Real-Time Air Quality Monitoring Using Sensors to Prevent Severe Acute Respiratory Syndromes (SARS)

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***Abstract*—This work presents the development, calibration, and validation of a device capable of actively capturing data related to the measurement of air quality for future prevention. This data can then be compared with pandemic/endemic data indices by location using PM2.5, temperature, and humidity sensors, along with a microcontroller capable of sending all necessary information to a database. As it is a project that needs a large scale so that it is possible to capture air quality indices in as many points as possible in order to obtain data with very high granularity, the development is always being thought of, always viewing the cost-effectiveness of the components used for replicating is possible, and also the development is part of a larger project, which should provide the community with a complete platform capable of providing real-time air quality data.**

***Index Terms*—COVID-19, Air Quality Index, Embedded System, Particulate Matter**

I. Introduction

One of the main indicators of poor air quality is the high number of suspended particles, mainly those around 2.5 micrometers (PM2.5). The high concentration of this type of particle helps to spread viruses and other disease vectors, which is known to increase the risk of complications from Severe Acute Respiratory Syndromes (SARS) [1], [2]. Nonetheless, to maintain a healthy level of air quality, which is one of the basic prerequisites for sustaining life according to the World Health Organization (WHO) [3], and in light of the COVID-19 pandemic and possibly future other pandemics and endemics, there is a recent increase in demand for real-time monitoring of air quality, especially in public indoor environments.

In this context, the main objective of this work is to propose a system to collect and provide air quality data to processes that can help real-time monitoring of indoor environments such as classrooms, offices, laboratories, and other public spaces. The system should also be capable to suggest actions for improving indoor air quality or alerting to preventive measures as necessary (e.g. masks, air purification). The proposed system is basically composed of a (hardware) sensing module coupled with low-cost sensors to monitor three main parameters, PM2.5, temperature, and humidity. The other component of the system is the software infrastructure to store and process the sensor's data. The system also encompasses the development of an IoT web platform capable of providing data sets in the form of Air Quality Indicator (AQI) parameters. Within this platform, raw data containing temporal and geographically annotated variables can be accessed by the academic community or the general population, through a web server. These parameters will then be processed by a Data Analysis module, which will use Machine Learning (ML) and Artificial Intelligence (AI) techniques, in the future, in order to indicate if the air quality is adequate and also show what actions can be taken to improve the quality of the air [4].

Thus, the main contribution of the present work is the development of an air quality checking device based on parameters captured by sensors measuring particulate matter (PM2.5 type), temperature, and humidity using an embedded system paradigm. A prototype has been developed during the work, with a more affordable cost of production than commercial air quality parameters capture stations, which generally do not provide data available openly to the academic community.

For this, basically, the first and most important activity was the choice of sensors to be used. After some tests were carried out with the sensors, the system's software platform was designed and implemented, with the design of functional diagrams, blocks, and structures. After that, activities were carried out to assemble the first prototype on a prototyping board and functional tests. After checking the functionality together, the 3D design was modeled to encapsulate the board and the various electronic components of our system, and the prototype was finalized in hardware.

As the main focus of the work is the development of the final device, due to the incidence of some errors not initially foreseen, we chose to focus on the construction of the final platform, leaving questions about the final aesthetics of the product and usability of the software system, as well as the data processing aiming at predicting air quality dynamics, to be carried out as future work.

We also emphasize that, in addition to the construction of

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the device itself, the project also encompasses the development of a platform capable of making this data available in a form treated in air quality indication parameters or AQI (Air Quality Indicator).

This work was developed as part of a larger project that uses diverse data to predict the dynamics of pandemics and endemic diseases using statistical tools and Artificial Intelligence tools. Input data such as contamination rate, number of susceptible people, number of current cases, number of deaths, and air quality, among others, are used for this. Noting the lack of air quality data in Brazil and the lack of platforms that meet the needs of the project, we decided to study, develop and build our own platform. Our initial studies indicate that air quality parameters, along with several others, can be used as data to obtain an estimate of the dynamics [5], using existing traditional tools and methods (methods based on mathematical models such as SIR, SEIR, SEIRS, SIRD, and ARIMA) and also Artificial Intelligence tools [6].

II. Related Works

Although the central proposal of the present work is the development of a system capable of acquiring data referring to the concentration and characteristics of suspended particulate matter, we emphasize that our work will also serve as an input to validate the hypothesis of the larger research of our group, which is the possible prediction of pandemic data, that includes data acquired through air quality sensors. Below, we perform a comparison between hardware development works capable of acquiring air quality data, in general. The works were selected based on some criteria or categories defined a priori, which are:

- Type: Open or closed project.
- Hardware development: detailing of material used.
- Transmission technologies used: WiFi, LoRa, Bluetooth, GSM, LPWaN;
- Data availability platform: Yes, No.
- Focus of work: Main objective development or use of data.
- Future Objective: The future objective of the work.
- Similarity to the author's work: Internal comparison with other models.

Since all related works are articles in journals, we tried to make a comparison mainly focused on the technical aspects of the hardware used, because the article has a space limited to a few pages, the hardware design may not be the main focus, but the demonstration of the results obtained from the sensor readings, so the focus of the work in question is also taken into account in the comparison performed.

After the initial technical/scientific comparison of all the works, we made a comparison emphasizing other characteristics, such as the type of sensor with its cost, accuracy, and range, and the total cost including the other electronics, as well as aspects of replicability. Table **??** shows this comparison between the particulate matter sensors used, in order to show the difference in cost, accuracy, and reading range.

Author	Sensor	Powered by	Replicable	Cost-US
[7]	MQ-135	Solar + battery	No Data	91,00
[8]	Sensirion SP30	Fonte + Battery	No Data	274,00
[9]	PMS5005	Solar + Battery	No Data	N / C
[10]	SDS011	Battery	No Data	37,00
[11]	DSM501A	Charger or Solar + Battery	Open	60,00

TABLE I
COMPARATIVE TABLE OF THE TECHNICAL/SCIENTIFIC ASPECTS OF OUR PROJECT

SENSOR	COST	PRECISION	RANGE
MQ-135	5 USD	±2%	10ppm-300ppm
Sensirion SP30	33,10 USD	±10μg/m3	3-100 μg/m3
PMS5005	13,50 USD	5%	No Data
SDS011	21 USD	15% e ±10μg/m3	0.0-999.9 μg/m3
DSM501A	8USD	±10μg/m3	0 - 140μg/m3

TABLE II
COMPARATIVE TABLE BETWEEN SENSOR CHARACTERISTICS

Table I shows the comparison of the cost of the total set of components, including the type of power and possibility of replicability. Table III shows the titles and authors' names, for all works.

A. Strictly Related Works

In the article by Saini et al. [12], it is possible to have a macro view of this line of research, with a systematic review of all air quality monitoring systems based on the Internet of Things. The author presents relevant data, which also serve as a guide for the execution of this work. A survey of articles addressing this topic was made, from 2015 to 2020, where it is possible to observe that the two countries that produce the most studies on this type of device are Portugal, with 17.5% of the articles found, and China, with 12.5%. No articles from Brazil appear in the review. Still, in the same article, it is also possible to observe that the vast majority of works focus on the construction of the device using mainly 3 types of sensors: Temperature, Humidity, and PM, together with ESP controllers. All use wireless transmission technology (WiFi), with system power via a power source connected to electrical outlets and interfaces divided into two parts: Web and Applications.

TABLE III
RELATED WORKS

Citation	Work Title
[10]	IoT-Enabled Wireless Sensor Networks for Air Pollution Monitoring with Extended Fractional-Order Kalman Filtering
[9]	Design and Implementation of LPWA-Based Air Quality Monitoring System
[8]	Development of Multi-Item Air Quality Monitoring System Based on Real-Time Data
[7]	Monitoring Air Quality of Dhaka using IoT: Effects of COVID-19
[12]	Air Quality Monitoring Systems Based on Internet of Things: A Systematic Review

The work most similar to our work found in the literature depicts the development step by step [8], however, not providing enough data for the project to be replicated. But, the author shows in the work all the components used, including sensors and the connections between the components through block diagrams. Unlike the other works found, the macro objective of the work, as well as ours, is the development of the complete system. However, in the article in question, the author works with the reading of 16 atmospheric pollutants, while in our work we work with only 3. Our proposal is for much simpler implementation and at a lower cost. In this case, for the reason of working with 16 sensors, the assembly cost is well above the average of the researched works.

Another work that can also be considered similar to ours, as it is an approach to building equipment capable of acquiring data and making them available to the community via a platform, is the one described by Saha et al. [7]. The difference from ours is that the author does not use suspended particle sensors, but carbon monoxide sensors in conjunction with an air quality sensor. The latter provides the user with data on gases harmful to health suspended in the air which, even though they are not data on particulate matter, also allows the calculation of the air quality index from them. By not using PM sensors, it is possible to observe that the approximate cost of the components used is also very low in relation to the other researched articles.

III. Methods and Materials

The main purpose of this work is the development of a system to collect, distribute and process air quality data to provide real-time monitoring of indoor environments such as classrooms, offices, laboratories, and other public places. The system is also capable of providing data so that managers can suggest actions to improve indoor air quality or alert for preventive measures (masks, air purification, etc.), if necessary. Thus, we start with the collecting data system and after we show the IoT interfaces that have been developed for it.

A. The Air Quality Data Collection System

We can verify through the WAQI [13] platform that there is a huge lack of field sensors in Brazil capable of acquiring data regarding air quality. Still, we can verify that most of the sensors installed are in the South, Southeast, and Midwest regions and that the regions that make data available for these platforms also have their own platform for sharing data with the population. Satellite data can be used in applications to complete this local data, based on measurements of certain image channels that can capture emissions of particulate matter in the atmosphere. Mainly PM2.5 type.

To collect data regarding the specification of suspended particulate matter in a given environment, and therefore determine air quality data, it is necessary to use a PM type sensor, which means particulate matter. This type of suspended matter is also called [14] particle pollution. The term can be used for a mixture formed by solid particles and liquid droplets found in the air. This type of sensor can vary from PM1 to PM10 and this variation occurs according to the diameter of the suspended particulate material capable of being measured. The numbers (1, 10) represent the diameter in micrometers (μm) of the suspended particle to be treated. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye, in which case they exceed these measurements. Others are so small that they can only be detected with an electron microscope, and this is the type of particles that we are interested in in the present work. Roughly speaking, particulate pollution typically includes:

- PM10: Inhalable particles, generally 10 micrometers in diameter and smaller;
- PM2.5: Inhalable fine particles, with diameters that are generally 2.5 micrometers and smaller.

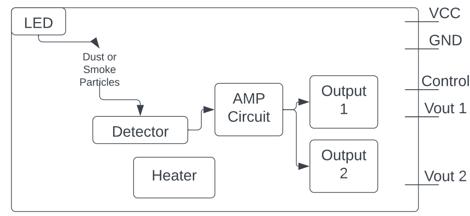

Fig. 1. Simplified sensor working diagram

A practical question that arises here is understanding how small is the meaning of 2.5 micrometers. If we think of a single human hair, its average diameter is about 70 micrometers, which makes it about 30 times larger than the largest fine particle that can be interpreted as particulate matter.

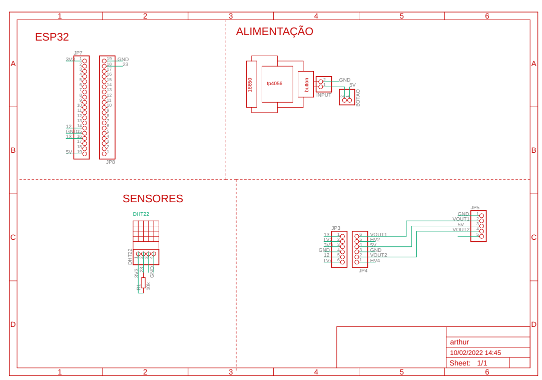

Fig. 2. System schematic

The schematic shown in Figure 2 illustrates the DSM501A sensor that is able to capture this information, making an average occupation of the microcontroller's digital port over time (ranging from 0 to 100%). From the graph shown in Figure 3, it is possible to associate the occupation ratio with the number of suspended particles in mg/m3 [15].

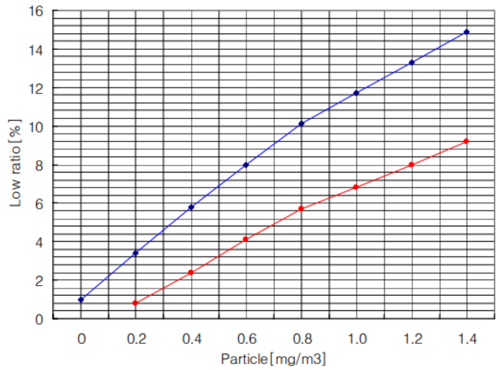

Fig. 3. PM sensor graph

B. System Architecture

As the schematic of Figure 4 shows, the hardware part of our system is basically composed of a sensor module (Sensors), which is a low-cost device to monitor three main parameters: PM2.5, temperature, and humidity. It also contains the data sending part (ESP32) and Power supply. The other aspect of the system is the software infrastructure to store and process the data. The planning foresaw the development of a platform capable of providing data sets in the form of Air Quality Indicator (AQI) parameters. Searches were carried out on national and international websites, in order to determine the best sensors.

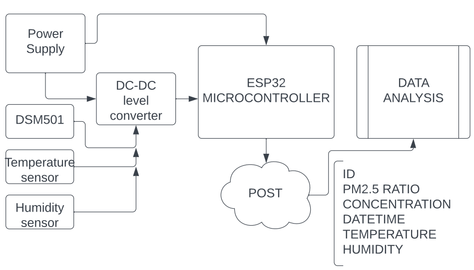

Fig. 4. System working diagram

The idea is that these raw data sets, that is, the way they are provided by the sensors, with temporal and geographically annotated data, can be accessed by the academic community or the general population through a web server. These parameters are then processed by the data analysis module, which will use machine learning (or machine learning - ML) and other artificial intelligence (AI) techniques to indicate if the air quality is adequate and also suggest actions to be taken. by managers, whether to improve air quality or mitigate some problem/event [5].

IV. Experiments

One of the first experimental steps was to carry out tests to verify the correct acquisition of data, mainly the sensor (PM2.5), with the system components all connected (sensors, Arduino, etc) via a prototyping board, before its physical construction. In this case, the platform described above was used, which was initially mounted on the prototyping board. The set of sensors and data transmission devices joined on the board, were placed in dependencies such as classrooms and hardware labs. We emphasize that in this last type of facility there are several types of equipment that can emit particulate matter, such as equipment for sanding different materials, and welding equipment, in addition to a wide variety of electronic equipment coupled with fans for cooling. Figure 5 shows the return of data referring to the proportion (ratio) of particles suspended in the air in the initially observed environments.

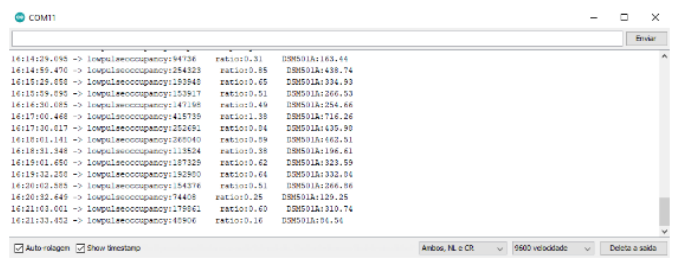

Fig. 5. Serial response return to with Arduino platform

During the design phase, data acquisition experiments were also carried out from devices mounted with sensors in classrooms and hardware laboratories (where sanding, soldering equipment, and electronic components are also available). It is possible to observe in Figure 7 installed in a laboratory the significant increase in the amount of PM2.5 at the time when daily activities start (04/13/2022 and 04/14/2022) and low concentration on other days without activities (15/04/2022 to 17/04/2022) due to local holiday.

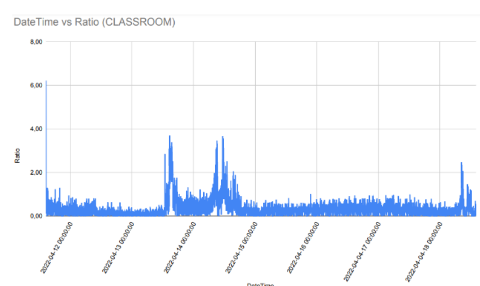

Fig. 6. PM2.5 ratio measured from a classroom.

This system is also scalable. Many low-cost data collection devices can be installed in multiple locations, allowing for a significant amount of air quality data for a dataset. With many devices installed, it is possible to map the air quality in real-time and perform analysis on the data obtained with ML and AI to inform the need for preventive measures, such as cleaning or disinfection alerts, instructing the use of masks, the level of dust in the environment, to activate air purifiers

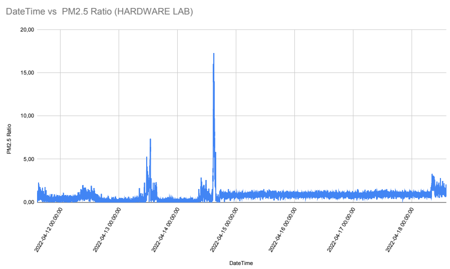

Fig. 7. PM2.5 ratio measured from a hardware lab.

or even to indicate the use of personal protective equipment in areas where dust can be harmful due to its large volume.

V. Conclusion

We propose a complete air quality measurement platform that consists of a functional prototype including hardware and software to make measurements performed by air quality sensors available on the Internet. Particulate matter (PM2.5), temperature, and humidity data are provided by the developed prototype. To build it, we chose and tested among the possible sensors, and implemented the first prototype on a prototyping board with only a particulate matter sensor (as this is the primary sensor of the system).

After the initial tests on a prototyping board, it was possible to better design the physical design of the platform and we encapsulated all the electronic components using our own equipment for making circuit boards (PCBs), as well as a 3D printer to make the case that involves the components. electronics. Humidity and temperature sensors were also added, in addition to the PM2.5 particulate matter sensor.

Finally, we also designed and implemented a software architecture that supports the sending of data via IoT to the research community and the general population, which was also tested together with the hardware, proving to be functional, with regard to basic requirements of usability.

A. Contribuiton

We can highlight two types of contributions to work, scientific and technological. The main technical contribution is the development of an air quality data acquisition platform itself, using particulate matter sensors (PM2.5 type), temperature, and humidity, integrated into an embedded system. As seen, a prototype was developed, with a much lower production cost than the current air quality parameters capture stations.

As a scientific contribution, we highlight the studies carried out and the possibility of using the available data to determine the air quality index in models for predicting the dynamics of pandemics, in collaboration with data provided by satellite. Studying the data that affect the pandemic, its causes, effects, and consequences for the population, is essential, not only to combat current outbreaks (for example, Covid-19) but also to possibly prevent future situations like the current one from happening. be neglected by governments, as was the case with Covid-19. There are several ways to prevent or mitigate such endemics, but all of them start by understanding their variables, parameters, and especially their mode of dissemination and effects on mortality.

Thus, this work contributes a step further, providing data in practice that corroborates the theoretical evidence [16], aiming to better understand how cooperation between particulate matter and the spread of the Sars-Cov-2 virus occurs, through the atmosphere, especially indoors. In practice, we have developed a complete sensory platform to determine variables related to the amount of suspended matter, which serves as one of the indicators of air quality (pollution). Pollution is considered a major factor in the acquisition of comorbidities, which is known to be the fundamental cause of mortality from Covid-19. In other words, studying and proposing solutions along these lines is a very relevant contribution.

B. Future Work

When developing the work it was found that it is possible to identify and detect anomalies that are occurring in the environment such as mainly fires, cigarette smoke, tire smoke, and plastic burning, among others. With the combination of the device developed in the present work with other sensors for capturing gases and chemical elements, it will be possible to design and implement a system for detecting anomalies in indoor environments, possibly using artificial intelligence and/or machine learning techniques. So, after completing this work, we intend to extend it with the addition of improvements so that it is a fully complete platform in terms of air quality and prevention of respiratory diseases.

Also, within our larger project that studies the dynamics of pandemics and endemic diseases with artificial intelligence tools, we will be making data available that can be used to assess the quality of data provided by systems that provide AQI from information provided by satellites. In the larger project, this type of data will also be used mainly in places where there is no presence of devices like the one we developed in the present work.

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