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IoT monitoring system for air quality assessment and collecting data

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ABSTRACT

The composition of the air has been visibly altered as a result of human activity, resulting in what we term air pollution. It is no longer necessary to prove the effects on ecosystems and human health. Under these conditions, governments all around the world are working to address this issue, notably in the area of real-time air quality monitoring. The implementation of a data provider is a necessary step in achieving this goal. In that case, this study presents a hardware and software solution to provide a low-cost deployable device to acquire environmental data related to AP such as CO, CO_2, NH_3, and NO_2, along with temperature and humidity. In addition to an user interface development, a complete circuit layout and a set of software criteria are set up to ensure a reliable implementation, data collection, and network communications. The results demonstrated that the device is capable of effectively obtaining real-time data. The analysis results indicate a link between environmental conditions and parameter values. This system deployment will ultimately contribute to providing a more elaborate mapped data distribution, according to a better understanding of our environment.

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1. INTRODUCTION

Nowadays, our environment is affected by several types of pollution. Moreover, governments are more than concerned by the place that our environment has, especially in the way of maintaining higher our standards of living. As a result, they're supporting a variety of monitoring methods in order to collect the proper data at the right time [1]. For instance, pollution effects such as air quality, water, and noise were respectively studied in [2]-[5]. Various technologies were used in these investigations to acquire environmental indicators, assess their quality, and analyse their distribution. Along with these studies, air quality importance no longer has to be proved [6]. Indeed, it has a worldwide global effect in general, but also affects other resources such as ocean [7] and human health [8]. All these kinds of research involve the use of systems which are mainly based on the internet of things (IoT) technologies. As the number of devices connected to the internet is nowadays increasing rapidly, the use of such equipment is becoming a standard in communication between each component for different purposes (medical [9], city management [5], [10], [11], and security issues and threats [12]).

The termair pollution (AP) or atmospheric pollution refers to the alteration of the air's chemical composition brought on by toxic gases, which have primarily been produced by human activity in recent years. The ecosystems and living beings on our planet are affected by a variety of events and effects caused by these gases and substances. AP has a major impact on the development process of plants by preventing photosynthesis in many cases. Furthermore, it has a serious consequence on the purification of the air we breathe. Pollution killed more people in 2016 than the acquired immunodeficiency syndrome, tuberculosis, and malaria combined [8]. Wind and rain carry the filthy air that is floating on the earth's surface. The dispersion of this pollution across wider distances from its place of origin is further aided by clouds and high temperatures. As an example, this last century is marked with a set of environmental damages such as acid rain, depletion of the ozone layer, global warming, and the greenhouse effect. The concentration of different harmful gases in the atmosphere increased by 43% relative to 1990, CO_2 accounts for about 80% of this, according to the US National Oceanic and Atmospheric Administration quoted in the WMO Bulletin [13]. Developing countries, such as Algeria are currently facing a deterioration of air quality due to many factors. Indeed, rural-urban migration, industrialisation and the huge increase of cars on roads, are the main factors for these rapid changes. Moreover, the prevalent situation in such countries is not known. In April 2013 and March 2015, a descriptive study has been performed to explore the health impact of particulate matter (PM) PM10 (PM10 are airborne particles with a diameter of less than 10 micrometers) air pollution on respiratory health in the city of Algiers (At the medical and surgical emergency department of the Mustapha University Hospital Centre of Algiers). From a total of 20,606 patients, observations showed that the predominant reason for consultation was cough 32%. Asthma attacks represented 28.51% and upper respiratory infections 27.63%. Results confirm that there was a strong correlation between daily particulate matter levels and exacerbations of respiratory symptoms [14]. Recently, another study on the region of Oran [15], focused on the effect of pollutants NOx and CO on the air quality. The resulting emissions of cars and certain factories indicates an increase of the pollutant contents in the air, but also, due to its geographical position, Oran benefits from weather conditions which are favourable to the dispersal of pollutants.

It is well known that global industrialisation has increased population pressure on natural resources. Thus, it has an immense effect on the availability of clean air and resulted in AP. Moreover, it affects human health (in both urban and rural environments) at first, but also caused perturbations in a range of ecosystems (diversity of different animals and insects, and plants) [16], [17]. An outdoor air pollution report [18] stated that 2% to 15% of the total deaths in 2017 were due to AP and associated risks, which leads to 9% at the global scale. Furthermore, they report a total of 8.21 billion deaths between 1990–2017 that are directly or indirectly related to AP. Along with the effect on human health, pollutants such as PM2.5, PM10, sulfur dioxide (SO2), oxides of nitrogen (NOx), ozone (O3) and carbon monoxide (CO), have a potential greenhouse effect and ecosystem losses which lead to the planet global warming such as in Iran [19] and India [20]. According to [21], works on air quality systems and studies reached the total of 11,047 in 2019, showing a continual growth throughout the years, which indicates the importance of implanting such systems and the warning that scientists are raising against AP. The review presented in [21] categorized air quality monitoring systems in five types, namely Ground-based laboratory and digital sensor systems, Aerial and satellite platform-based, and integrated/coupled sensor systems. Regarding the importance of setting up an air quality monitoring system and the technological advances that make it possible, several entities offer such a system. Reviews in [10], [22] reveal the different setups of IoT based air pollution monitoring systems. In addition, we have selected two systems that seem close to our objective, namely CityAir and Brussels AQS.

CityAir represents a partnership of technology companies and research centers from around the world. Started in 2016 in Novosibirsk (Russia), its main goal is to digitize air quality throughout the planet by providing a convenient platform for building and integrating air quality monitoring networks. Brussels AQS, set up in 2018, provides continuous monitoring and in real time evolution of pollutant concentrations in the ambient air in the Brussels-Capital region (the "Air quality" website of Brussels Environment). Indeed, it works mainly on informing citizens about local air quality, but also enable the city to anticipate an air quality deterioration.

To tackle the problem of AP monitoring, works tend to improve two main areas, which are hardware [23]-[25] and software [26], [27] solutions. In this context, and to truly study the air quality, we aim to provide a veritable air composition sampling in our country and more. In fact, According to our review on the subject, we noticed that systems used to acquire data are different (software, hardware, and prices) from one study to another. That is, we clearly need to find a way to provide people and authorities a standardized way of collecting data in real-time, for taking decisions but also to construct a true asset for research studies.

In this paper we present a first attempt to develop a dedicated system for air quality monitoring which we named AQS for air quality system (categorized as a ground-based digital sensor system). We start by presenting in detail the hardware and software implementation. Thus, our contribution mainly focuses on providing the electronic circuit layout, noticed hardware and software problems, and the solutions found to tackle them. All collected data during the tests are reported, results are presented, and discussions with a conclusion and further future works are proposed.

2. METHOD

In this section, we present the adopted layout of the implemented hardware and provide details about data collection management. Initially we used the ESP8266 (a wifi SOC (system on a chip) produced by Espressif systems, a highly integrated chip designed to provide full internet connectivity in a small package) as the main communications manager to collect and redistribute data, but when deploying the AQS device over several days, we found that it was not reliable as it was failing for unknown and unexplained reasons. We could not make a real time response over the local network, as taking measurements from 5 sensors took more than 4 seconds. Separating the network communication and the sensor communication between the two cores by the use of the ESP32 (presented below) instead solved this problem. As shown in Figure 1, we used the Arduino Framework to support different sensor libraries, but also to provide us functional mutual exclusion using freeRTOS (A small footprint, portable, pre-emptive and open source real-time operating system (RTOS) for microcontrollers). Moreover, parallel programming with ESP32 does not allow the execution of atomic instructions, because mutual exclusion is not provided by the hardware. We therefore used the real-time operating system FreeRTOS, to ensure data integrity when writing into the random access memory (RAM) by one of the two cores.

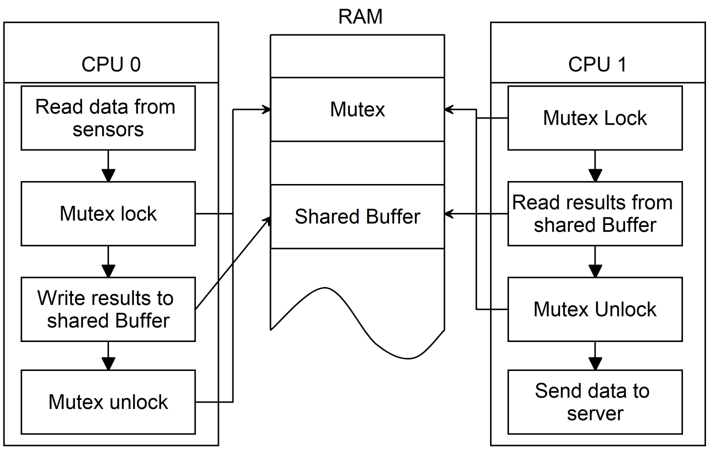


Figure 1. The proposed multi-threads communication solution

2.1. Electronic circuit layout

Figure 2 shows the whole circuit layout, which contains the main processing device as a data collector at the centre, but also all the sensors. Table 1 lists all details about the acquired parameters from each sensor. The ESP32-WROOM-32, designed to be a generic WiFi and Bluetooth microcontroller unit (MCU) module. It targets a wide variety of applications, and the internet of things (IoT) systems at the top of these applications. The embedded chip (The ESP32-D0WDQ6) is designed to be scalable and adaptive. There are two central processing unit (CPU) cores that can be individually controlled with an adjustable clock frequency (from 80 MHz to 240 MHz). Moreover, a low-power co-processor is present and used instead of the CPU to save power while performing low-consumption tasks like monitoring peripherals [28]. Temperature and humidity were collected using DHT22 and CJMCU-680v2, pressure was collected using CJMCU-680v2, CO_2 was collected using MH-Z19 and compared to the estimated values given by CJMCU-30, and NH_3, NO_2, and CO were collected using CJMCU-6814 only.

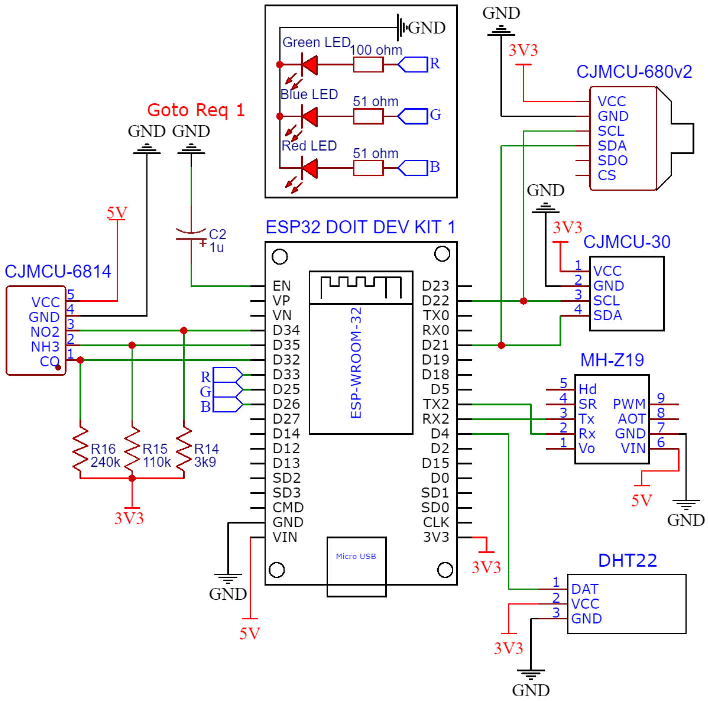


Figure 2. The proposed electronic circuit layout details

Table 1. Sensors details and acquired parameters

Sensors	Parameters	Detection range	Precision
DHT22	Temperature	−40-85 ^oC	± 0.5 ^oC
	Humidity	0-100 %	± 5%
MH-Z19	CO_2	0-5000 ppm	± 50 ppm + 5%
CJMCU-30	eCO_2	400-60,000 ppm	(1, 3, 9, 31 ppm)[a]
	NH_3	1-300 ppm	± 50 ppm + 10%
CJMCU-6814	NO_2	0.05-10 ppm	≤5%
	CO	1-1,000 ppm	± 50 ppm +10%
	Humidity	0-100 %	≤ 3%
CJMCU-680v2	Temperature	−40 - 85 ^oC	± 0.5 ^oC
	Pressure	300-1,100 hPa	≤ 0.6%

[a] 1 : 400-1,479, 3 : 1,479-5,144, 9 : 5,144-17,597, 31 : 1,7597-60,000 ppm

2.2. Database and network communication

For rapid and secure database setting up, We used Cloud Firestore (CF), a database from Firebase and Google Cloud that is adaptable and scalable for mobile, web, and server development. CF is a non-SQL document, which allows to store, synchronize, and query a web or mobile application easily on a global scale. We have structured our database into 3 collections: i) the user collection which contains the phone number, a unique identifier (UID), GPS location and the list of the installed devices for the user, ii) the records collection which contains data collected by the devices, and iii) the bridge collection which links the two previous collections for security purposes. Communication between the system components is done using the HTTP REST-API (representational state transfer, is an architectural style for providing standards between computer systems on the Web) protocol.

The JSON (JavaScript object notation, a textual data format derived from the object notation of the JavaScript language) format was used as a standard for communication between the different components of the system. It allows the representation of structured information in the same way as XML for example.

In order to secure a system, a number of criteria must be met, such as confidentiality, integrity, availability, non-repudiation and authentication. CF allows us to specifically implement the security rules that we want to integrate into our system. To do this, we have chosen to go through several checkpoints:

i) Validate the structure of the received data:
   - Check if the http query is a POST (used to store a new Firebase configuration) query.
   - Check if the http query body is a JSON text and has a valid format.

ii) Ensure the authenticity of the user by checking whether the UID of the user of the http query exists in the Firestore database.

iii) Limit data flooding by:
   - Checking the user write data rate limit (set at 10 min).
   - Write the current time and date to the Users collection for write-rate limit and have a fixed and reliable date and time.

iv) Adds the server's date and time to the http query, letting the server manage the date and time of the received packets with the NTP (the network time protocol, a networking protocol for clock synchronization between computer systems) Protocol.

v) Minimise the cost of the AQS by avoid using the RTC module (fast memory of the ESP32 that allows data to be stored even when the processor is idle).

2.3. User application

Along with implementing a data collection device, we also made all data accessible through a mobile application. This application is directly connected to the database manager and provides live information about the captured values. Figure 3 shows how data are presented according to the device positioning on a map and the chosen parameter.

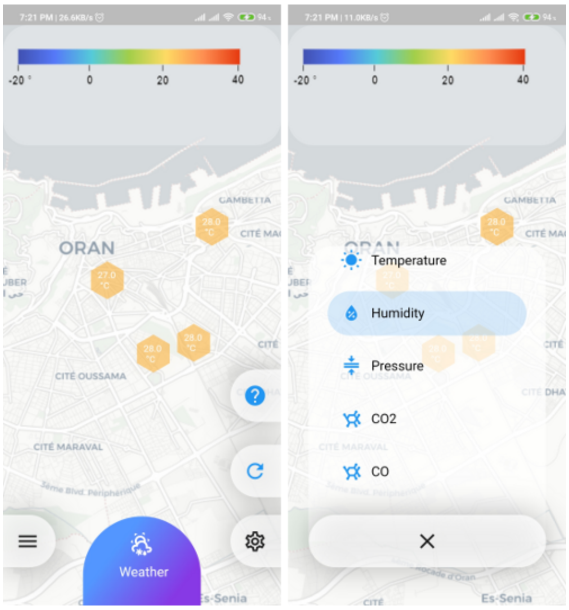


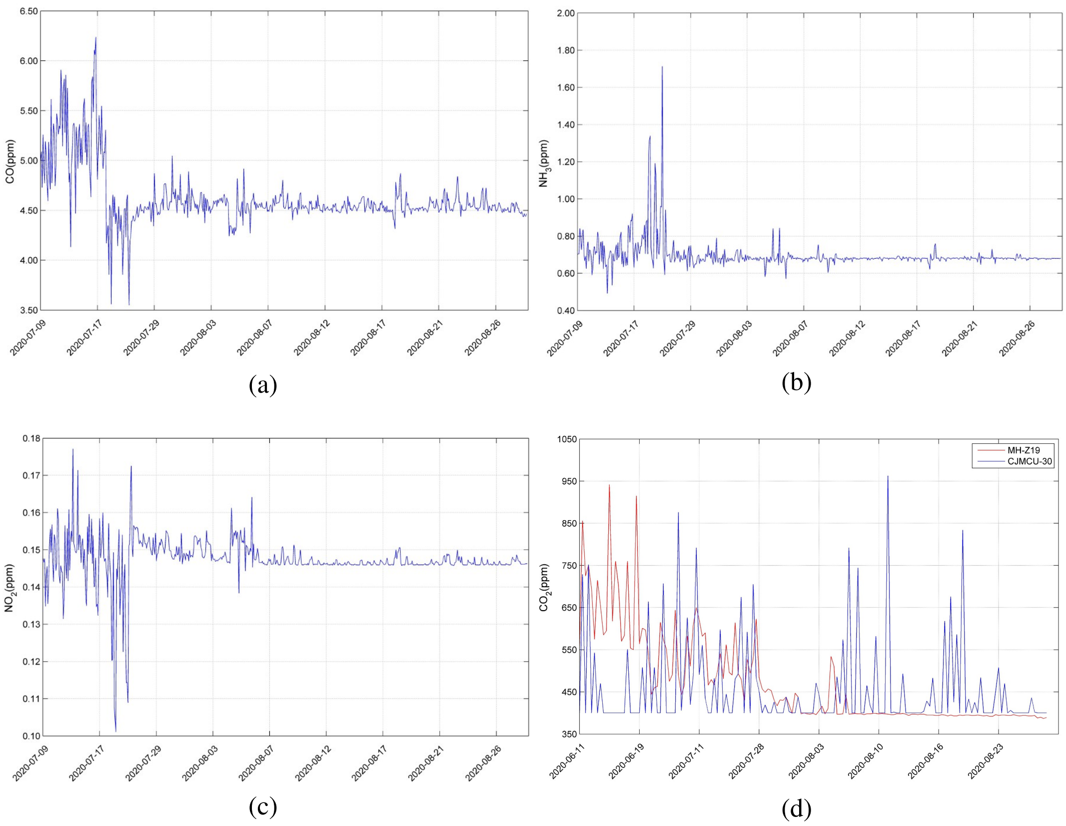
Figure 3. User application screenshots examples

3. RESULTS AND DISCUSSION

In this section, we present at first a set of figures that show the different data provided by our collecting system. We then go further in data distributions from the different sensors to discuss the results. All data presented were collected in Bir-El-Djir city, Oran, Algeria. The whole device was fixed outdoor at the third floor of the building (GPS point: 35°42'59.1"N 0°34'35.2"W) during approximately two and a half months. Depending on each sensor's time-shift to provide data, the system was able to collect a complete one-time information from all sensors with a 5 minutes ±30 sec time-shift.

Figure 4 presents data of CO, NH_3, NO_2, and CO_2, collected using the CJMCU-6814, MH-Z19 and CJMCU-30 sensors, furthermore, Figure 5 presents temperature and humidity from the DHT22 and CJMCU-680v2 sensors. Figure 4(a) to Figure 4(c) presents data values for the three main gas indicators of the AP that are implemented in our system (CO, NH_3, and NO_2). In addition to CO_2 (presented below), these parameters are well known to be the most harmful gases which have a direct impact on humans. Compared to the other sensors, we could collect data from the specific sensor for these gases (CJMCU-6814) for the last two months (mainly because of sensor configuration to make it work correctly). As shown in this figure, we can easily note fluctuation during the first period of 20 days. Our hypothesis concerning this disturbance of the data was caused by two reasons: i) the main one is that the device was placed near to a place where a building construction site was active. This was confirmed by the fact that data remained stable after this period in which the COVID-19 pandemic situation forced all types of activities to stop; and ii) important values were reached in this period and coincides with the religious celebration in which many barbecues are done daily. Peaks are also noticed in the remaining period after this one but have never reached such recorded values in the first period.

In Figure 4(d), CO_2 collected by MH-Z19 shows high values during the first one and a half month which decrease continuously to remain stable after this period. This confirms our previous hypothesis. For the same reasons presented before (construction site and religious celebration), we notice that higher values of CO_2 are observed in that period. We also notice an overestimation of the CO_2 calculated by CJMCU-30 compared to that of the MH-Z19, these differences are quite noticeable but require more investigations to be able to fully explain why. However, these differences are in the form of peaks which leads us to say that the problem could come from the way the CO_2 is calculated (as it is an estimated value by the CJMCU-30 sensor).



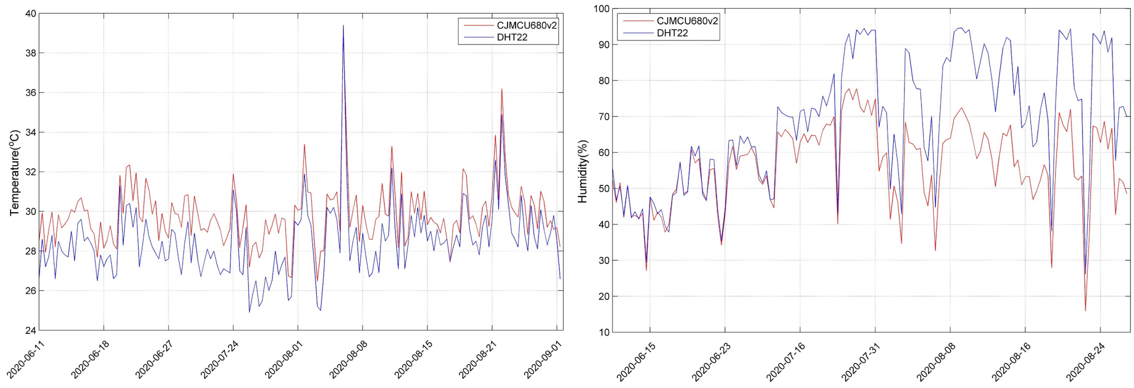
(a) (b)

(c) (d)

Figure 4. Collected CO, NH_3, and NO_2 (CJMCU-6814 sensor), and CO_2 (MH-Z19 and CJMCU-30 sensors) (a) CO, (b) NH_3, (c) NO_2, and (d) CO_2

Results and observations presented in Figure 5, concerning impact of the pandemic lockdown on AP, are substantially in accordance with those in different regions in the world, as an example in China [29], in India [30], or Brazil [31]. Temperature and humidity values are presented respectively in Figure 5(a) and Figure 5(b). Since data were recorded in the summertime, temperatures are relatively high, between approximatively 25 °C by night to 33 °C during the day, except for some days of strong heat in which we noticed values which exceeded 39 °C.

Humidity values had an upward trend from mid-June to mid-July, after which, it fluctuated between a remaining mean depending on each sensor. In fact, we noticed a difference between DHT22 and CJMCU-680v2 represented by approximately 1 °C and 12% respectively for temperature and humidity. Data analysis showed that there are two main differences between the two sensors: i) the DHT22 sensor tends to underestimate temperature compared to the CJMCU-680v2, which it the opposite for humidity, and ii) the difference between the two sensors is quite stable for temperature but get bigger when humidity becomes higher.



(a) (b)

Figure 5. Collected parameters (DHT22 and CJMCU-680v2 sensors) (a) Temperature and (b) Humidity

4. CONCLUSION

The use of a standardized method for air composition sampling is critical for accurate air quality monitoring. In this paper, we presented a hardware and software implementation for AP data collection. Multiple sensors were used to acquire environmental data related to AP such as CO, CO_2, NH_3, and NO_2, along with temperature and humidity. The experimentations showed that the use of an ESP32 with its multiple-core capabilities performed well when it came to manage network communications and sensors data acquisition at the same time. Furthermore, we provided a complete circuit layout for the used device, so that everyone can reproduce the same layout using the same sensors. A discussion was performed to interpret sensors values and to study differences. A smartphone application was also developed to show how a user could access live data and get a mapped overview of data distribution. As future works to this experimentation, we aim to add more and more sensors for the same parameter to get more accurate values. Even if we based our experimentation on precalibrated sensors, the use of multiple sensors could provide a multi-source data device that can be compared in one hand, but helps in having a better precision in the other hand. In addition to that, deploying this device across a greater region would undoubtedly generate more data, allowing us to do estimates and interpolation to get a more detailed mapped distribution. All in all, monitoring systems such as our AQS represents one step in the study of multiple harmful gases in our environment. This opens the route to a more sophisticated device that could act as data provider, but also as an alarming equipment.

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