Monitoring Indoor Air Quality to Improve Occupational Health

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Abstract. Indoor environments are characterized by several pollutant sources. As people typically spend more than 90% of their time in indoor environments. Thus, indoor air quality (iAQ) is recognized as an important factor to be controlled for the occupants' health and comfort. The majority of the monitoring systems presently available is very expensive and only allow to collect random samples. This work describes the system (iAQ), a low-cost indoor air quality monitoring wireless sensor network system, developed using Arduino, XBee modules and micro sensors, for storage and availability of monitoring data on a web portal in real time. Five micro sensors of environmental parameters (air temperature, humidity, carbon monoxide, carbon dioxide and luminosity) were used. Other sensors can be added for monitoring specific pollutants. The results reveal that the system can provide an effective indoor air quality assessment to prevent exposure risk. In fact, the indoor air quality may be extremely different compared to what is expected for a quality living environment.

Keywords: Indoor air quality, indoor environment, air quality monitoring, wireless sensor network, ZigBee, gas sensors, smart cities.

1 Introduction

Indoor environments are characterized by several pollutant sources. Thus, indoor air quality (iAQ) is recognized as an important factor to be controlled for the occupants' health and comfort. This issue is more important if we take into consideration that today most people spend more than 90% of their time in artificial environments [1]. But is also important that health problems and diseases caused by poor indoor air quality can negatively affect the productivity. According to the United States Environmental Protection Agency [2], human exposure to indoor air pollutants may be 2 to 5 times—occasionally more than 100 times higher than outdoor pollutant levels, because a home's interior accumulates and concentrates pollutants given off by finishes, furnishings and the daily activities of the occupants [3]. In fact, indoor air pollutants have been ranked among the top five environmental risks to public health. Ventilation is used in buildings to create thermally comfortable environments with acceptable IAQ by regulating indoor air parameters, such as air temperature, relative humidity, air

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Á. Rocha et al. (eds.), *New Advances in Information Systems and Technologies*,
Advances in Intelligent Systems and Computing 445,
DOI 10.1007/978-3-319-31307-8_2

speed, and chemical species concentrations in the air [4]. In this study the authors present some numerical predictions of pollutants dispersion in a ventilated room.

An indoor air quality assessment system helps in the detection and improvement of indoor air quality. Local and distributed assessment of chemicals concentrations is significant for safety (gas spills detection, pollution monitoring) and security applications as well as for to effectively control heating, ventilation and air conditioning (HVAC) system for energy efficiency [5]. In fact, the indoor air quality measured in the built environment provides a continuous stream of information for seamless controlling of building automation systems, and provides a platform for informed decision making [6]. However, the monitoring systems presently available are normally very expensive and only allow to collect random samples.

Recently, several new systems have been developed for monitoring environmental parameters, always with the aim of improving the indoor air quality efficiency [7]. Actually, the availability of cheap, low power, and miniature embedded processors, radios, sensors, and actuators, often integrated on a single chip, is leading to the use of wireless communications and computing for interacting with the physical world in applications such as air quality control [8]. A wireless indoor air quality monitoring in order to provide real time information for assisted living is proposed by [9]. The proposed system has carbon dioxide, carbon monoxide, propane and methane sensors. Another study involving wireless sensor networks for indoor air quality monitoring was proposed by [10].

This study describes the iAQ system, developed by the authors, which aims to ensure, autonomously, accurately and simultaneously, the indoor air quality monitoring of different building rooms. The system consists of a low cost indoor air quality monitoring wireless sensor network system, developed using Arduino, XBee modules and micro sensors, for storage and availability of monitoring data on a web portal in real time. This system collects five environmental parameters (air temperature, humidity, carbon monoxide, carbon dioxide and luminosity) from different places simultaneously. Other sensors can be added for monitoring specific pollutants. Currently, in the preliminary laboratory tests, only two remote modules were used.

2 Technical Solution

2.1 Implementation

The **iAQ** system is an automatic indoor air quality monitoring system that allows the user, such as the building manager, to know, in real time, a variety of environmental parameters as air temperature, relative humidity, carbon monoxide (CO), carbon dioxide (CO2) and luminosity. Other sensors for specific pollutants can be added.

The parameters are monitored using the **iAQ Sensor** system that collects data and sends it to the **iAQ Gateway** system that records the data in a MySQL database using web services developed in PHP.

The end user can access the data from the web portal **iAQ Web** built in PHP. After login, the end user can access the **iAQ Web** and can get all the information about environmental parameters. The monitoring data are shown as numeric values or in a chart form. This portal also allows the user to keep the parameters history. Providing a history of changes, the system helps the user to analyze precisely and detailed the air quality behaviour. This is very important to decide on possible interventions to improve the air quality in the building. The **iAQ Web** is also equipped with a powerful alerts manager that advises the user when a specific parameter exceeds the maximum value.

2.2 Wireless Sensor Network Architecture

The wireless communication is implemented using the XBee module what implements the IEEE 802.15.4 radio and ZigBee networking protocol [11]. The IEEE 802.15.4 standard specifies the physical and medium access control layers for low data-rate wireless personal area networks. ZigBee is a low-cost, low-power, wireless mesh networking standard built upon 802.15.4 [12,13].

Communication signals are transmitted from the **iAQ Sensor** to the base station **iAQ Gateway** use XBee. The modules operate within the 2.4 GHz frequency band and outdoor RF line-of-sight range up to 4000 ft. (1200 m) and RF data rate 250,000 bps. These modules use the IEEE 802.15.4 networking protocol for fast point-to-multipoint or peer-to-peer networking. They are designed for high-throughput applications requiring low latency and predictable communication timing. XBee modules are ideal for low-power, low-cost applications. XBee-PRO modules are power-amplified versions of XBee modules for extended-range applications [14].

2.3 Hardware and System Architecture

The **iAQ** system is composed of one or several **iAQ Sensor's.** They are used to collect and transfer environmental factors from the different rooms where they are installed. The **iAQ Sensor's** send the data to the **iAQ Gateway** (Fig.1), which is connected to the Internet with an Arduino Ethernet Shield, for recording data in the database.

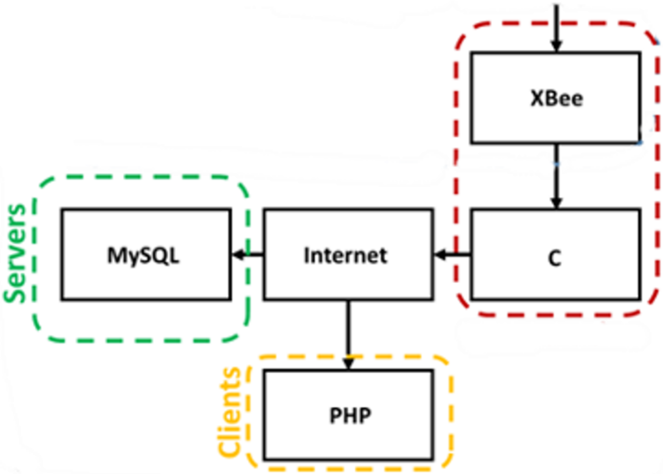

Fig. 1. iAQ GATEWAY Architecture.

Therefore, it is made possible to construct a modular system that can monitor one or more spaces simultaneously. Figure 2 schematically illustrates the system architecture used in the **iAQ**.

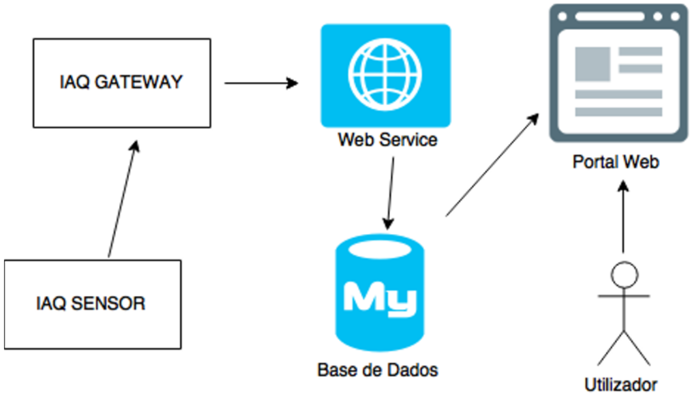

Fig. 2. iAQ System Architecture.

The **iAQ Sensor** is built using the embedded Arduino Mega system, an open source platform that incorporates an Atmel AVR microcontroller [15,16]. In order to allow communication between the iAQ Sensor's and iAQ Gateway, the ZigBee technology was applied with the use of Xbee modules.

The **iAQ Sensor** is equipped with multiple sensors, a processing unit (Arduino MEGA), and a wireless communication and mesh networking module as schematically shown in Fig. 3 (see also [17]). Currently, the **iAQ Sensor** is equipped with five sensors (Fig. 4): air temperature, relative humidity (RH), carbon monoxide (CO), carbon dioxide (CO2) and luminosity.

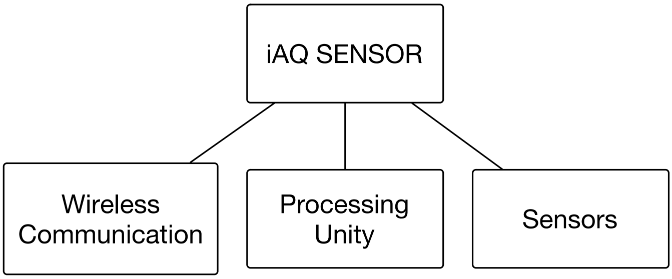

Fig. 3. iAQ Sensor

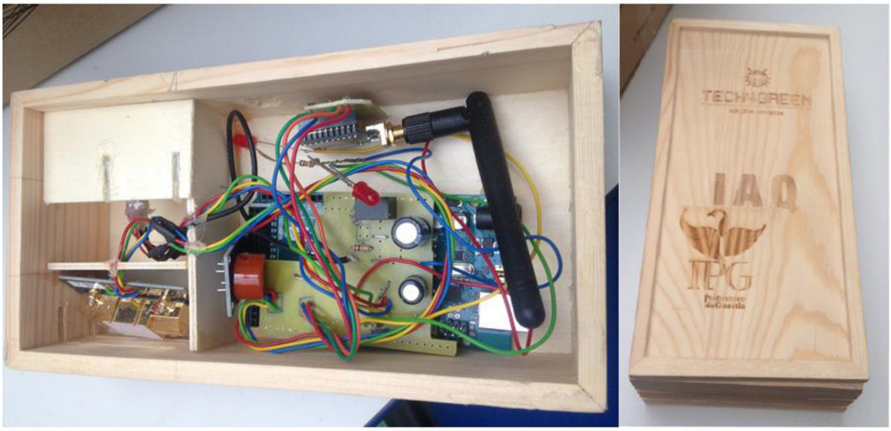

Fig. 4. iAQ Sensor Hardware

A brief description of the used sensors is presented below.

- Sensor SHT10 – it is a low power, stable and fully calibrated Relative humidity and Temperature sensor [18]; Measurement range: 0-100% (humidity), -40ºC ~ 120ºC (temperature); Accuracy: ±4,5% (humidity), ± 0.5 ºC (temperature); Response time < 30 seg.

- MQ7 Sensor – it is a high sensitivity CO (carbon monoxide) sensor with several many features [19]: high sensitivity, fast response, wide detection range (20 to 2000 ppm), stable performance and long life, simple drive circuit; Requires manual calibration.

- T6615 CO2 Sensor – it is a low power, good performance CO2 (carbon dioxide) sensor (designed for HVAC purposes), with the following main specifications [20] - Measurement range: 0-5,000ppm; Accuracy: ±50 ppm ± 3% of Reading; Response time: 2 minutes; Automatic calibration (every 24h).

- LDR 5 mm Sensor – it is a sensor that allow to detect light; it is basically a resistor that changes its resistive value (in ohms) depending on how much light is shining onto the squiggly face [21]; Since it is low cost but inaccurate, they shouldn't be used to try to determine precise light levels in lux; instead, we can expect to only be able to determine basic light changes. Resistance range: 200K ohm (dark) to 10K ohm (10 lux brightness); Sensitivity range: CdS cells respond to light between 400nm (violet) and 600nm (orange) wavelengths, peaking at about 520nm (green).

2.4 Software

The firmware of the **iAQ Sensor** and **iAQ Gateway** was implemented using the Arduino platform language in the IDE ARDUINO. It belongs to the C-family programming languages.

The **iAQ Web** was developed in PHP and MySQL database. Web services that allow data collection are also built in PHP [22].

3 Results and discussion

The **iAQ Web** allows viewing the data as numeric values or in a chart form. A sample of experiment data for a selected room is shown in Figures 5 to 7. As examples, the graphs of relative humidity (Fig. 5), air temperature (Fig. 6) and CO2 (Fig. 7) were chosen.

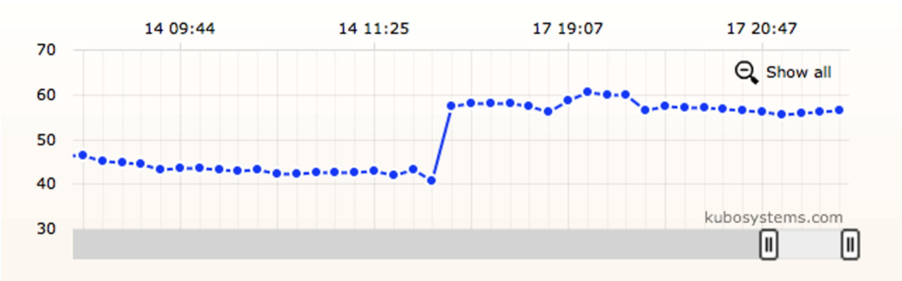

Fig. 5. Data visualization: Relative Humidity (%)

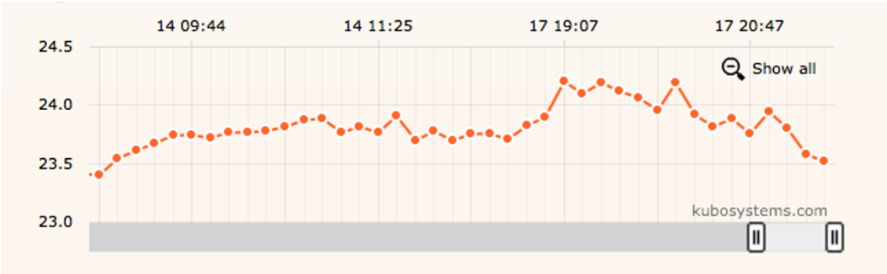

Fig. 6. Data visualization: Temperature (ºC)

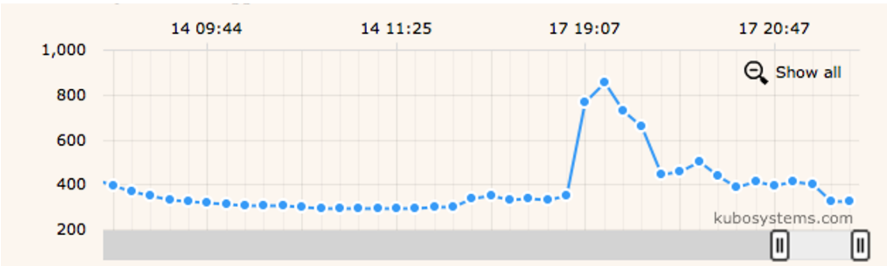

Fig. 7. Data visualization: carbon dioxide (CO2) concentration (ppm)

The graphic display of the environmental factors allows a greater perception of the behaviour of the monitored parameter than the numerical display format. On the other hand, the Internet portal also allows the user to access the historical data, which enables a more precise analysis of the detailed temporal evolution of environmental parameters. Thus, the system is a powerful tool for the detection of problems and decision making on possible interventions to improve air quality in the building.

The iAQ system is in the testing phase. At this stage the main goal is to make technical improvements, including their calibration. Among other advantages of the iAQ system, it stands out for its modularity, small size, low cost of construction and ease installation. Improvements to the system hardware and software are planned to make it much more appropriate for specific purposes such as hospitals, commercial buildings or factories.

4 Conclusion

This work aimed to present an effective indoor air quality monitoring system to prevent exposure risk. The system is developed using low-cost micro gas sensors and an open source microcontroller development platform Arduino. Five micro sensors of environmental parameters were used in each module, but other sensors can be added as needed. The system was tested by monitoring two classrooms. The results obtained are very promising, representing a significant contribution to indoor environmental studies. Nevertheless, the system needs further experimental validation in real environments, in particular with the assembly of more than two remote modules as used in laboratory tests, in order to verify and calibrate the system more accurately. In addition to this validation study, physical system and web portal improvements have been planned with a view to adapt the system to specific cases or problems, such as schools, kindergartens or shops.

Compared to existing systems, it has great importance due to the use of low cost and open-source technologies. Note that the system has advantages both in ease of installation and configuration due to the use of wireless technology for communication between the IAQ sensor and IAQ Gateway, but also due to its small size, about 20x10 cm2, compared to other systems.

This system is extremely useful in monitoring air quality conditions inside buildings to better understand the current status of air quality as well as to study the behavior of environmental parameters. Thus, the system can be used to help the building manager for proper operation and maintenance to provide not only a safe and healthy workplace, but also a comfortable and productive one.

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http://www.springer.com/978-3-319-31306-1

New Advances in Information Systems and Technologies
Volume 2
Rocha, Á.; Correia, A.M.; Adeli, H.; Reis, L.P.; Mendonça Teixeira, M. (Eds.)
2016, XXIV, 773 p. 256 illus., 92 illus. in color., Softcover
ISBN: 978-3-319-31306-1