# Monitoring environments with new generation devices ⋆

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**Abstract.** Currently, a number of studies have found that high levels of carbon dioxide in an enclosed space increase the probability of COVID-19 infection and can have adverse health effects. The control of the levels of certain gases, such as carbon dioxide, has become significantly relevant during the period of the COVID-19 pandemic. Therefore, this study presents a system for indoor air quality monitoring and counting in an enclosed space. Furthermore, the system has been evaluated in a case study with different scenarios and it is analysed how the ventilation affects the air quality levels in the enclosed space. For example, the raw carbon dioxide value obtained from the MQ135 sensor is 63 without any person in the room compared to the raw value of 148 when there are 4 people. All this is done using the Internet of Things paradigm and the implementation of intelligent ambients.

**Keywords:** Intelligent ambients · Internet of Things · Monitoring system · Low-cost development board

## 1 Introduction

COVID-19 has been a major focus of global attention since its emergence. From its early stages, research focused on how the virus was transmitted in order to prevent its massive spread. These studies have concluded that a healthy person can contract the disease through the inhalation of aerosols containing the virus, as they remain suspended in the air for extended periods of time [20].

The higher the concentration of aerosols in an enclosed space, the higher the viral load and therefore the greater the possibility of infection. Therefore, good ventilation, together with maintaining an adequate safety distance in enclosed spaces, has become a key measure to control the percentage of aerosols suspended in the air and thus reduce the spread of the virus. [2].

From another perspective, several studies have shown that high levels of carbon dioxide ($CO_2$) in the environment can have negative effects on health,

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affecting both personal performance and physical fitness. In particular, the study by Satish et al. [18] looked at the impact on decision-making and physical health (such as headaches and dizziness) or physiological health (such as increased blood pressure). Therefore, it is essential to maintain adequate ventilation in enclosed spaces to prevent the accumulation of $CO_2$. However, in cases such as offices or classrooms with a high concentration of people, keeping windows permanently open may not be feasible due to energy savings in heating or air conditioning[6].

Consequently, indoor air monitoring has a dual objective: to control the quality through $CO_2$ saturation and viral load. For $CO_2$ monitoring, the use of new technologies to obtain, analyse and visualise the data is important. Accordingly, the aim of this work is to address the current problem in relation to air quality and propose a potential solution through the monitoring of intelligent ambients by leveraging the IoT paradigm.

The paper is structured as follows. Section 2 presents a review of existing works on current technologies related to sensorisation in gases and intelligent ambients. Section 3 presents the system architecture and data collection. Section 4 shows the case studies carried out and their corresponding results. Finally, Section 5 presents the conclusions and the contribution provided.

## 2 Related works

This section reviews intelligent ambients and gas monitoring, both of which are considered fundamental applications of the IoT and are the foundation of this paper.

It should be noted that the concept of IoT emerged in 1999, coined by computer engineer Kevin Ashton, who at that time was working in the field of radio frequency identification (RFID) [16]. According to Gartner, IoT is defined as a network of physical objects that incorporate technology to communicate, sense or interact with their internal states or the external environment [1]. On the other hand companies such as Cisco point out that IoT refers to the time when there were more objects connected to the internet than people between 2008 and 2009 [7]. However, both definitions highlight the idea of things connected to the network with embedded technology for connectivity and data transmission.

The future of IoT is being realised in the concept of the Internet of Everything (IoE), which is defined as the networked interconnection of people, processes, data and objects, which benefits from the value generated by this extensive connection as everything is integrated online. This definition goes one step further, because while IoT is considered one technology transition, IoE encompasses multiple technology transitions, including IoT, and is emerging as one of the most important trends in technology today [15,8]

Both IoT and IoE have applicability in various fields, such as domestic, business, industrial, health, education, among others [17]. In the context of this paper, the topic of intelligent ambients is addressed. Intelligent ambients are electronic environments that are sensorised and responsive to the presence of a user, who remains unnoticed in the environment, with only the user interface being perceptible. This paradigm, known as Ambient Intelligence (AmI), is based on persuasive or ubiquitous computing, profiling, context awareness and human-centred interaction design [14]. An example of intelligent ambients is the Smart Lab of the University of Jaén. This laboratory is characterised by the integration of a wide range of sensors at various points, which allows its use in multiple projects and applications [10].

An important component of intelligent ambients is gas monitoring, specifically in this work on $CO_2$. Gas monitoring involves the use of sensors for gas detection. Each sensor has its own characteristics, such as sensitivity, accuracy, ability to select between various gases, detection ranges, response time and recovery time, which determine the performance of the sensor in question.

In a literature review, it is possible to find several types of gas sensors, among which, according to Z. Yunusa et al. [4]:

- Catalytic sensors. Detect toxic, flammable or combustible gases. They operate by a chemical reaction in which gases interact with a catalyst, generating an electrical current which is measured to determine the gas concentration [19].
- Thermal conductivity sensors. Detect the presence of gas by measuring the amount of heat that the gas transfers to the sensor. This device is composed of two elements: one is kept at a constant temperature and the other cools in response to the gas flowing over it. The temperature difference between the two elements is proportional to the thermal conductivity of the gas, which allows the concentration of the gas to be determined. They are simple but robust sensors, however, they require a heating wire [5].
- Electrochemical sensors. Work by generating an electrical current from a chemical reaction between the gas to be detected and an electrode. The electrode is coated with a gas-sensitive material that acts as a catalyst for the chemical reaction. As the gas comes into contact with the sensitive material, an electrochemical reaction takes place which produces an electrical current proportional to the gas concentration [12].
- Optical sensors. Measure the absorption of light at a specific wavelength by the gas to be detected. The sensor contains a light source and a light detector, and the gas is placed between the two. When light is emitted from the source, it passes through the gas and reaches the detector. The amount of light reaching the detector is reduced by the amount of gas present, as the gas absorbs some of the light. The decrease in the amount of light detected is converted into an electrical signal that can be measured to determine the gas concentration. This type of sensor is commonly used in gas detection applications, such as measuring carbon monoxide in air. Its main disadvantage is the influence that ambient light can have, however, it is not sensitive to electromagnetic interference and the detection area is very large [21].
- Infrared sensors. These are a sub-type of the optical sensors mentioned in the previous point. In this case, they are based on the emission of an infrared light source. These sensors are highly sensitive and can detect gases even at low concentrations [11]. And there is variety on the market [3]

- Semiconductor sensors . Based on a chemical reaction between the gases and the semiconductor material, which is usually a tin oxide layer, producing a change in the electrical resistance of the sensor. This change is measured and used to determine the gas concentration. Advantages include speed of response, low cost, high sensitivity and ease of use [9].
- Acoustic wave sensors. Work by measuring the resonant frequency of an acoustic wave propagating along a piezoelectric crystal. When gases bind to the crystal surface, they change their resonant frequency and this measurement determines the gas concentration. In addition, they have high sensitivity, selectivity and stability, as well as fast response and low power consumption. They are widely used in gas monitoring and environmental analysis applications [13].

In this work, a semiconductor sensor of the MQ series has been used, due to the great advantages of low power consumption, speed of response and ease of use And above all because we are looking to design a low-cost device and this sensor has a very low price. However, a disadvantage is the cross-sensitivity which in this case in ideal conditions (closed room) would not be a problem.

## 3 Materials and Methods

This section presents the architecture of the system and the procedure carried out for data collection.

### 3.1 System architecture

The architecture of the prototype system is presented in Fig. 1. The hardware part is composed of:

- NodeMcu V3 (ESP8266) development board. It has a 5V pin that allows powering the gas sensor and accelerometers. Through its analogue-to-digital converter (ADC) pin, the raw values of the gas sensor can be obtained in a range from 0 to 1023 unsigned integers (10bits). In addition, this small-sized board incorporates Wi-Fi connectivity, which will be used to transmit the data obtained during the measurement.
- Raspberry Pi 3 Model B+ development board. It is compact in size but has considerable computing power. Thanks to its ability to manage the flow of information between the ESP8266 boards, the database and the IoT platform, it becomes a key part of the correct working of the system.
- MQ135 sensor. It is highly sensitive and accurate, with fast response and low power consumption and is compatible with different development platforms, making it ideal for use in IoT projects and ambient monitoring. It detects the presence of various toxic gases, such as ammonia, benzene, carbon dioxide, carbon monoxide and sulphur dioxide.

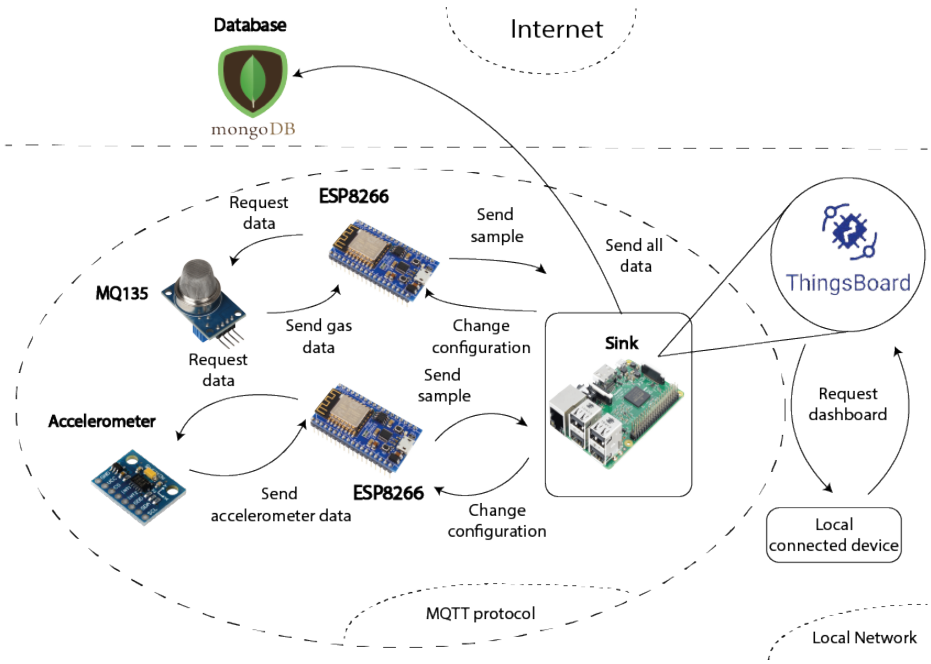



Fig. 1: Initial system prototype diagram.

- Voltage divider. It is an intermediate stage between the MQ135 sensor and the ADC pin of the ESP8266. Its function is to adapt the electrical signal generated by the gas sensor, which has a range of 0-5V, to the reading range of the ESP8266 ADC pin, which is 0-3.3V. In this way, the voltage divider allows a suitable connection between the gas sensor and the development board, guaranteeing the correct capture and analysis of the data obtained.
- MPU6050 sensor. It is an inertial measurement device that integrates a three-axis gyroscope and a three-axis accelerometer on a single chip. It is used to determine the open/closed status of door and window.
- Smartphone. It is used to count the presence of nearby people through Wi-Fi technology.

On the other hand, the software part is composed of:

- Visual Studio Code. Development tool used to program ESP8266 development boards.
- Message Queuing Telemetry Transport (MQTT). It is the communication protocol based on subscription and publication that has been used to communicate and send data between the different devices in the system.
- MongoDB. It is the database used to persistently store all the data coming from the MQ135 and MPU6050 sensor.
- ThingsBoard. The open source IoT platform that enables device management and data collection, processing and visualization. It offers paid and

Community Edition versions, which will be used in this project and is compatible with various architectures. ThingsBoard offers features such as horizontal scalability, customization and communication via MQTT, HTTP and LrM2M.
- ThingsBoard Gateway. It is used for integrating devices connected to legacy and third-party systems with ThingsBoard IoT. This allows the extraction of data from devices connected to external MQTT brokers, OPC-UA servers, Sigfox Backend, Modbus slaves or CAN nodes.

### 3.2 Data Collection

In this section, the data collection of the system is discussed. For this, an ESP8266 board connected to an MQ135 sensor is placed near the main door of the room. In the same way, another board with the same sensor is deployed near the window to measure possible differences. The connection between the board and the sensor and the applied voltage divider is shown in Fig. 2.

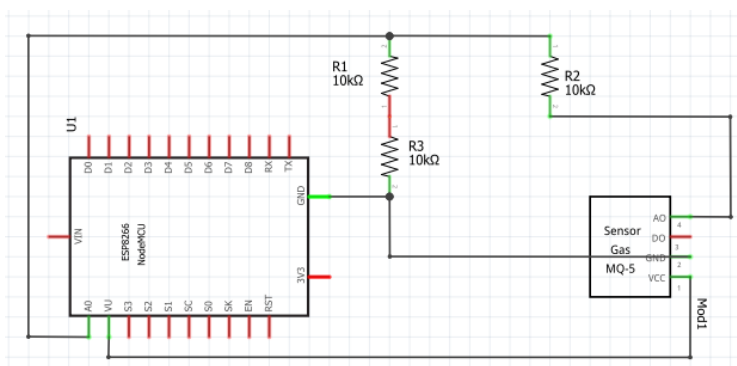



Fig. 2: Schematic of MQ135 and ESP8266 sensor assembly near window and door.

On the other hand, another ESP8266 board connected with a MPU6050 sensor is deployed and attached to the window. Similarly, another board and sensor is mounted on the main door to check the open/closed status of the window and the door, as shown in Fig.3.

Finally, a local Wi-Fi network created by one of the ESP8266 boards is established. This device is based on the principle of communication between networks and nearby mobile devices to obtain basic data such as the network identifier and the Received Signal Strength Indicator (RSSI). The RSSI is used to establish the inflow based on a threshold value defined by experts.

The data collected by the 4 ESP8266 boards plus the Wi-Fi based flow information from the mobile devices is collected and sent to a remote database for

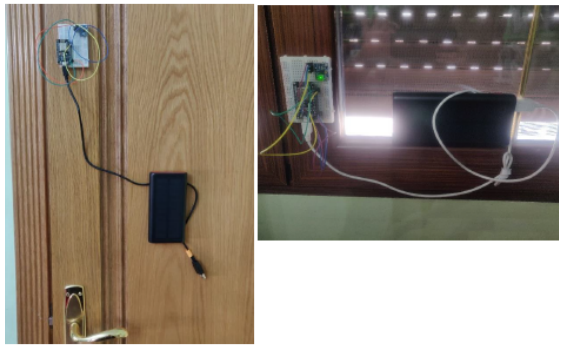


Fig. 3: Device installed on the door and window.

persistence by a central element. In addition, an own dashboard has been created on the ThingerBoard IoT platform for real-time visualisation on a designed dashboard shown in Fig.4.


Fig. 4: Our complete dashboard.

## 4 Case study

In this section, the system is evaluated through a case study with three different scenarios that have been carried out to observe the progress of the $CO_2$ gas variable. The closed space in which the three case studies are presented is given by Fig. 5.Its total area is estimated to be $12m^2$.

The variables to be studied are the following: the number of people in the room at each instant, the opening of both the window and the door at each

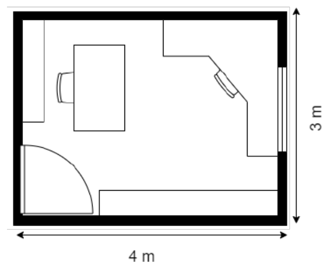



Fig. 5: Map of the room where the case studies are implemented.

instant, as well as the differences between the values recorded by the $CO_2$ meter located near the window and the one located near the door. The way to collect data is as follows: close both the door and the window and keep as many people as necessary inside, depending on the scenario you want to experiment with. Then, you start collecting data which is visualised from the graphs on the dashboard that has been generated. After an extended period of time, which can vary depending on the scenario between one hour and two hours, both the window and the door are opened and the data collection continues, this time, ventilating to observe the changes that may occur.

### 4.1 First scenario

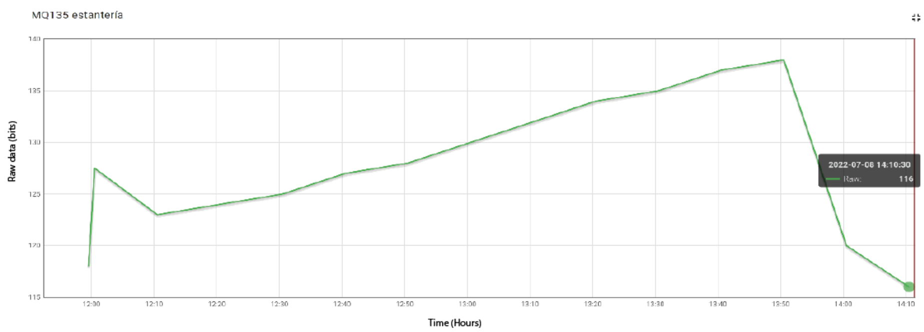
In this first scenario, a session was conducted without the participation of any person and both the window and the door were closed, in order to observe the minimum values of $CO_2$ in the absence of any external influence. Over a period of one hour, stable values around 63 were recorded. These values indicate low and constant $CO_2$ levels in the passenger compartment, suggesting good air quality under these controlled conditions.

### 4.2 Second scenario

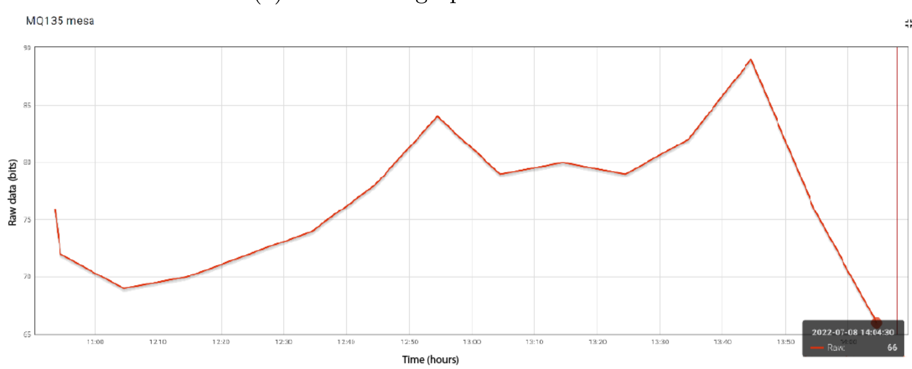
In this second experiment, one session was carried out with the participation of two people, with an approximate duration of two hours. The gas recording started at 11:53 h and ended at 14:10 h.

Fig. 6a shows the raw values obtained from the MQ135 gas sensor for the measurement of $CO_2$. These values are in the range of 0 to 1023 unsigned intergers (10 bits). During the measurement, a first peak of high values is observed, which corresponds to the calibration process of the sensor. This process starts with a stabilisation around the value of 123, until it reaches a new maximum close to 138 at 13:50 h, at which time the device had been measuring for two hours without ventilation. Subsequently, a sharp decrease in the values recorded can be seen, just after the opening of the door and the window at 14:00 h. This decrease is kept until the last recorded value at 14:10 h, where a minimum of 116 is reached after a short period of ventilation.

Fig. 6b shows the results obtained from the MQ135 gas sensor located near the window. In this case, it can be seen that the maximum peak of 89 obtained occurred at 13:44 h, which coincides with the maximum recorded in the gas sensor mentioned above. After the ventilation period, a minimum peak of 66 is obtained at 14:04 h. It should be noted that this minimum value corresponds to a much lower $CO_2$ level than the previous maximum value, indicating that the ventilation has been effective in reducing the $CO_2$ levels in the passenger compartment.




(a) Gas sensor graph near to the door




(b) Gas sensor graph near to the window

Fig. 6: Second scenario

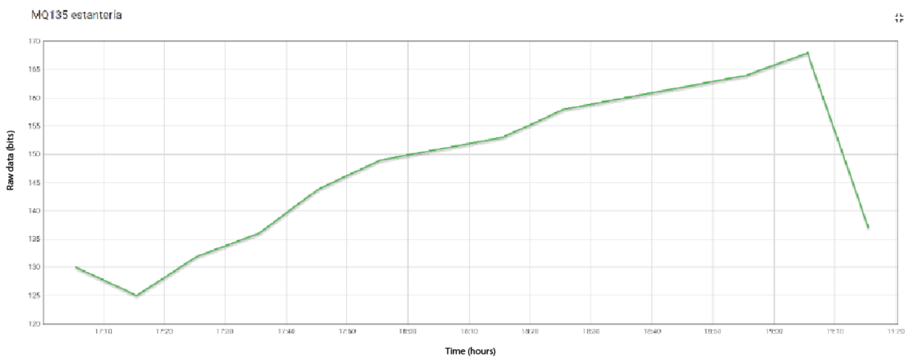
### 4.3 Third scenario

In the third scenario, a session was held with the participation of four people, lasting approximately two hours.

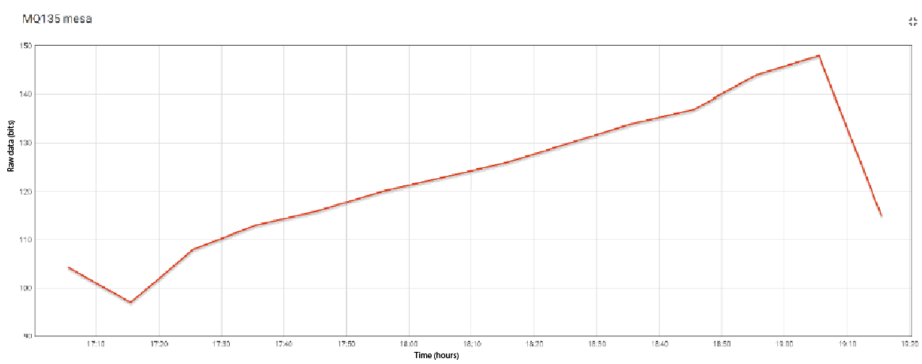
Fig. 7a shows the raw values obtained from the MQ135 gas sensor located near the door. During the measurement, a first global minimum of 125 is observed. After a period of 110 minutes without ventilation, a maximum peak of

168 is observed. Subsequently, when ventilation is started, the values decrease quickly.

In Fig. 7b the results obtained from the MQ135 gas sensor located near the window are presented. In this case, it is observed that the maximum peak of 148 also occurs after 110 minutes without ventilation, as in the previous case. Finally, at the beginning of the ventilation period, the values decrease sharply in only 10 minutes, reaching 89.




(a) Gas sensor graph near to the door




(b) Gas sensor graph near to the window

Fig. 7: Third scenario

Thus, it can be observed that as the number of people in the room increases, in this case 4 people, there are changes in the values recorded by the MQ135 sensor near both the window and the door. In the case of the sensor near the window, the maximum peak increases from 138 bits from the second scenario to 168 bits. For the sensor near the door, the maximum peak increases from 89 bits to 148 bits.

# 5 Conclusions

This work has focused on the design, implementation and experimentation of a low-cost IoT-based system to observe and record $CO_2$ measurements in an enclosed space, using two sensors, as well as collecting additional information from the ambient environment, such as door and window status and affluence.

The results obtained from the case studies have shown favourable conclusions (refer to Table1). Over the course of the time without ventilation, a gradual increase in gas concentrations has been observed, especially in situations of increased human traffic in the studied ambient. However, a significant decrease in gas concentrations was observed when both the door and the window were opened to allow suitable ventilation.

Table 1: Summary of the results of the different scenarios.

| Nº Scenario | Nº of people | Max raw data of carbon dioxide |
|---|---|---|
| 1 | 0 | 63 |
| 2 | 2 | 138 |
| 3 | 4 | 168 |

These results conclusively demonstrate the efficacy of ventilation as an effective measure to reduce gas concentrations in the analysed ambient.

## 5.1 Limitations and future works

This work aimed to raise knowledge of the benefits of using smart gas devices to monitor environments. However, some improvements that could be made in the future would be to calibrate the MQ135 sensor to provide ppm values and not just raw values, to use contact sensors for opening and closing doors and windows and reduce the computational load on the development board, generate a statistical analysis including significance tests on the differences that are observed and finally, to extend the study to new environments and gases.

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