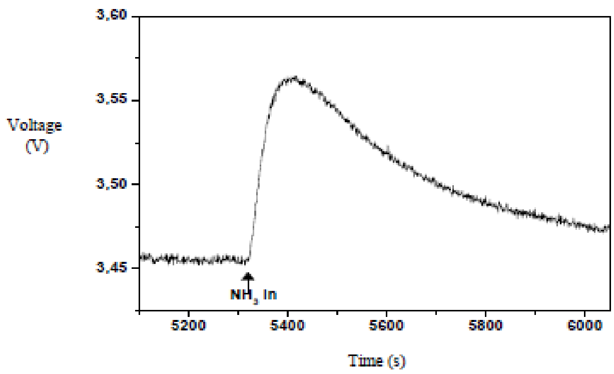

Figure 7. Dynamic response of the sensor TGS 826 at a concentration NH_3, of 800 ppb

Good is the rapidity with which the presence of ammonia is detected, with response times to the order of a second.

The base line is quickly recovered as soon as the ammonia is removed from the gaseous mixture.

The observed peak is due to a change in flow, as a consequence of the flow meter activation, that introduces the recovery air at the initial conditions.

The repeatability tests have provided a good answer.

4.1 Breath tests by subjects not affected by pathology

Tests with air exhaled by subjects not affected by pathology, were performed by connecting a small tube to the sampling system. The exhaled air from a subject has been taken three times every quarter of an hour, obtaining the sampling basis that was useful then to compare with those of other two healthy subjects.

We can highlight how the pattern of the array sensor responses changes from one subject to another.

This is to be related to pulmonary ventilation and especially to the health of the individual.

The histogram in Fig.8 shows the comparison of the 3 subjects breath components.

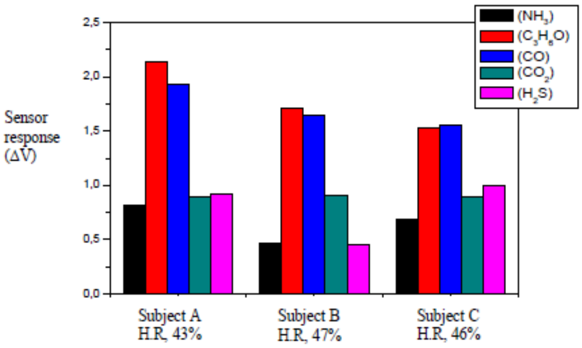

Figure 8. Comparison of the components of three subjects

4.2 Test with air exhaled by a person on dialysis

Afterwards tests have been performed on patients in dialysis, using a device for monitoring the exhaled air.

The array of the sensor response has been acquired by performing measurements before and during the dialysis treatment, at half an hour intervals from each other.

Fig.9 reports the sensors response trend of the array components acquired during the dialysis cycle.

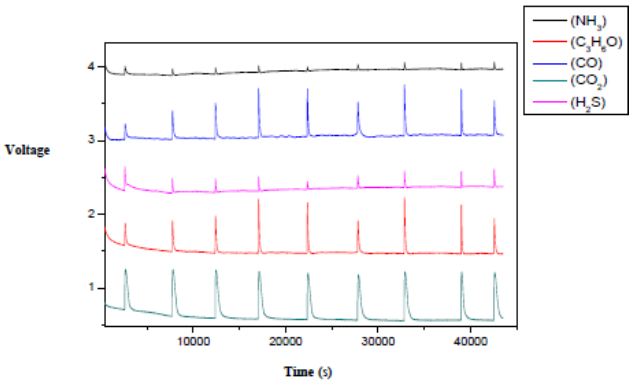

Figure 9. Sensor response in function of the exhaled air by a dialysate

The histogram in Fig.10 shows the values by components of exhaled air by people in dialysis therapy, for different values of air humidity.

The answers of the array vary over time accordingly to changing patient's clinical condition during dialysis.

For a careful analysis it is necessary to compare the data obtained with the clinical values performed, in the same conditions, through the analysis of blood.

These analysis moreover vary according to the subject's therapy and state of health.

You can notice the behavior recorded by the sensors is worthy of attention.

Specifically, the ammonia sensor has a regular decrease in response to the dialysis time.

It was already highlighted, that ammonia present in human exhaled air, is considered a biomarker correlated to the nitrogenous substances (urea and creatinine) of blood.

These last are the routine references in the assessment test of the clinical status during dialysis.

Urea and creatinine are progressively eliminated during dialysis, so that blood is purified of these toxic substances.

Since there is a balance with the ammonia in breath even the latter decreases over time.

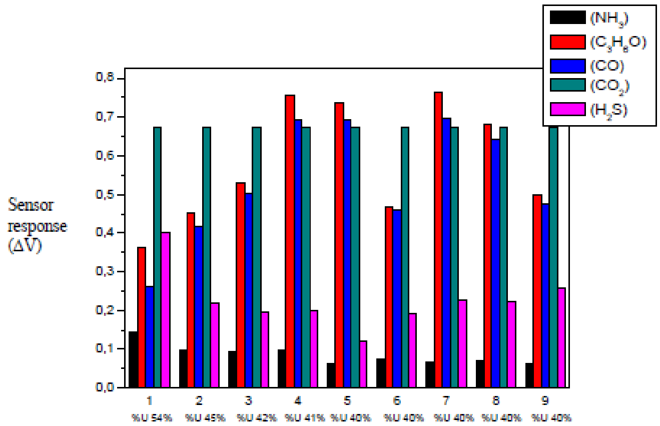

Figure 10. Components exhaled by a subject in dialysis therapy

The gradual lowering of the NH_3 sensor response, shown in Fig.11, is in line with what was expected.

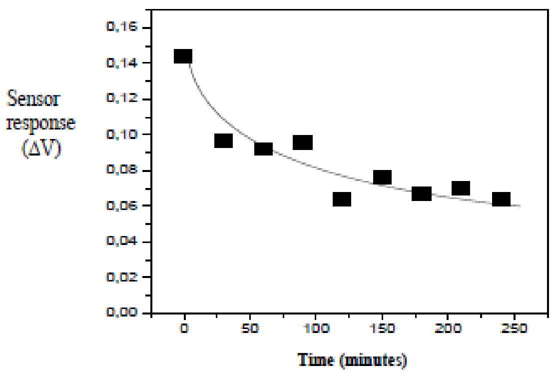

Figure 11. Sensor response NH_3 to changes of the dialysis time

5. CONCLUSIONS

The device is of great interest, both in scientific and commercial area, as it is able to give us real extemporaneous indications of dialysis.

From a clinical point of view it is also important to follow the responses evolution of the other sensors over time.

The research, which has led to the creation of an electronic nose for biomedical applications, is the beginning of a project still to improve.

The first steps have made it possible to verify the sensor responses, both in laboratory and in biomedical field.

From a medical point of view, its use constitutes a valuable, non-invasive tool, for physiological and pathological diagnosis of patients during the dialysis therapeutic cycle, improving their quality of life.

Through a simple breath, and considering the array of the sensors response, it is possible to observe the differences of the exhaled air components.

In a patient during the phases of dialysis treatment, with a simple breath, considering the array of the sensors response, it is possible to observe the differences of the exhaled air components, respect at the standard values of the subjects in healthy.

Tests carried out in hospital show how the qualitative sensors response concurs with the variations of the commonly monitored target through blood samples.

Applications of such sensors were obtained in sectors shown in Tab.1, in particular of environmental and industrial monitoring and for the control of Indoor comfort parameters [27, 30].

REFERENCES

[1] Yea, B., Konishi, R., Osaki, T. and Sugahara, K. "The discrimination of many kinds of odor species using fuzzy reasoning and neural networks," *Sens. Actuat*, vol. 45, pp. 159-165, 1994.

[2] Egashira, M. and Shimizu, Y., "Odor sensing by semiconductor metal oxides," *Sens. Actuat*, vol. 14, p. 443, 1993.

[3] Yim, H.S., Kibbey, C.E., Ma, S.C., Kliza, D.M., Liu, D., Park, S.B., Torre, C.E. and Meyerhoff, M.E., "Polymer membrane-based ion-, gas-, and bio-selective potentiometric sensors," *Biosens. Bioelectron*, vol. 8, pp. 1-38, 1993.

[4] Persaud, K.C.; Qutob, A.A.; Travers, P.; Pisanelli, A.M.; Szyszko, S. "Odor evaluation of foods using conducting polymer arrays and neural net pattern recognition," Olfaction and Taste XI., Kurihara, K., Suzuki, N., Ogawa, H., Eds., Springer-Verlag, Tokyo, Japan, 1994, pp. 708-710.

[5] Aishima, T., "Discrimination of liqueur aromas by pattern recognition analysis of responses from a gas sensor array," *Anal. Chim. Acta*, vol. 243, pp. 293-300, 1991.

[6] Hanaki, S.; Nakamoto, T. and Moriizumi, T. "Artificial odor recognition system using neural network for estimating sensory quantities of blended fragrance," *Sens. Actuat.*, vol. 57, pp. 65-71, 1996.

[7] M. Cannistraro, G. Cannistraro, A. Piccolo and R. Restivo, "Potential and limits of oxidative photocatalyses and possible applications in the field of cultural heritage," *Advanced Materials Research*, vol. 787, pp. 111-117, 2013, Trans Tech Publications, Switzerland.

[8] G. Cannistraro, M. Cannistraro, R. Restivo, "Messina's historical buildings after the earthquake of 1908: energy and environmental analysis through a global screening methodology," *International Journal of Heat & Technology*, vol. 31, no. 2, pp. 155, 158, 2013. DOI: 10.18280/ijht.310221.

[9] G. Cannistraro, M. Cannistraro, R. Restivo, "Some observations on the radiative exchanges influence on thermal comfort in rectangular open-space environments," *International Journal of Heat & Technology*, vol. 33, pp. 79-84, 2015. DOI: 10.18280/ijht.330213.

[10] G. Cannistraro, M. Cannistraro, and R. Restivo, "The local media radiant temperature for the calculation of comfort in areas characterized by radiant surfaces," *International Journal of Heat & Technology*, vol. 33, pp. 115-122, 2015. DOI: 10.18280/ijht.330116.

[11] G. Cannistraro, M. Cannistraro, A. Cannistraro, A. Galvagno and G. Trovato, "Evaluation of the convenience of a citizen service district heating for residential use. A new scenario introduced by high efficiency energy system," *International Journal of Heat & Technology*, vol. 33, no. 4, pp. 167, 172, 2015, DOI: 10.18280/ijht.330421.

[12] G. Cannistraro and M. Cannistraro, "Hypothermia Risk, monitoring and environment control in operating rooms," *International Journal of Heat & Technology*, vol.34, no. 2, pp. 165, 171, June 2016. DOI: 10.18280/ijht.340202.

[13] G. Neri, *Solid-State Gas Sensors for Clinical Diagnosis*, Chapter 8, pp. 201-227, 2012.

[14] G. Neri, A. Lacquaniti, G. Rizzo, N. Donato, M. Latino and M. Buemi, "Real-time monitoring of breath ammonia during haemodialysis: Use of ion mobility spectrometry (IMS) and cavity ring-down spectroscopy (CRDS) techniques," pp. 1-8, 2011.

[15] M. Cannistraro, S. G. Leonardi, D. Aloisio, E. Patti, C. Pace, W. Khalaf, N. Donato and G. Neri, "Development of electronic-nose technologies for biomedical applications," Congresso Intern.le XVII Annual Conference AISEM, Brescia, Feb. 5-7, 2013.

[16] C. Marichy, N. Donato, M.-G. Willinger, M. Latino, D. Karpinsky, S.-H. Yu, et al., "Tin dioxide sensing layer grown on tubular nanostructures by a non-aqueous atomic layer deposition process," *Advanced Functional Materials*, vol. 21, no. 4, pp. 658–666, 2011.

[17] W. Khalaf, C. Pace and M. Gaudioso, "Least square regression method for estimating gas concentration in an electronic nose system," *Sensors*, vol. 9, pp. 1678-1691, 2009.

[18] A. Caddemi, F. Catalfamo and N. Donato, "Cryogenic HEMT noise modeling by artificial neural networks," *Fluctuation and Noise Letters*, vol. 5, no. 3, pp. L423-L433, Sept 2005.

[19] C. Pace, W. Khalaf, M. Latino, N. Donato, G. Neri, "E-nose development for safety monitoring applications in refinery environment", Elsevier, *Procedia Engineering*, vol. 47, pp. 1267, 1270, 2012.

[20] Wongchoosuk, C., et al., "WiFi electronic nose for indoor air monitoring," *In: 2012 9th International Conference on Electrical Engineering/Electronics, Computer, Telecom and Information Technology*, ECTI-CON, 2012.

[21] Zhanga, L., et al., "Classification of multiple indoor air contaminants by an electronic nose and a hybrid support vector machine," *Sens. Actuators*, vol. B174, 2012.

[22] Neri, G., Bonavita, A., Galvagno, S., Pace, C. and Donato, N., "Preparation, characterization and CO sensing of Au/Iron oxide thin films," *J. Mater. Sci. Mater. Electron*, vol. 13, pp. 561–565, 2002.

[23] Solga, S.F., et al., "Current status of clinical breath analysis," *Appl. Phys. B*, vol. 85, 2006.

[24] Goerl, T., et al., "Volatile breath biomarkers for patient monitoring during haemodialysis," *J. Breath Res.*, vol. 7, 2013.

[25] Neri, G., et al., "Real-time monitoring of breath ammonia during haemodialysis: use of ion mobility spectrometry (IMS) and cavity ring-down

spectroscopy (CRDS) techniques," *Nephrol Dial Transp*., vol. 27, pp. 2945–2952, 2012.

[26] Chang, C.C. and Lin, C.J.. *Libsvm: A Library for Support Vector Machines*, Version 3.17 released on April Fools' day, 2013. http://www.csie.ntu.edu.tw/~cjlin/libsvm/

[27] Khalaf, W., et al., "Least square regression method for estimating gas concentration in an electronic nose system," *Sensors*, vol. **9**, pp. 1678–1691, 2009.

[28] Pace, C., Khalaf, W., Latino, M., Donato, N. and Neri, G., "E-nose development for safety monitoring applications in refinery environment," *Proc. Eng.*, Elsevier, vol. 47, pp. 1267–1270, 2012. ISSN: 1877-7058

[29] G. Cannistraro, M. Cannistraro, A. Galvagno, G. Trovato, "Evaluation technical and economic the integrations of co-trigeneration systems in the dairy industry," vol. 34, special issue 2, October 2016, pp-s332, s336. DOI: 10.18280/ijht.34S220

[30] G. Cannistraro, A. Cannistraro M. Cannistraro, A. Galvagno and G. Trovato, **"**Analysis of the air pollution in the urban center of four sicilian cities," vol. 34, Special Issue 2, October 2016, pp. S219, 225. DOI: 10.18280/ijht.34S205.

[31] G. Cannistraro, M. Cannistraro, A. Galvagno, G. Trovato, "Reduced the Demand of Energy Cooling in the CED, Centers of Processing Data, with use of Free-Cooling Systems", *V*ol. 34, N.3, Sept 2016, pp. 489, 502. DOI: 10.18280/ijht.340321.

[32] G. Cannistraro, M. Cannistraro and A. Cannistraro, "Evaluation of the sound emissions and climate acoustic in proximity of one railway station", *International Journal of Heat and Technology*, vol. 34, Special Issue 2, October 2016, pp. S589, 596. DOI: 10.18280/ijht.34S255.