Chapter 2
A Mobile Computing Solution for Enhanced Living Environments and Healthcare Based on Internet of Things

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Abstract Since most people spend a considerable part of their time indoors, the indoor environment has a determining influence on human health. In several instances, the air quality parameters are extremely distinctive from those defined as healthy values. Using real-time monitoring, occupants or the build manager can administer interventions in order to improve indoor air quality (IAQ). The constant scientific improvements in numerous areas such as Ambient-Assisted Living and the Internet of Things (IoT) make it possible to build smart things with significant features for sensing and connecting. Therefore, the authors introduce an IoT architecture for real-time monitoring of IAQ. This system named ***iAQ Wi-Fi+*** uses an open-source Arduino UNO as processing unit, an ESP8266 for Wi-Fi 2.4 GHz as a communication unit, and incorporates a temperature and humidity sensor, a CO_2 sensor, a dust sensor, and a digital light sensor operating as a sensing unit. This solution is also composed of a smartphone application for data consulting. The monitored data can be discussed by clinicians to support medical diagnostics for enhanced healthcare. Compared to other solutions, the ***iAQ Wi-Fi+*** is based on open-source technologies and brings a Wi-Fi system, with several advantages such as its modularity, scalability, low-cost, and easy installation. The results obtained are very encouraging, representing a meaningful contribution to IAQ monitoring systems based on IoT.

2.1 Introduction

Indoor air quality (IAQ) assumes an important role as far as personal exposure to pollutants is concerned because several people such as retired, students in classrooms, and disabled persons could stay most of their time in indoor environments. Older people and new-borns who are most likely affected by poor IAQ may spend all their time in indoor environments [1].

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The assessment that IAQ indicators must thereby provide is how good and clean is it (a) by meeting thermal and respiratory requirements, (b) preventing unhealthy accumulation of pollutants, and (c) allowing for a sense of well-being [2].

Environmental Protection Agency (EPA) is responsible for indoor and outdoor air quality regulation in the USA. EPA considers that indoor levels of pollutants may be up to 100 times higher than outdoor pollutant levels and ranked poor air quality as one of the top 5 environmental risks to the public health [3].

The problem of poor IAQ becomes of utmost importance impacting severely the poorest people in the world who are most vulnerable presenting itself as a dangerous threat for world health such as tobacco use or the problem of sexually transmitted diseases [4].

Research should be done on IAQ to improve legislation and inspection and create real-time supervision systems for public health promotion. Those systems should be incorporated not only in public places such as institutions and hospitals but also in private places to increase the building's construction guidelines. Avoidance of smoking indoors and the use of natural ventilation are important behaviours which provide numerous positive impacts in IAQ and should be taught to children through educational programs [5]. Despite the importance of IAQ for public health, there is a lack of interest in the research community to study new methods for IAQ promotion [6].

The Ambient-Assisted Living (AAL) concept aims to create sophisticated tools and services to increase the quality of life, health, and well-being of older people by study new methods for enhanced living environments [7, 8].

However, some technical challenges still exist in the creation of AAL frameworks for enhanced occupational health [9]. Besides this, social and moral issues still exist, for example, the acceptance of these technologies by older persons and privacy and security problems which are remarkably imperative in each AAL project. It is essential to guarantee that innovation does not replace human care but rather introduces new methods to increase and support medical services and frameworks. At 2050, 20% of the total population will be aged 60 or above [10], which will increase the expansion and propensity for diseases, medical services costs, deficiency of parental figures, dependence, and a severer social effect. 87% of individuals wish to remain in their homes and bolster the enormous cost of nursing [11]. All these arguments assert the need to create systems to improve the quality of life for enhanced indoor living environments.

Internet of Things (IoT) stands as a standard where things are linked to the Internet and incorporate data collection capabilities. The basic idea of the IoT is the pervasive presence of a variety of objects with interaction and cooperation capabilities among them to reach a common objective [12–14].

This chapter aims at presenting the ***iAQ Wi-Fi+*** , a solution for IAQ monitoring based on IoT architecture. This solution is composed of a hardware prototype for ambient data collection and web/smartphone compatibility for data access. This system uses an open-source Arduino UNO as processing unit, an ESP8266 for Wi-Fi 2.4 GHz as communication unit and incorporates a temperature and humidity sensor, a CO_2 sensor, a dust sensor, and a digital light sensor as sensing unit. The previous chapter presents a similar solution for wellness monitoring of the elderly by the observation of routing activities as an aid to caregivers. However, the ***iAQ Wi-Fi+*** uses an entirely wireless approach as well as providing easy installation.

The chapter is structured as follows: besides the introduction (Sect. 2.1), Sect. 2.2 introduces IoT; Sect. 2.3 is concerned to presents smart homes; Sect. 2.4 focuses on IAQ; Sect. 2.5 presents the materials and methods used in ***iAQ Wi-Fi+*** development; Sect. 2.6 shows the results, and the conclusions are in Sect. 2.7.

2.2 Internet of Things

The IoT concept is the result of different views: things-oriented vision, Internet-oriented vision and semantic-oriented vision [15]. The IoT consists of a global network of interconnected objects that have a unique address based on standard communication protocols. The things-oriented vision focuses on intelligent autonomous devices that use technologies such as near-field communication (NFC) and radio frequency identification (RFID) objects, applied to our daily lives. The Internet-oriented vision focuses on the idea of keeping the devices connected to the network, having a single address and using standard protocols.

Semantic vision focuses on storage, searching, and data classification generated by IoT. This vision centres on the development of software architecture solutions to manage the data produced by IoT devices.

The IoT is divided into five different layers such as Objects or Perception Layer, Object Abstract or Network Layer, Service Management or Middleware Layer, Application Layer, and Business Layer (Fig. 2.1).

On the one hand, the Perception Layer refers to physical sensors and actuators that IoT systems incorporate [16]. On the other hand, the Network Layer transfers data produced by the Perception Layer to the Middleware Layer through secure channels using technologies such as RFID, ZigBee, WPAN, WSN, DSL, UMTS,

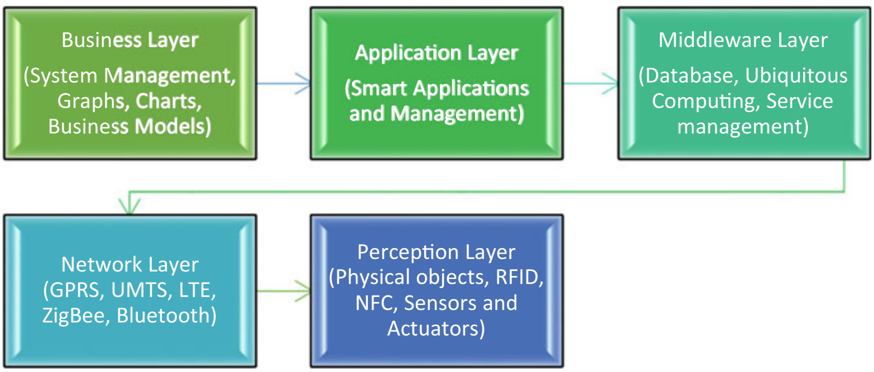


Fig. 2.1 IoT architecture layers (adapted from [16])

GPRS, Wi-Fi, WiMax, LAN, WAN, 3G, and LTE. Furthermore, the Middleware Layer pairs a service with its requester based on addresses and names to maintain independence from the hardware. On the contrary, the Application Layer provides the services requested by consumers passing the system output information to the client that demands that information.

Finally, the Business Layer manages the overall IoT system activities and services to build a business model, graphs and flowcharts based on the received data from the Application Layer.

Despite the numerous technologic enhancements, some issues in the construction of IoT systems continue to exist corresponding to privacy, confidentiality, and security of such systems. To address the privacy issues, the ambient sensing system (AmbLEDs) project presents the use of LEDs instead of other types of more invasive sensors such as cameras and microphones to interact with people in AAL revealing the importance of using intuitive interfaces in this applications [17].

Humans will often be an integral part of the IoT system. Therefore, the IoT will affect every aspect of human lives. Due to the large scale of devices carrying privacy and security issues, the cooperation between the research communities is deemed essential [18]. The SPHERE Project [19] aims to build a generic platform that fuses complementary sensor data to generate rich datasets that support the detection and management of various health conditions. This project uses three sensing technologies: environment, video and wearable sensing. SPHERE is a specially impressive project that makes a beneficial bridge between IoT and AAL. An AAL cloud-based IoT platform was proposed by [20] to manage the integration and behaviour-aware orchestration of devices as services stored and accessed via the cloud.

2.3 Smart Homes

There are decades of research about smart homes. The MIT Media Lab has developed the first project [21]. Today, three main categories of smart homes exist. The first category detects and identifies the actions of its residents to determine their health. The second category aims at the storing and retrieving of multimedia captured within the smart home, in different levels from photos to experiences. The third category is surveillance, where the data captured in the environment is processed to obtain information to raise alarms and protect the home and the residents. There is also a type of smart homes that have the objective to reduce energy consumption by monitoring and controlling electric devices [22].

Recent advances in information technology allowed lower prices of smart homes but provide them intelligence environments to make complex decisions remains a challenge. In the future, the number of smart homes will increase with the use of sensors that will store the data acquired in monitoring databases in real-time.

Three broad views are introduced by [23]: a functional view, an instrumental view, and a socio-technical view. The functional view sees smart homes as a way of better managing the demands of daily living through technology. The instrumental view shows smart homes' potential for managing and reducing energy consumption. According to a socio-technical view, smart homes provide continuous digitalization to daily life activities.

In Europe, some smart home projects include iDorm [24], Gloucester Smart Home [25], CareLab [26], and others.

Several challenges are related to IoT and AAL such as security, privacy, and juridical. In general, IoT devices are wireless and exposed to a public range. Therefore, the ownership of data collected needs to be established. The IoT systems should adopt encryption methods and privacy policies.

An integrated platform for monitoring and control of a home that uses ZigBee wireless network and is distinguished by the use of open-source technologies that combines IoT and AAL has presented by [27].

As regular people spend a considerable part of their time inside buildings, the smart homes will have a significant role in occupational health. Therefore, smart homes should incorporate pervasive sensors for ambient quality evaluation to identify harmful situations in real-time and correlate the indoor environmental conditions with the occupant's health status.

2.4 Indoor Air Quality

An IAQ supervision system is an essential tool for air quality assessment, and furthermore is also an important decision tool for planning interventions to promote occupational health. An IAQ evaluation framework supports the identification and variation of IAQ parameters. Nearby and disseminated evaluation of IAQ is critical for enhanced occupational health, such as gas spills identification or security applications, but also to control heating, ventilation and air conditioning (HVAC) systems [6]. An IAQ real-time monitoring system gives a predictable stream of IAQ information for a stable administration and building managing. The remote IAQ monitoring provides continuous data collection for enhanced AAL standards, as proposed in [28], by presenting an effective air quality system for different gas sensors monitoring such as methane, propane, and carbon dioxide and monoxide.

In general, the existing IAQ frameworks are expensive and only implement random sampling. Thus, only a few new systems have been created for checking environmental parameters with the objective to enhance occupational health [29]. The accessibility of cost-effective sensors and communication technologies provide the criteria to develop intelligent systems for data collection and physical interaction, e.g., air quality monitoring and control systems [30]. Some solutions aimed at IAQ supervision are beginning to take centre stage [31–36]. A dedicated, miniaturized, low-cost electronic system based on metal oxide sensors and signal processing techniques that supports carbon monoxide, nitrogen dioxide in mixtures with relative humidity and volatile organic compounds supervision through an optimized gas sensor array and effective pattern recognition methods is presented by [37]. Another wireless solution for environmental parameters supervision such as temperature, humidity, gaseous pollutants and aerosol is proposed by [38]. A monitoring system that uses a low-cost wireless sensor network, to collect IAQ information developed using Arduino, XBee modules and microsensors, for storage and availability of monitoring data in real-time is presented by [39].

2.5 Materials and Methods

In general, the quality of indoor environments covers the visual and thermal comfort but also the IAQ. In this context, environmental parameters such as temperature, humidity, airspeed, lighting level and pollutants concentrations are crucial for a proper evaluation of indoor environments.

The ***iAQ Wi-Fi+*** is an IAQ monitoring solution that provides temperature, humidity, PM_{10}, CO_2 and luminosity supervision in real-time. It is a completely wireless solution, where the wireless communication is implemented using the ESP8266 module which implements the IEEE 802.11 b/g/n networking protocol, a family of specifications developed by the IEEE for WLANs. The IEEE 802.11 standard supports radio transmission within the 2.4 GHz band [40].

This solution is based on open-source technologies, and it uses an Arduino UNO [41] as a microcontroller and an ESP8266 module for data communication. The data collected by the system is stored in a ThingSpeak platform. ThingSpeak is an open-source IoT application that offers APIs to store and retrieve data from sensors and devices using HTTP over the Internet [42].

The end user can access the data from the web page provided by ThingSpeak platform or can use the smartphone app developed in Swift, an open-source programming language with Xcode integrated development environment (IDE) created for the iOS operating system. By providing a history of changes, the system helps the build manager to make a precise and detailed analysis of the IAQ. Therefore, this data could support him to decide on possible interventions to improve IAQ.

Figure 2.2 represents the system architecture.

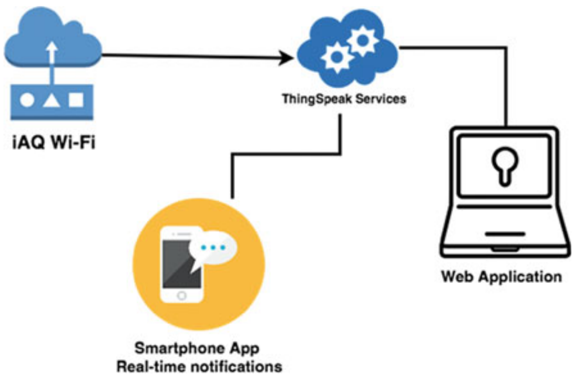


Fig. 2.2 ***iAQ Wi-Fi+*** system architecture

The ***iAQ Wi-Fi+*** can be divided into three major parts: a processing unit, a sensing unit, and a communication unit. This system is built using the embedded Arduino UNO microcontroller as the processing unit. Arduino is an open-source platform that incorporates an Atmel AVR microcontroller [41]. The sensing unit incorporates temperature, humidity, dust concentration, light, and CO_2 sensors. The system incorporates an ESP8266 as the communication unit (Fig. 2.3).

The ***iAQ Wi-Fi+*** prototype is shown in Fig. 2.4, and a brief description of the components used is described in Table 2.1.

The firmware of the ***iAQ Wi-Fi+*** is implemented using the Arduino platform language on the Arduino IDE. It belongs to the C-family programming languages. The Arduino UNO is responsible for data collection and is connected to the communication unit (ESP8266) by serial communication.

The Arduino UNO sends a string with the data from the sensors to the ESP8266, and this is responsible to upload this data to the ThingSpeak platform (Fig. 2.5).

Table 2.2 describes the cost of the components incorporated in the ***iAQ Wi-Fi+***.

Compared to the existent systems on the market which have an excessively higher cost and do not provide real-time monitoring data, the ***iAQ Wi-Fi+*** is a suitable solution for enhanced living environments and occupational health.

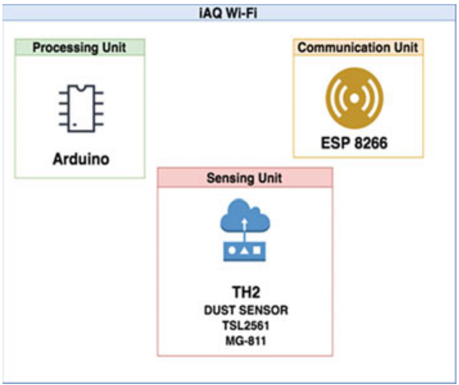


Fig. 2.3 Schematic diagram of ***iAQ Wi-Fi+***

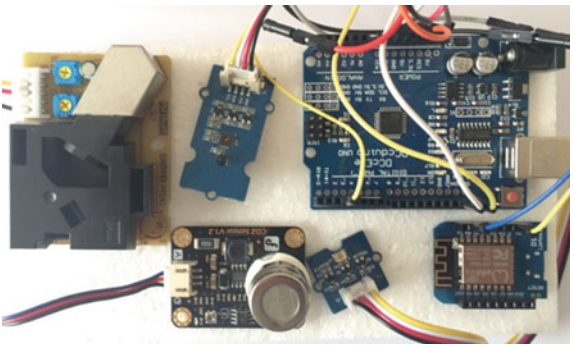


Fig. 2.4 ***iAQ Wi-Fi+*** prototype

Table 2.1 Type, interface, operating voltage and other details of the used components in the ***iAQ Wi-Fi+***

Component	Type	Interface	Operating voltage (V)	Details
Temperature and relative humidity sensor	TH2	I2C	3.3–5	Accuracy: ±4.5% RH and ±0.5 °C Range: 0–100%RH and 0–70 °C
Dust sensor	Shinyei Model PPD42NS	PWM	5	Sensitive to 1 μm and major particles [43]
Light sensor	TSL2561	I2C	5	Range: 0.1–40,000 lx Working temperature: (−40–85 °C) [44]
CO_2 sensor	MG-811	Analog	5	Range: 340–10,000 ppm [45]. Working temperature: 20–50 °C [46]
Wi-Fi chip and MCU (microcontroller unit)	ESP8266	I2C	3.3	32-bit MCU and supports 802.11 b/g/n protocols Working temperature: −40–125 °C [47]

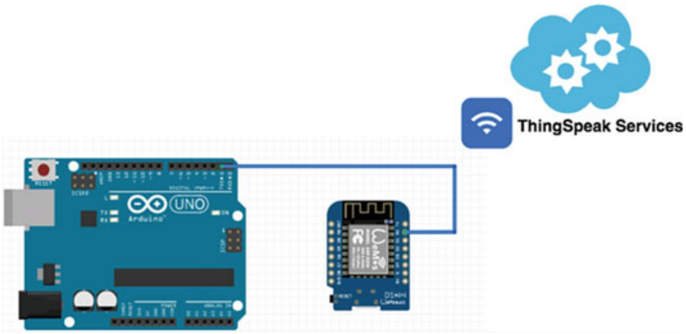


Fig. 2.5 Arduino UNO and ESP8266

Taking into consideration that ***iAQ Wi-Fi+*** is intended to be used in indoor environments where electricity is available, there was no great concern with the choice of ultra-low-power sensors and the research focus on the real-time data collection and notification features. The selection of the sensors was based on the cost of the system.

The ESP8266 has an important feature that provides to the end user an easy configuration of the Wi-Fi network to which it will be connected. The ESP8266 is by default a Wi-Fi client, but if it is unable to connect to the Wi-Fi network or if there

Table 2.2 Component costs of the ***iAQ Wi-Fi+*** system

	Cost
Arduino UNO	8.59 USD
ESP8266	3.39 USD
TH2	9.46 USD
Shinyei dust sensor	13.31 USD
TSL2561	11.20 USD
MG-811	39.10 USD
PCB	3.65 USD
Cables and box	9.59 USD
Total	98.29 USD

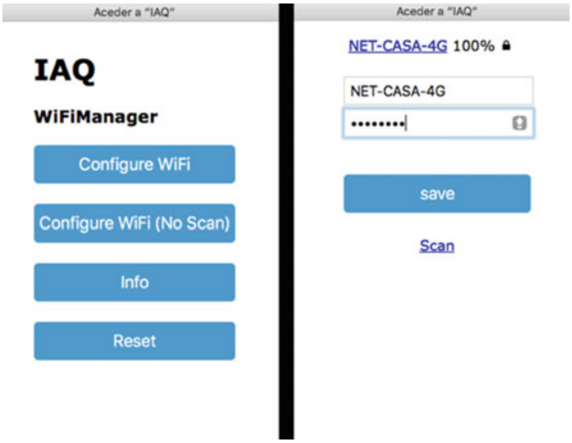


Fig. 2.6 Wi-Fi network configuration

are no wireless networks available, the ESP8266 will turn to hotspot mode and will create a Wi-Fi network with an SSID “IAQ”. At this point, the end user can connect to the created hotspot which permits the configuration of the Wi-Fi network to which the ***iAQ Wi-Fi+*** is going to connect through the introduction of the network SSID and password (Fig. 2.6).

2.6 Results and Discussion

The ***iAQ Wi-Fi+*** allows viewing the data according to graphical and numerical values by using a web browser or a smartphone app.

For testing purposes, two ***iAQ Wi-Fi+*** modules were been used. All modules are powered using 230–5 V AC-DC 2A power supply. IAQ data were collected for two months and show that under certain conditions, air condition is significantly affected.

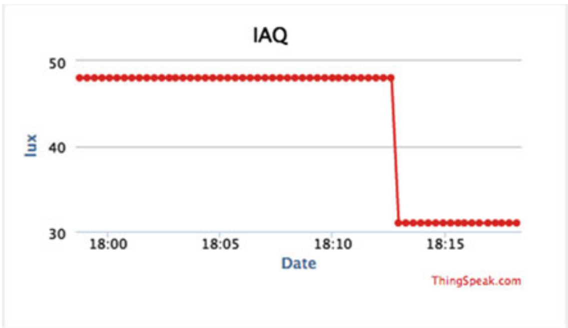
The end user can access the data using the ThingSpeak platform but also from the web portal built in PHP. After login, the end user can easily access the IAQ data in real-time. The web application allows the user to keep the parameters history. The system helps the user to provide a precise and detail analysis of the air quality behaviour. The map view feature allows the user to check in real-time the latest values collected by ***iAQ Wi-Fi+*** referencing their location (Fig. 2.7).

A sample of the data collected by ***iAQ Wi-Fi+*** is shown in Figs. 2.8, 2.9, 2.10 and 2.11. Figure 2.8 represents luminosity data measured in lux, Fig. 2.9 represents temperature data measured in Celsius, Fig. 2.10 represents dust sensor data measured in $\mu g/m^3$ and Fig. 2.11 represents the humidity data measured in %. The graphs display the results obtained in a real environment with induced simulations.

The ***iAQ Wi-Fi+*** is also equipped with a powerful alerts manager that notifies the user when the IAQ is poor. The maximum and minimum health quality values are

Fig. 2.7 Map view functionality

Fig. 2.8 Luminosity (lux)



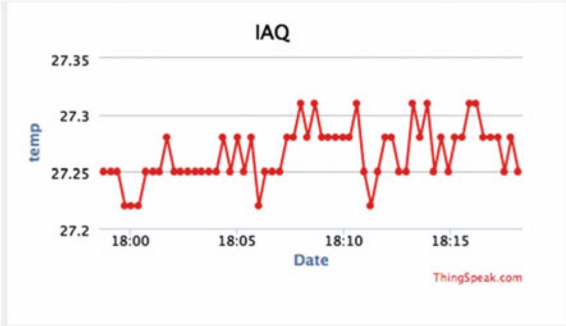


Fig. 2.9 Temperature (ºC)

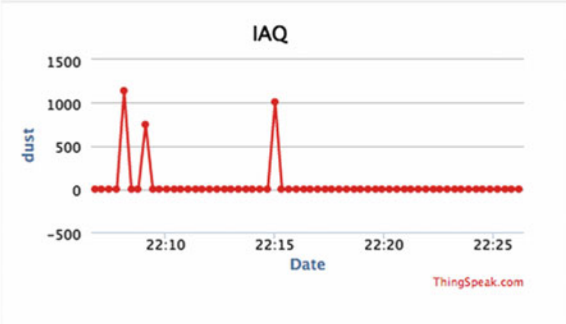


Fig. 2.10 Dust sensor PM_{10} ($\mu g/m^3$)

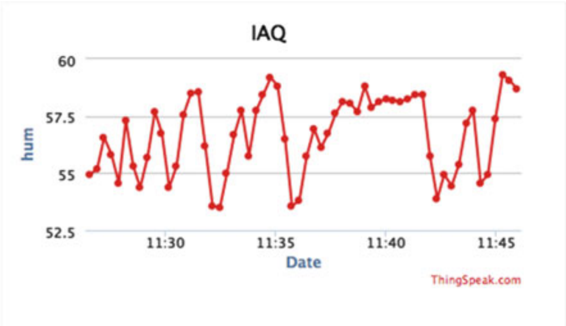


Fig. 2.11 Humidity (%)

predefined by the system based on well-studied values, but the user can also change these values to specific proposes (Fig. 2.12).

When a value exceeds the defined threshold, the user will be notified in two ways by e-mail or by smartphone notification in real-time (Fig. 2.13). This functionality enables the user to act in real-time ensuring excellent ventilation for enhanced living environments and occupational health.

The smartphone application allows a quick, simple, intuitive and real-time access to the monitored data in numerical and graphical form (Fig. 2.14). Mobile computing

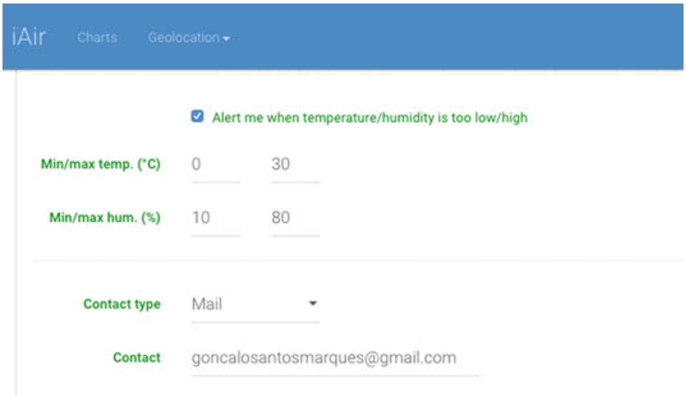


Fig. 2.12 Alert configuration manager

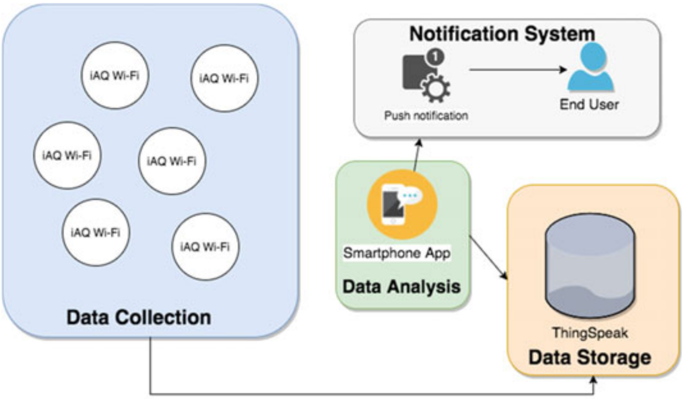


Fig. 2.13 ***iAQ Wi-Fi+*** smartphone notifications architecture

in the USA has an exponential growth as adult smartphone device ownership was at 33% in 2011, 56% at the end of 2013 and 64% in early 2015 [48]. In the Netherlands, 70% of the global population and 90% of the adolescents own a smartphone [49]. In Germany, 40% of the population uses a smartphone [50] and 51% of adults owned smartphones in the UK [51]. About 36–40% of smartphone owners use their smartphone 5 min before bed and in the next 5 min after waking up [50]. Smartphones not only have excellent processing and area capabilities but also people carry them in their daily lives. Therefore, a mobile application has been created to allow a quick, easy and intuitive access to the monitoring data. In this way, the user can carry the IAQ data of their home with him for everyday use.

On the one hand, the IAQ charts allow greater perception of the parameters behaviour than the numerical format. On the other hand, mobile computing technologies enable a precise analysis of the temporal evolution. Thus, the system is

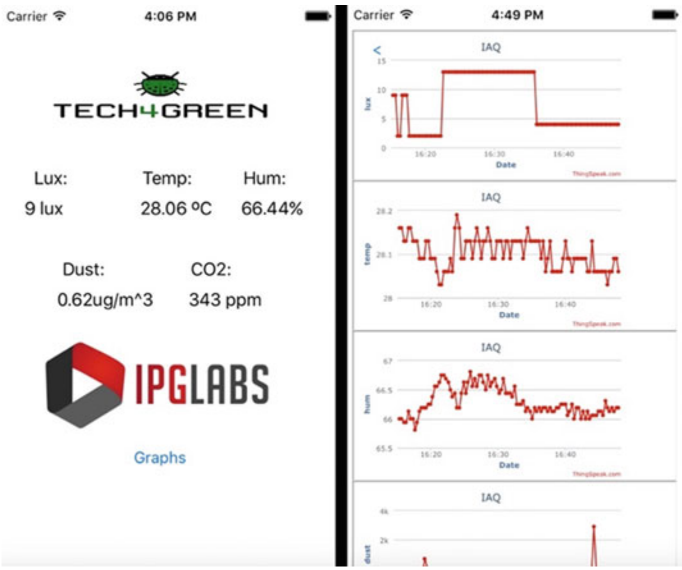


Fig. 2.14 ***iAQ Wi-Fi+*** mobile application

a powerful tool for air quality evolution analysis and decision making on possible interventions for enhanced living environments and occupational health.

Compared to other systems, the ***iAQ Wi-Fi+*** system has the following advantages: modularity, small size, low-cost construction and easy installation [52, 53].

In the future, the principal objective is to improve the work by adding a context-awareness approach to automate the of HVAC equipment's [54–57]. Improvements to the system hardware and software are planned to make it much more appropriate for specific purposes such as hospitals, schools, and offices. Formaldehyde (FA) is a high-volume chemical, which is used for disinfection purposes and as a preservative. FA is genotoxic, causing DNA adduct formation, and has a clastogenic effect; exposure–response relationships were nonlinear [58]. Therefore, the possibility to incorporate an FA sensor in ***iAQ Wi-Fi+*** should be noted.

2.7 Conclusion

By monitoring IAQ is possible to provide analysis of the ventilation conditions in real-time and plan interventions to increase the air quality if needed.

This chapter has presented a complete wireless solution for IAQ monitoring based on IoT architecture. This solution is composed of a hardware prototype for ambient data collection and smartphone compatibility for data access. The results obtained are promising, representing a significant contribution to IAQ monitoring systems based on IoT.

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

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 proposed system should find ways to respond to these problems. Data security, in particular, is of the utmost importance in the field of health care. Therefore, Part II of this book presents several significant approaches on security and privacy in IoT-based e-health applications. As future work, it is expected to introduce new sensors to this system for monitoring other IAQ parameters as well as the development of a platform that allows sharing in a secure way the collected data to health professionals. In addition to system validation, physical system and related software improvements have been planned to adjust the system to specific cases such as hospitals, schools, and industrial factories.

Systems like ***iAQ Wi-Fi+*** will be a part of the indoor spaces in the future. IAQ data can be used by health professionals to support clinical diagnostics to address occupational health problems.

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