A Wireless Electronic Nose for Emergency Indoor Monitoring

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Abstract—**The non-compliance with the ambient air quality standards in hospitals as well as in all working settings can cause possible adverse effects on health of people. It is extremely important to monitor public exposure of air pollutant contaminants in order to prevent air quality related emergencies such as heavy smoke from fires or toxic releases.**

In this paper a wireless device for monitoring air quality is presented. Each node, based on commercial gas sensor arrays and a ZigBee wireless network interface, is local powered by plugging it into a generic light socket. No wiring is required for data transmission. Air data measured by nodes are delivered via ZigBee network to a database station where different technical analyses can be used to obtain pollutant dispersion information. This system can be used for monitoring and classifying Hazardous Air Pollutants in various places: laboratories, offices and operating rooms. Thus, the wireless electronic nose approach aims at strengthening its potential for automatic environment monitoring with regard to many industrial applications too.

Keywords: e-nose, environment, emergency

I. INTRODUCTION

The implementation and development of electronic noses are linked to different areas of application today. In food field artificial olfactory systems have an important role for preventing food fraud. Similarly, in industrial areas (e.g., industry of perfumes and cosmetics) there are many potential applications, such as the dangerous chemical agent detection. In the healthcare field, extensive researches, based on a thorough examination and appropriate investigations of relevant data as a result of medical diagnosis in this regard, were conducted. The most promising results have been obtained with the detection of lung cancer through breath. The principle is based on clinical chemistry. In fact, the chemical composition of a person's breath changes when they develop this disease. Furthermore, numerous scientific studies have clearly demonstrated the influence that the air has on human health. The great importance of the continuous air monitoring in residential areas or in workplaces is really self evident. Particular attention is given to the risk factors for specific population groups (children, elderly, sick, etc). This paper aims to define a low-cost, real time, self configurable sensor network for the continuous evaluation of indoor/outdoor air quality.

A classical limit of monitoring is the data network wiring. Currently, fully wired buildings are going to become the norm, but this feature is typically reserved to working areas and not to service and technical areas (i.e. storage room, basement and wire way).

Particular consideration, by the same authors, has been given to air quality in hospital environments. In [1] we report an application of monitoring system within laboratories, operating rooms, and executive offices. However this technology can be applied to several industrial and domestic fields.

From the environmental perspective, the hospital is characterized by a mixture of gases and chemical products (many of which are volatile organic compounds) used in therapy and generic activity (cleaning, maintenance, potting etc).

The monitoring stations, for checking the presence of hazardous substances to human health, are only located in operating rooms and in specific laboratories (that use antiblastic and another dangerous compounds). Therefore, these devices cannot provide the control of the whole hospital, but only of some spaces.

In addition to human risks, the presence of oxygen, butane and other technical gases highlights the risk of explosion.

Significant examples of rules to be observed are offered by the Italian Public Health Office: Circular letter n. 5 of the year 1989, that establishes the maximum concentration levels of substances used for anesthesia gases in operating rooms (*Guidelines for environmental and hygienic procedures in operation theatre)* and the DECREE on April 9, 2008, n. 81 for the protection of health and safety at work [9].

It is clear that the proposed technologies can be used in fire, flooding and contamination detection [2-3].

With the continuous development of wireless sensor network (WSN), the usability of sensors is becoming increasingly prevalent in our environments. Therefore, combining an electronic nose technology with WSN to realize wireless detection system can be seen as a very important step in the right direction of human safety research. According to this trend, a wireless electronic nose has been developed; the device has been based on IEEE 802.15.4 or the so-called ZigBee and tested for environment monitoring in various rooms and areas.

ZigBee technology is a short-range (10-300 feet), low power, low-speed, low-cost wireless communication technology, mainly for wireless sensor networks, automatic control and remote control areas. It is, generally, considered as a good wireless communication protocol, because it fully meets the requirements of WSN application and owns such property as higher reliability, self-organization network, self-cure capacity and large network volume [2].

In this paper after a methodological approach, describing the sensors and the circuits of the electronic nose, a case study with the related results is discussed.

II. METHODOLOGY

The design of the wireless electronic nose node (e-nose) can be divided into three parts including sensor and electronic hardware, power supply and ZigBee network interface.

A. Electronic Hardware and Sensor

The e-nose is composed of an acquisition module comprising the sensors and the signal conditioning circuitry, and an interface to the ZigBee transponder, also a different protocol transponder or a data-logger that records the data in an SD memory can be used [4]. For specific applications in medical and hospital environments, the following sensors are provided: LM335 sensors for detecting temperature, HIH-4000-001 for relative humidity, TGS2620 for CH_4 and TGS2602 to monitor CO, MQ811 for CO_2, and MQ137 for NO_x, and MQ131 for O_3 and MQ136 for SO_x.

The criterion for the choice of these sensors was based on the need for covering the greatest range of pollutants to be observed in hospital environment [Table I].

These sensors are semiconductor gas sensors and they are widely used for detecting inflammable gases and certain toxic gases in air. The adsorption or reaction of a gas on the surface of the semiconducting material induces a change in the density of the conducting electrons in the polycrystalline sensor element. This chemical reaction can be described by four steps as follows:

- Pre-adsorption of oxygen on semiconducting material surface;
- Adsorption of specific gas;
- Reaction between oxygen and adsorbed gas;
- Desorption of reacted gas on surface.

The sensing element gas sensor is a tin dioxide (SnO_2) semiconductor, which has low conductivity in clean air. In the presence of a detectable gas, the sensor resistance decreases depending on the gas concentration in the air. An electrical circuit can convert the change in resistance to an output signal operating the preliminary correction as function of temperature and humidity.

B. Power supply

A very simple and low cost constant voltage power supply has been used. Main feature is 5V DC, 1 A (high current for gas sensor header supply). The circuit is designed around ON's NCP1014 integrated controller with internal mosfet in a discontinuous mode flyback topology. A low drop serial regulator IC has been used to reduce 5 Volts outputted to 3.3 volts for ZigBee transponder supply. Due to low current used by the transponder, the dissipated thermal power is about 170 mW. In order to evaluate the features of powerline communications an OFDM-based modem is also present on the board [Figure 1-2].

C. ZigBee Modules

ZigBee technology is based on the IEEE 802.15.4 standard, which also represents the personal area wireless network (PAN) [4]. ZigBee is characterized by its low cost, low power consumption and miniaturization.

The ZigBee stack architecture defines two layers, namely, the physical layer and the medium access control sub-layer. The ZigBee alliance provides the network layer and the framework in the application layer. In the test-bed a commercial ZigBee module has been used (XTR-ZB1-xHE from Aurel). From specifications, the line of sight distance of this module can extend up to 1000 feet (open air) with power consumption of 350 mW. ASCII strings commands are used to configure the module (PAN ID, channel scan function, time to join the network, destination address, hopping parameters, data baud rate, sleep mode function

TABLE I. SENSORS USED IN THE ZIGBEE E-NOSE NODE PROTOTYPE.

Gas	Sources	Typical concentrations	Sensor
CO_2	Decomposition of organic matter; combustion	380 ppm throughout the troposphere	MQ811
CO	Decomposition of organic matter; combustion of fossil fuels	0.05 ppm unpolluted air, 10-50 ppm in the urban traffic areas	TGS2602
CH_4	Decomposition of organic matter; natural gas emission	1-2 ppm throughout the troposphere	TGS2620
NOx	Electric shock; internal combustion engines, combustion of organic matter	0,01 ppm ppm unpolluted air; 0,5 ppm in air pollution	MQ137
O_3	Electric shock; photochemical smog	Up to 0.01 ppm in the air unpolluted, 0.5 ppm in photochemical smog	MQ131
SO_2	Volcanic gases, forest fires, fossil fuels, roasting ore	Up to 0.01 ppm in the air unpolluted, 0.5 ppm in photochemical smog	MQ136
Temperature		-10 °C to + 40° C	LM335
Humidity		0-100% relative	HIH-4000

Figure 1. Wireless electronic node for environmental emergency application (e-nose). Here, it is possible to note the power supply modules with OFDM modem, the ZigBee transponder antenna and the gas sensors.

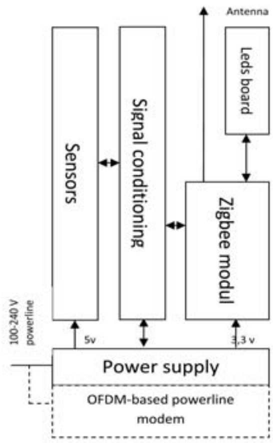

Figure 2. Block diagram of the electronic node. Dot line highlights an additional feature under test.

etc). This ZigBee module uses a frequency band at 2.4 GHz and 128 bits cryptography. We have employed a stylus external antenna in order to work also in reinforced concrete buildings. The Figure 3 depicts a ZigBee module (on the right).

In general, a ZigBee network can be implemented using one of topologies, as depicted in left side of the Figure 3. The used modules adopt the mesh topology allowing nodes to have as many paths as possible for communication. As a result, the mesh topology is very reliable and the extension of the network size can be done with a simple reconfiguration (up to 6 links in the used Aurel firmware). However, this network topology requires each node to be activated for most of the time, thus consuming more energy than other topologies. The base node is realized using the same module, with specific network interface (in our case USB) collecting data from all nodes in the network.

A previously-tested database, MySQL base was used for storing data. Before storing, two relevant operations are made on the row-data. The first one is needed to correct the sensors output for temperature and humidity dependence [5]. The second one is needed to reduce the ambiguity of this class of sensors.

It is well known that low-cost oxide-based resistive sensors are sensitive to a wide spectrum of VOCs, however their selectivity is generally low [6] thus providing an ambiguous response in terms of individual components of the gas mixture. Several attempts have been made to overcome this problem. With reference to tin oxide chemical sensors, two typical measurement strategies are employed [7]: multi-sensor arrays or dynamic measurements based on a single sensor [8].

In this paper, according to previous works of the same authors, an IF THEN inference system is used [10].
The experimental results seem to be in good agreement with what has been previously observed experimentally for these systems and show the effectiveness of the proposed method consistent with those in literature

III. APPLICATION AND CASE STUDY

In hospitals both medical gas cylinders and compressed gases are used. The most commonly used gases are: oxygen, air, carbon dioxide, propane, acetylene and anesthetic gases (nitrous oxide and halogenated agents). They are generally available in vial forms. These substances, with their distribution systems are the subject of close attention for a

Figure 3. On the left: high power Aurel XTR-ZB1-xHE module, based on IEEE 802.15.4 standard and ZigBee protocol [15]; On the right: topology of ZigBee wireless networks: star, tree, and mesh.

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proper assessment and management of potential chemical hazards in a hospital [12]. We can suppose that in a hospital there could be:

- ✓ Operating rooms and medical center
- ✓ Hospital rooms
- ✓ Offices
- ✓ Laboratories and kitchen
- ✓ Hall and open public areas
- ✓ Unattended rooms.

Here, several logistic and health activities are performed and these require the adoption of specific security measures. In particular, the operating rooms [11] are equipped with ventilation and air change systems and fixed monitoring stations. In fact, here there are many pollution sources due to the several activities performed by the staff.

Another important issue regards air quality of hospital rooms and medical center, equipped with air conditioning systems. Therefore, in these areas, it is important to adhere to air quality safety features by equipping the rooms with humidification and dehumidification system, filtration, and air flow regulation devices. In fact, in these rooms microclimatic conditions must be respected according to Italian standards, (referring to D. P.R. 01/14/1997). In these areas, however, air quality can be altered (e.g., a low number of air changes per hour, cigarette smoke, etc). This situation cannot be detected, because in these places there are not any monitoring devices.

The same thing could occur within the laboratories. They are a potential source of chemical hazard. Here, the solvents and detergents have to be used, in accordance with appropriate safety procedures (under the hood, with gloves and masks). However, they could cause accidental releases of hazardous substances thus bringing about dangerous situations such as poisoning or fire.

The kitchens are hazardous too for the presence of propane gas. Specific risk areas may also be halls (open public room) and administrative offices. For adequate air exchange, these places must be equipped with efficient air conditioning systems and active and passive ventilation systems providing fresh air circulation. A default of air exchange may be a source of microbiological risk, causing the inhalation of microbial aerosol or deposition of contaminated particles. Particular attention should be given also to the unattended areas, which represent approximately 20-30% of all hospital. The lack of staff to check regularly or occasionally spills, changes in humidity or other similar risks is a condition that deserves attention. They are typically intended for ancillary services to health care:

- ✓ Technical areas
- ✓ Paper archives
- ✓ Computer rooms
- ✓ Conducted for the gas adduction gas and other products within the hospital
- ✓ Power and data distribution lines.

In normal conditions there are not gas leaks and therefore the direction does not perform a periodic inspection. In fact, usually, technical staff is only in charge of annually maintenance operation, with the exception of occasional conditions, such as emergency or concurrent events (restructuring, maintenance) [14].

The fire detection system, as required by the regulations for public and private healthcare settings, is the only security measure that is effective in these places.

In addition, many of these spaces are also used to store laboratory materials, disused electrical devices or waste. This stuff stationed here for a long time.

In fact, the material can show the signs of wear over the times. This could cause small leaks of various kinds of substances, sometimes with harmful consequences. It should also be recalled that seasonal temperature changes i.e., the climatic variations occurring from warm to cold seasons in these storage rooms involve a high risk of incorrect maintenance of materials, for instance the degradation of papers or radiological materials. In many cases, these risk situations are very difficult to cope with if there is no outside automatic control.

In these conditions, the environmental relief appears to be very complex. It will be measured only by the subjective perception of people entering into the room (smell of damp, smelly material, acrid smell of gas). The devices that can detect the problem are extremely expensive and complex (e.g., hygrometer, gas detector, samples of chemicals).

These phases of control, however, are not very useful in

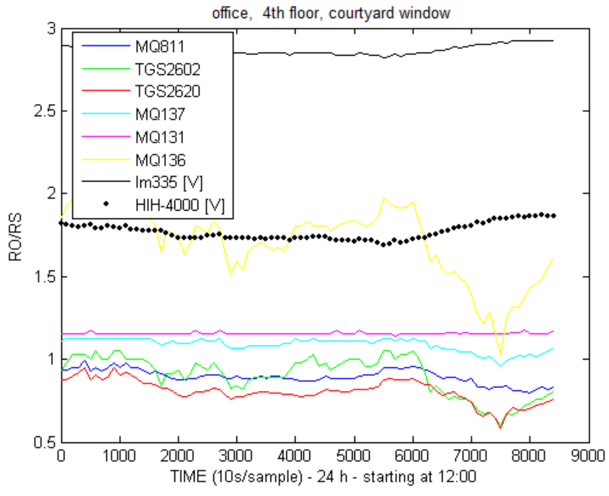

Figure 4. Row-data of the acquisition realized in an office on the 4th floor of the hospital with a courtyard window.

emergency situations that may arise from sudden emission of toxic gases, when we have not time to sample the surrounding air and analyze it with sophisticated instruments that provide detailed concentrations of pollutants, but require extremely long time to report a hazard [13].

According to the aim of this paper, the wireless e-nose was tested in three operating rooms, in the hall and an office of a public hospital. The first test has been realized in an office on the 4th floor with a courtyard window. The office belongs to a Head Physician. Row-data (electric output of the sensors as ratio Ro/Rs) from the sensor, except for direct voltage output sensors (LM335 and HIH-4000-001) are shown in Figure 4. The same data after humidity/temperature correction and disambiguation are shown in Figure 5 according to [10].

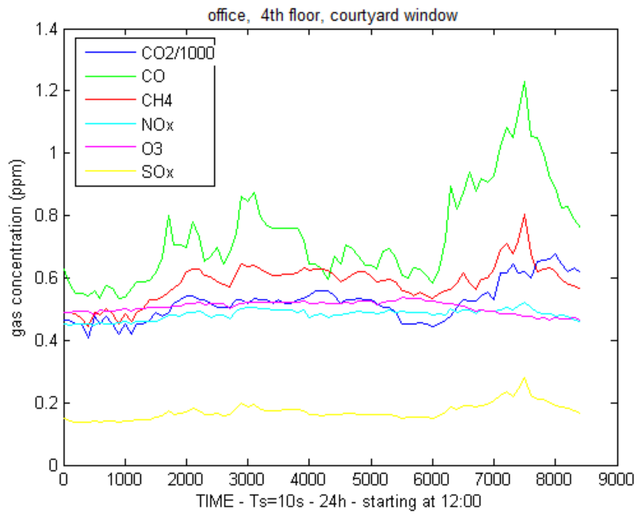

Figure 5. Gas concentration (ppm) of the acquisition realized within a 4th floor office of the hospital with a courtyards window.

The second test has been realized in the hall of the Hospital with the access to Emergency Room. The hall is open and exposed to an urban traffic-congested street, with private cars, ambulances and bus. There are at least 30 persons including patients, relatives, staff and waiting persons. Gas concentrations in ppm are reported in Figure 6.

The last test has been made in a surgical room. As already reported in [4] all operating rooms are equipped with continuous monitoring stations and they have air conditioning and ventilation systems with HEPA filters. The volume of each room is 25 m^2. The presented data are related to a plastic surgery facility (specifically in relation to mastectomy operation). The smell of alcohol was perceived by the operators, probably due to use of Betadine (alcohol disinfectant), Sevoflurane (vaporized) and Propoform. During the surgery operation, the door of the operating room is often open or ajar and there is continuous passing-by of personnel (doctors, nurses and auxiliary ones). An electrosurgical device was used. Gas concentrations of the monitoring performed in operating rooms on the 1th floor in 1 hour of acquisition, are shown in Figure 7 and, after 25 minutes, a probably sensor saturation can be seen, synchronized to use electrosurgical devices and a strong smell perceived by the operators.

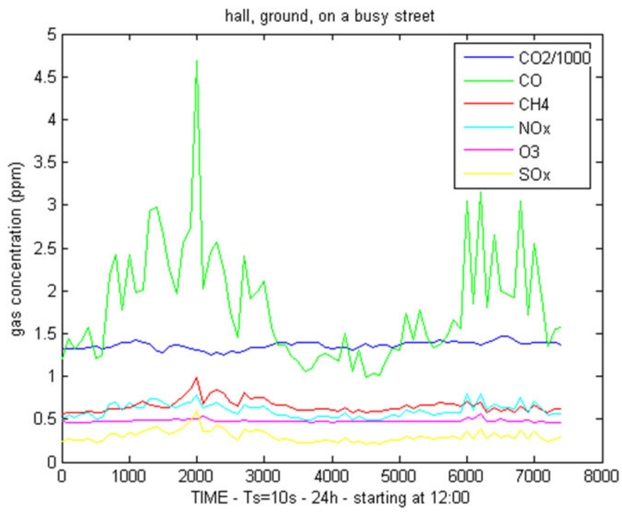

Figure 6. Gas concentrations of the monitoring carried out in a hall hospital on the ground floor exposed to an urban traffic-congested street (private cars, ambulances and bus). There are at least 30 persons including patients, relatives, staff and waiting persons.

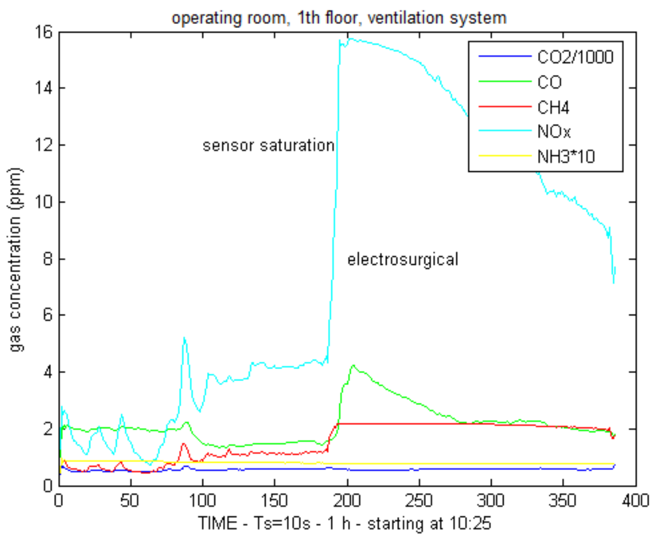

Figure 7. Gas concentrations of the monitoring carried out in operating room on the 1th floor in 1 hour of acquisition, where, about after 25 minutes, the electrosurgical device was used during a mastectomy operation.

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IV. Results and Conclusion

In this study, six gas sensors were used to test air quality inside different rooms and areas of a public hospital. It should be noted that after a warming up period (some minutes for data sheet, about 1 hour in our tests) the sensors are able to measure the presence of pollutants in the air.

Typical responses of gas sensing measurement are shown. None of the data are reposted by the existing sensor. Some of these data show the exceeding of the limits imposed by a directive of Italian Public Health policy.

But low-cost solid state sensors are generally sensitive to a number of different gases and are characterized by a high response to the temperature and the humidity. In this work, the problem of discrimination abilities of these sensors has been solved. The basic idea grounds on the hypothesis that, if the same gas is actually measured by two or more sensors, then their estimated concentrations will be similar, with accuracy related to the number of concordant sensors.

The sensors are connected to the hub using the ZigBee protocol. Main features of this choice refer to the high connectivity ability. In particular, the adopted mesh topology is very reliable and extension of the network size can be done without reconfiguration.

Joining these two technologies a very cheap gas sensor network arrangement has been realized, tested and proposed in this paper.

The same technology, tested for a hospital application, can be used in any class of application. Farms, workshops, offices, public area can suffer from air contamination. The classical solutions, based on air sample or chemical tests are very slow and expensive. Moreover, the proposed solution does not require wiring and fixed installation, it is possible to reconfigure dynamically the network configuration. As described, a kit with a mixture of different selectivity e-noses can be considered as a smart and cost effective solution to emergency air monitoring.

Therefore, the experimental results, albeit grounding on a set of catalytic sensors, seem to support the idea that smart compositions of low-cost sensors are able to manifest surprising discrimination abilities.

The achieved goals are in line with our expectations and show that overall our system is able to perform an analysis, efficient enough to be of practical use. Future works will focus on studying further improvements of the system for getting higher accuracy level measurements.

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References

[1] V. Di Lecce, A. Amato, R. Dario, C. Martines, Air Quality Control for Health Care Centres. The Application of an Intelligent Distributed System. 2009 IEEE Workshop on Environmental, Energy, and Structural Monitoring Systems. EESMS 2009 Crema (Italy) 25/09/2009, ISBN: 978-1-4244-4848-7 . Pag 27-30.

[2] T. Defeng, L. Shixing, X. Wujun, Z. Yongming “A Fire Monitoring System in ZigBee Wireless Network” CYBERC 2010 - The 2nd International Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery CyberC 2010. October 10-12, 2010. Huangshan/China.

[3] M. Xiangyin, X. Shide, X. Ying, H. Huiping “ZigBee Based Wireless Networked Smart Transducer and Its Application in Supervision and Control System for Natural Gas Gate Station”. July 25-28, 2009 Nanning, China.

[4] R. Dario, A. Mundo, A. Leaci, V. Di Lecce, J. Uva, G. Bianco “Medical Environment Spot Exposure: a Solid State Personal Dosimeter” 2010 IEEE Workshop on Environmental, Energy, and Structural Monitoring Systems, pag. 19-25. Taranto, Italy, 9 September 2010.

[5] http://www.figarosensor.com/products/common%281-104%29.pdf

[6] P. Moseley and B. Tofield “Solid-State Gas Sensors” Bristol, U.K. Adam Hilger, 1987.

[7] X. Huang, F. Meng, Z. Pi, W. Xu and J. Liu “Gas sensing behavior of a single tin dioxide sensor under dynamic temperature modulation”, Sensors and Actuators B: Chemical, Volume 99, Issues 2-3, 1 May 2004, pp. 444-450.

[8] A. P. Lee and B. J. Reedy, “Temperature modulation in semiconductor gas sensing”, Sensors and Actuators B: Chemical, Volume 60, Issue 1,2 November 1999, pp. 35-42.

[9] http://www.ego-gw.it/public/about/VIR-0558A-09.pdf

[10] V. Di Lecce, M. Calabrese, R. Dario “Computational-based Volatile Organic Compounds discrimination: an experimental low-cost setup” Proc. of the 2010 IEEE International Conference on Computational Intelligence for Measurement Systems and Applications Taranto (CIMSA2010), Italy, 6-8 September 2010, pp. 54-59, ISBN: 978-1-4244-7229-1.

[11] S. Mehta, W. J. Cole, J. Chaw and K. Lewin, “Operating room air pollution: Influence of anaesthetic circuit, vapour concentration, gas flow and ventilation”, Canadian Journal of Anesthesia, Volume 22, Number 3, pp. 265-274.

[12] M. Leung, A. H.S. Chan, “Control and management of hospital indoor air quality”, Med Sci Monit, 2006; Volume 12, Number, 3, pp.17-23.

[13] J. E. Hall, K. A. Henderson, T. A. Oldham, S. Pugh and M. Harmer, “Environmental monitoring during gaseous induction with sevoflurane”, British Journal Anaesthesia Volume 79, Issue 3, pp. 342-345, 1997.

[14] D. Norback, M. Ingegerd, J. Widstrom, “Indoor air quality and personal factors related to the sick building syndrome”, Scand Journal Work Environmental Health, Volume 16, pp.121-128.

[15] http://www.aurel-zigbee.com/download/documents/italiano/manuale-XTR-ZB1-xHE.pdf