IAQ Evaluation Using an IoT CO_2 Monitoring System for Enhanced Living Environments

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Abstract. Indoor air quality (IAQ) parameters are not only directly related to occupational health but also have a huge impact on quality of life. In particular, besides having a very influence on the public health as it may cause a great variety of health effects such as headaches, dizziness, restlessness, difficulty breathing, increase heart rate, elevated blood pressure, coma and asphyxia, carbon dioxide (CO_2) can be used as an important index of IAQ. In fact, due to people spend about 90% of our lives indoors, it is extremely important to monitor the CO_2 concentration in real-time to detect problems in the IAQ in order to quickly take interventions in the building to increase the IAQ. The variation of CO_2 in indoor living environments is in most situations related to the low air renewal inside buildings. CO_2 levels over 1000 ppm, indicate a potential problem with indoor air. This paper aims to present iAirC a solution for CO_2 real-time monitoring based on Internet of Things (IoT) architecture. This solution is composed by a hardware prototype for ambient data collection and a web and smartphone compatibility for data consulting. This system performs real-time data collection that is stored in a ThingSpeak platform and has smartphone compatibility which allows easier access to data in real time. The user can also check the latest data collected by the system and access to the history of the CO_2 levels in a graphical representation. iAirC uses an open-source ESP8266 for Wi-Fi 2.4 GHZ as processing and communication unit and incorporates a CO_2 sensor as sensing unit.

Keywords: IAQ (Indoor air quality) · Monitoring · IoT (Internet of Things) Energy efficiency · Smart cities · iOS

1 Introduction

Ambient Assisted Living (AAL) is an emerging multi-disciplinary field aiming at providing an ecosystem of different types of sensors, computers, mobile devices, wireless networks and software applications for personal healthcare monitoring and telehealth systems [1]. Currently, there are different AAL having as basis several sensors for measuring weight, blood pressure, glucose, oxygen, temperature, location and position and which are usually applied wireless technologies such as ZigBee, Bluetooth, Ethernet and Wi-Fi.

There is a lot of challenges in designing and implementation of an effective ambient assisted living system such as information architecture, interaction design,

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human-computer interaction, ergonomics, usability and accessibility [2]. There are also social and ethical problems like the acceptance by the older adults and the privacy and confidentiality that should be a requirement of all AAL devices. In fact, it is also important to ensure that technology does not replace human care and should be a really amazing complement.

In the USA, indoor and outdoor air quality is regulated by Environmental Protection Agency (EPA). This organization considers that indoor levels of pollutants may be up to 100 times higher than outdoor pollutant level and ranked poor air quality as one of the top 5 environmental risks to the public health [3].

The problem of poor IAQ is of utmost importance affecting especially severe form the poorest people in the world who are most vulnerable presenting itself as a serious problem for world health such as tobacco use or the problem of sexually transmitted diseases [4].

High-quality research should continue to focus on the quality problems of indoor air in order to adopt legislation, inspection and creating mechanisms that act in real time to improve public health, both in public places such as schools and hospitals and private places and further increase the rigorousness of the buildings construction rules. In the major cases, simple interventions provided by home-owners and building operators can produce great positive impacts on IAQ such as the avoidance of smoking indoors and the use of natural ventilation are important behaviours that should be taught to children through educational programs that address the indoor air quality [5].

The concept of the “smart city” has recently been introduced as a strategic device to encompass modern urban production factors in a common framework and, in particular, to highlight the importance of Information and Communication Technologies (ICTs) in the last 20 years for enhancing the competitive profile of a city as proposed by [6]. Nowadays cities face interesting challenges and problems to meet socio-economic development and quality of life objectives and the concept of “smart cities” correspond to answer to these challenges [7]. The smart city is directly related to an emerging strategy to mitigate the problems generated by the urban population growth and rapid urbanization [8]. The most relevant issue in smart cities is the no interoperability of the heterogeneous technologies, the IoT can provide the interoperability to build a unified urban-scale ICT platform for smart cities [9]. The smart city implementation will cause impacts at distinct levels such as impacts on science, impacts on technology and competitiveness and impacts on society but also will cause ethical issues as the smart city need to provide correct information access as it becomes crucial when such information is available at a fine spatial scale where individuals can be identified [10]. IoT has an incredible potential for creating new real-life applications and services for the smart city context [11].

Increase the IAQ is extremely important as people typically spend more than 90% of their time in indoor environments.

In one hand, when carbon dioxide (CO_2) concentration reaches 7–10%, a person will lose consciousness within a few minutes and may be at risk of death. In other hand, a low concentration of CO_2 is harmless to humans, it can still cause dizziness and sleepiness leading to poor work performance [12]. For those reasons is extremely import to monitor CO_2 and providing notifications in real-time to improve occupational health and productivity. The concentrations of CO_2 - the main greenhouse gas - are steadily increasing to 400 ppm (ppm), reaching new records every year since they began to be produced in 1984 [13].

This paper aims to present a solution for CO_2 real-time monitoring based on IoT Architecture. In order to create a low-cost system, only one type of indoor air pollutant was chosen. CO_2 was selected since it is easy to measure and it is produced in quantity (by people and combustion equipment). Thus, it can be used as an indicator of other pollutants, and therefore of the IAQ in general. The solution is composed by a hardware prototype for ambient data collection and a web and smartphone compatibility for data consulting. The iAirC is based on open-source technologies and is a totality Wi-Fi system, with several advantages compared to existing systems, such as its modularity, scalability, low-cost and easy installation. The data is uploading to the cloud platform service ThingSpeak and the can be accessed using a smartphone. This system is based on an ESP8266 microcontroller with built-in Wi-Fi communication technology as communication and processing unit and incorporates a CO_2 sensor as sensing unit.

The paper is structured as follows: besides de introduction (Sect. 1), Sect. 2 presents the related work and Sect. 3 is concerned to the methods and materials used in the implementation of the sensor system; Sect. 4 demonstrates the system operation and experimental results, and the conclusion is presented in Sect. 5.

2 Related Work

Several examples of projects on air quality monitoring are available in the literature. In this section, the most outstanding solutions are the use of open-source, low cost and mobility technologies.

A battery-free sensor that is capable to monitor IAQ in real time that consists of three main components: a fully passive ultra-high frequency (UHF) smart tag for communication with an UHF radio frequency identification (RFID) reader, a smart sensing module with ultra-low power sensors and a microcontroller unit (MCU), and an RF energy harvester is proposed by [14].

A low-cost indoor air quality monitoring wireless sensor network system developed using Arduino, XBee modules, and micro gas sensors that is capable of collecting six air quality parameters from different locations simultaneously is proposed by [15].

A system that is capable to detect the level of seven gases, ozone (O3), particulate matter, carbon monoxide (CO), nitrogen oxides (NO2), sulfur dioxide (SO2), volatile organic compound, and carbon dioxide (CO_2), on a real-time basis and provides overall air quality alert timely is proposed by [16].

Several IoT architectures for indoor air quality monitoring that incorporates open-source technologies for processing and data transmission and microsensors for data acquisition but also allows access to data collected from different places simultaneously through web access and through mobile applications in real time are proposed by [17–22].

The excessive levels of CO_2 inside classrooms is a problem known and studied for several years [23–27]. Through the use of real-time monitoring and availability of data, occupational health risk situations can be detected and assertively intervened. The iAirC system aims to provide a useful tool for management enhanced living environments of smart cities. The benefits for health, comfort and productivity of good IAQ conditions can be improved by decreasing the pollution load while the ventilation remained unchanged [28].

The authors develop a completely wireless solution using the ESP8266 module which implements the IEEE 802.11 b/g/n networking protocol. This microcontroller with built-in Wi-Fi capabilities is used both as processing and communication unit. The monitored data is stored in a ThingSpeak platform. ThingSpeak is an open source IoT application that provides developers with APIs to store and retrieve data from sensors and devices using HTTP over the Internet. For data consulting this solution uses a web page provided by ThingSpeak platform and a mobile phone application developed in SWIFT for the iOS operating system (Fig. 1).

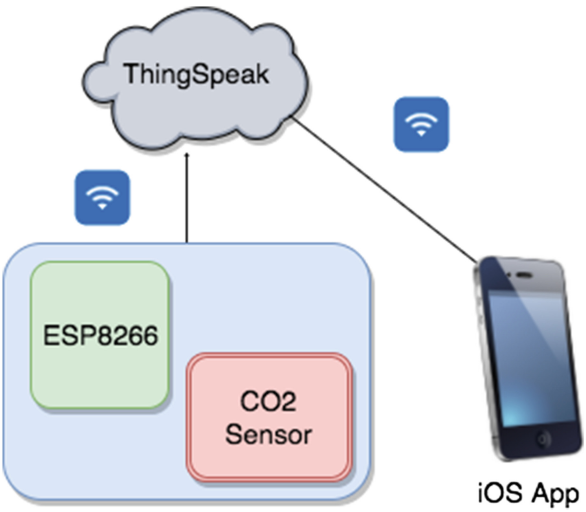

Fig. 1. iAirC architecture.

3 Materials and Methods

Our goal was to create a low-cost reliable system that can be easily configured and installed by the average user. For this, we selected a low cost but very reliable carbon dioxide sensor and a microcontroller with native Wi-Fi support. In this section will be discussed in detail the hardware and software that make up the system as well as its construction cost.

This system consists of 2 components, an ESP8266 Thing Dev (Sparkfun) microcontroller and a MHZ-19 carbon dioxide sensor developed by Winsensor. Figure 2 represents the prototype used by the authors.

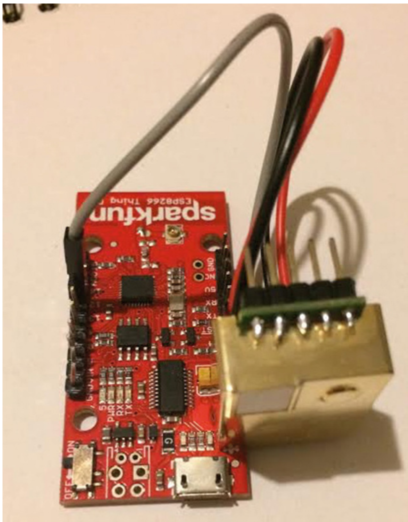

Fig. 2. iAirC prototype.

A brief introduction of each component used is shown below

- ESP8266 – is a Wi-Fi chip with integrated antenna switches, RF balun, power amplifier, low noise receive amplifier, filters and power management modules. It support 802.11 b/g/n protocols, Wi-Fi 2.4 GHz, support WPA/WPA2, has a integrated low power 32-bit MCU, a integrated 10-bit ADC, has a standby power consumption of<1.0 mW (DTIM3) and can operate at temperature range −40 °C–125 °C [29].
- MH-Z19 NDIR (non-dispersive infrared) is a small CO_2 sensor is non-oxygen dependent with a built-in temperature sensor for temperature compensation. It provides a digital output and analogue voltage output. This sensor can operate at 0–50 °C and 0–95% of temperature and humidity respectively. This sensor has a measurement range of 0–2000 ppm, a lifespan higher than 5 years and an average current consumption lower than 10 mA. The MH-Z19 has a 3.3 V interface level and a PWM and UART output signal.

The iOS application is denominated by iAirCMobile was developed with Swift programming language in XCODE IDE and its compatible with iOS 7 and above [30]. This app has two important features as it permits not only real-time consulting of the last data collected and also to receive real-time notifications in order to advise the user when the air quality is defective (Fig. 3).

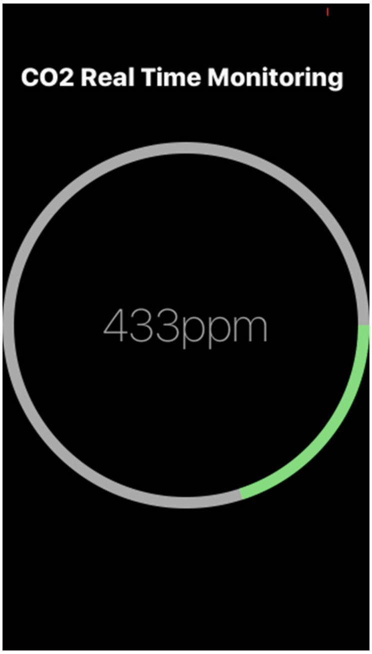

Fig. 3. iAirCMobile app.

4 Discussion and Results

The iAirC allows viewing the data as graphical and numerical values by using a web browser or a smartphone app. A sample of the data collected by iAirC is shown in Fig. 4 that represents the CO_2 sensor data measured in ppm.

The graphic display of the air quality data allows a greater perception of the behaviour of the monitored parameters than the numerical display format. On the other hand, the web and smartphone software also allows the user to access the data, which enables a more precise analysis of the detailed temporal evolution. Thus, the system is a powerful tool for analyse air quality consumption and to support decision making on possible interventions to improve a healthy and more productive indoor environment. As future work, the main goal is to make technical improvements, including the development of important alerts and notifications to notify the user when the quality of indoor air has serious deficiencies. Compared to other systems, the iAirC system has the following advantages: modularity, small size, low-cost construction and easy installation. Improvements to the system hardware and software are planned to make it much more appropriate for specific purposes such as hospitals, schools and offices.

Ample physical evidence shows that CO_2 is the single most important climate-relevant greenhouse gas in Earth's atmosphere and high external charges mean that they naturally lead to higher indoor concentrations due to the contribution of the

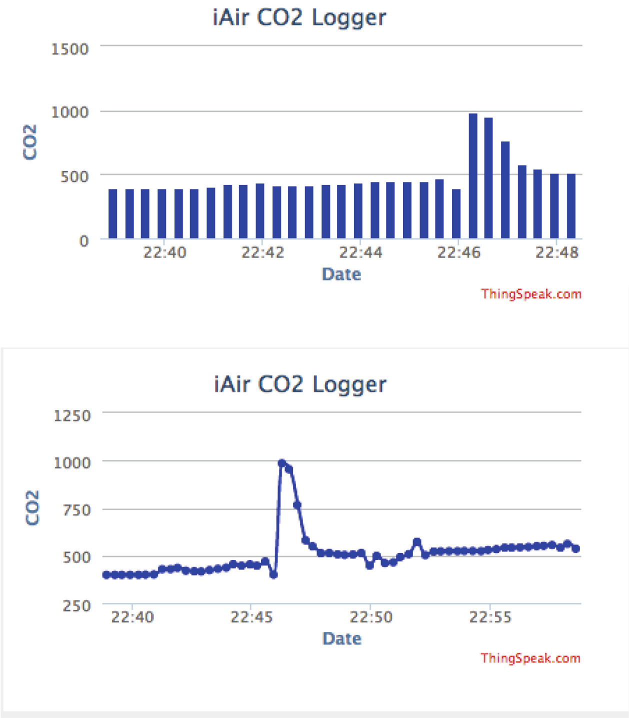

Fig. 4. Data of CO_2 concentration (ppm)

internal sources (human metabolism and combustion equipment) [31, 32]. It is imperative to effectively control the concentration of CO_2 and we believe that the first step is to monitor in order to perceive its variation in real-time and to plan interventions for its reduction.

5 Conclusion

This paper had presented an IoT architecture for CO_2 real-time monitoring composed by a hardware prototype for ambient data collection and a web and smartphone compatibility for data consulting. One of the best indicators of the concentration of IAQ is CO_2, which man emits in large quantities and is fairly easy to measure. CO_2 is a good quantitative indicator of human presence in a room. In addition, it can be used as an indirect indicator to show the presence of high concentrations of other pollutants and consequently the degradation of the IAQ as a whole. The results obtained are very promising, representing a significant contribution to CO_2 monitoring systems based on IoT. Despite all the advantages in the use of IoT architecture, still exist many open issues as scalability, quality of service problems and security and privacy issues. The system should find ways to respond to these problems.

Compared to existing systems, it has great importance due to the use of low cost and open-source technologies but also to the easy installation. The system has advantages both in installation and configuration, due to the use of wireless technology for communications, but also because it was developed for to be compatible with all domestic house devices and not only for smart houses or high-tech houses.

As future work is expected to introduce new monitoring products in order to create an ecosystem for IAQ as well as the development of a platform that allows sharing in a secure way the collected data to health professionals in order to support medical diagnostics. The authors planned software and hardware improvements in order to adapt the system to specific cases such as hospitals, schools and industry. We believe that in the future, systems like this will contribute to enhanced living environments but also be an integral part of the human daily routine. The CO_2 level data can be extremely useful to provide support to a clinical analysis by health professionals. Only through air quality monitoring indoors is that it is possible to perceive correctly the ventilation conditions that influence the health of occupant's plan interventions to decrease the CO_2 levels if needed.

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