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doi:10.15199/48.2023.01.27

IoT system for CO2 level monitoring and analysis in educational environments

***Abstract**. From the need derived from the pandemic originated by COVID-19 regarding the development of academic activities in a face-to-face manner, respecting biosafety protocols and ensuring that the air quality in classrooms is adequate, in this article we proposed as a contribution the development of an IoT system based on free hardware and software tools and technologies for the monitoring and analysis of CO2 level in educational classrooms, which is framed in a software architecture with three architectural views: business, functional and implementation, each of which has four layers: capture, storage, analysis and visualization.*

Streszczenie.** Z potrzeby wynikającej z pandemii wywołanej przez COVID-19, dotyczącej rozwoju działalności akademickiej w sposób bezpośredni, z poszanowaniem protokołów bezpieczeństwa biologicznego i zapewnieniem odpowiedniej jakości powietrza w salach lekcyjnych, w tym artykule zaproponowaliśmy jako wkład rozwój systemu IoT w oparciu o bezpłatne narzędzia i technologie sprzętowe i programowe do monitorowania i analizy poziomu CO2 w salach lekcyjnych, który jest ujęty w architekturę oprogramowania z trzema widokami architektonicznymi: biznesowym, funkcjonalnym i wdrożeniowym, z których każdy ma cztery warstwy : przechwytywanie, przechowywanie, analiza i wizualizacja.* (System IoT do monitorowania i analizy poziomu CO2 w środowiskach edukacyjnych***)

Keywords: Air quality; CO2 level; Covid-19; IoT; IoT system.
Słowa kluczowe: Jakość powietrza; poziom CO2; Covid-19; IoT; system IoT.

Introduction

From the early 2020s to the present, the world is facing a health emergency, so that in the educational context, universities have taken advantage of the benefits of virtuality to provide access to education under the modality of remote attendance [1,2,3,4,5]. However, international organizations such as UNESCO and UNICEF maintain that the absence of face-to-face classes generates a loss of significant learning, increases dropout rates and has negative effects on the mental health of students [6].

Likewise, it is important to mention that with the gradual return to face-to-face attendance, students, teachers and administrative personnel carry out activities in the different environments of the educational institutions and are exposed to health risks because sharing the same environment increases the CO2 level [7,8]. According to [9], indoor air contains a mixture of pollutants from different sources, being the concentration of carbon dioxide (CO2) one of the main factors to be evaluated to determine whether an environment is healthy or not. When staying in unhealthy environments, i.e. with high levels of CO2, the risk of airborne transmission of COVID-19 is higher, affecting the health of students, teaching staff, teaching managers, administrative staff, etc. [10].

Through the advancement of information and communication technologies, it is possible to address the problems described above and propose alternative solutions, such as taking advantage of the Internet of Things (IoT) for monitoring environmental variables [11,12]. According to [13] and [14], IoT can be understood as an integrated system that includes machine-to-machine communication, cyber-physical systems, wireless sensor networks and web of things. Although the conceptualization of the Internet of Things (IoT) has been evolving, its main objective is to collect information without human intervention using Internet standards to provide services for information transfer [15]. Similarly, according to [16] and [17], the new IoT paradigm is understood as the intelligent connection of things and extends beyond providing connectivity between humans, data, business processes and things, which faces various challenges due to network and device constraints for memory, power, processing, link speed.

A mong the most relevant characteristics of IoT are: interconnectivity, scalability, dynamic changes and heterogeneity [18]. Studies have shown that the benefits of the Internet of Things (IoT) and the monitoring of environmental variables associated with air quality make it possible to obtain value-added information for end users, generating alerts for timely decision making [19,20]. According to [21], air pollution is a considerable environmental health risk, so through the reduction of air pollution levels the burden of disease can be reduced. On the other hand, [20] proposes an architecture using open source and Internet of Things (IoT) to measure some variables related to air quality, concluding that the implementation of their proposal was technically and economically feasible. Likewise, [22] proposed the design of a system to acquire data from a climatological station, taking into account variables such as atmospheric barometric pressure, solar radiation, precipitation, ozone, nitrogen monoxide, nitrogen oxides, nitrogen oxides and nitrogen dioxide. Similarly, in [23] a case study was developed in which records of different environmental variables such as temperature, humidity, CO2, among others, are captured inside school classrooms in Spain, making use of IoT nodes, which allow a statistical analysis of the captured data. In [8] is presented a study of different ventilation strategies and CO2 distribution in a classroom using IoT sensors, which allowed to obtain detailed data on the spatial distribution of CO2. According to previously described works, in [22] and [24] the contribution is centered on the proposed architecture, without focusing on the implementation or construction of monitoring systems based on these architectures. Similarly, in [8] and [23] are presented case studies centered on the analysis of data captured in classrooms from the use of IoT sensors of CO2 level and other associated variables, so that these systems are not focused on the use of free software hardware tools, nor in the automatic application of machine learning models from the captured data.

In view of the above, it is important to guarantee the application of biosecurity measures such as physical distancing, signage, ventilation, washing stations and disinfection in the environments of educational institutions. In response to this need, in this article we proposed as a contribution the design and implementation of an IoT system based on free hardware and software tools for the monitoring and analysis of the C02 level in educational environments, in order to support decision making regarding the capacity of classrooms within educational institutions. The proposed IoT system is articulated within the conventional 4-layer IoT architecture (capture, storage, analysis and visualization) [25] and described by 3 architectural views (business, functional and implementation). Thus, in the capture layer, the IoT system, using a DFRobot CO2 sensor, periodically obtains Co2 levels and sends them to an Arduino capture board, which makes these values available via WiFi through HTTP requests. In the storage layer, once the data is consulted, it is stored in the non-relational database TinyDB, which allows flexibility in the integration with data analytics models. Within the analysis layer, the IoT system makes use of the scikit-learn library for the implementation of supervised and unsupervised learning models for the analysis of CO2 level captures performed in the capture layer. Finally, in the visualization layer, the system makes use of the Javascript CanvasJS library and the Python matplotlib library, which respectively allow the real-time visualization of the CO2 level variation and the generation of graphs that represent the results of the machine learning models.

The rest of the article is organized as follows: Section 2 describes the methodology considered for the development of this research. Section 3 presents the results obtained in the present work, which includes the description of the proposed system architecture, together with the prototype derived from the architecture and a case study developed from this prototype in the "Free Software" course of the Systems Engineering program of the University of Cartagena. Section 4 presents the discussion of the results, with respect to other proposals evidenced in the state of the art. Finally, Section 5 presents the conclusions and future work derived from this research.

Methodology

For the development of the present research, the iterative research pattern proposed by Pratt [26] was taken into consideration, which consists of four methodological phases: "observe the application", "identify the problem", "develop the solution" and "test the solution" (see Fig. 1).

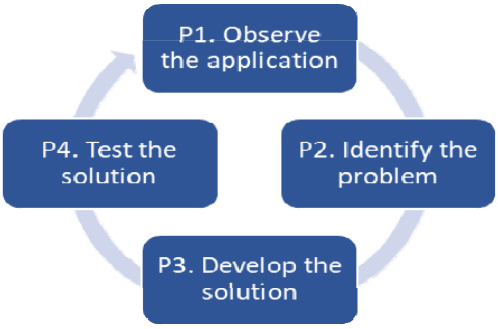


Fig.1. Methodology considered

In phase 1 of the methodology, the variable to be monitored through the IoT system was characterized in order to determine the CO2 levels or ranges to be taken into account. Thus, based on what was presented in [27], the CO2 levels to be considered in this research were chosen (see Table 1).

Table 1.CO2 levels considered.

Range	Level	Description
CO2<400	0	Outdoor spaces
400<=CO2<800	1	Good ventilation
800<=CO2<1500	2	Stifling space
1500<=CO2	3	Inadequate ventilation

Also, within this phase, the exploration and selection of free hardware and software tools for the monitoring and analysis of CO2 in educational scenarios was carried out. On the other hand, in phase 2 of the methodology, the architecture of the IoT system to be implemented was specified in three views (business, functional and implementation), considering the four conventional layers of the IoT architecture (capture, storage, analysis and visualization). For the above, the tools and technologies selected in phase 1 were taken into account. In phase 3 of the methodology, the implementation of the IoT system for the monitoring and analysis of the Co2 level in educational environments was carried out, taking into account the architecture specified in phase 2. The IoT system was implemented through a web-based system using the Python Flask microframework, so that the capture, storage and analysis layers were implemented in the backend, while the visualization layer was implemented in the frontend. Finally, in phase 4 of the methodology, the IoT system implemented was evaluated through the conduction of a case study, which was conducted in a classroom of the University of Cartagena and specifically within the classroom in which the "Free Software" course of the Systems Engineering program of the University of Cartagena-Colombia is developed.

Results

This section presents the results obtained in this research, which includes the description of the IoT system architecture for monitoring and analysis of CO2 level in educational environments, as well as the prototype built from the architecture and a case study in which the IoT system was validated in the classroom of the elective course "Free Software" of the Systems Engineering Program of the University of Cartagena.

For the construction of the proposed IoT system, an architecture structured by four layers (capture, storage, analysis and visualization) was designed, which is represented by business, functional and implementation views (see Fig. 2). In the business view, the architecture is presented from the point of view of the stakeholders, so that in this view it is possible to appreciate the contribution of the IoT system to the specific context of use. Within the functional view, the different processes developed in each of the four layers considered in the architecture are described. Finally, the implementation view shows the tools and/or technologies chosen to fulfill the processes described in the functional view.

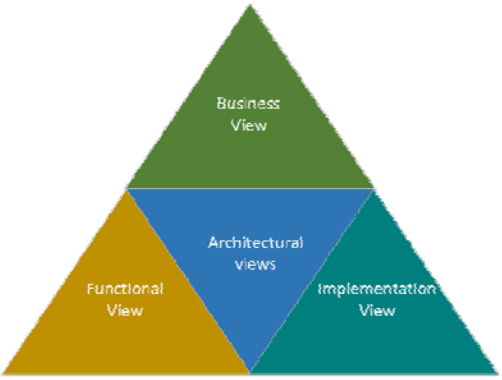


Fig.2. Architectural views

Considering the above, Fig. 3 presents the business view of the IoT system architecture for Co2 level monitoring and analysis in educational environments.

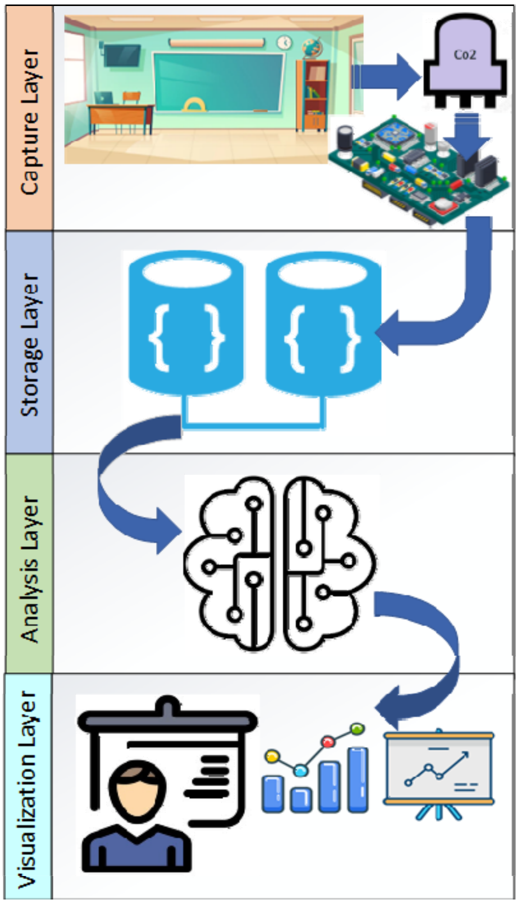


Fig.3. Business view

In the capture layer, through the use of CO2 sensors located in a classroom, CO2 levels are measured and sent to a capture board, which allows the consultation of these levels via WiFi. In the storage layer, once the CO2 levels are periodically consulted from the capture board, they are stored in a non-relational database locally or in the cloud. In the analysis or processing layer, the data stored in the database is consulted in order to perform both statistical analysis and analysis based on data analytics models. Finally, in the visualization layer, it is possible to monitor the variation of the CO2 level in real time, as well as to visualize both the results of the application of statistical analysis methods and the results of the application of models based on machine learning. In this way, the visualization layer is intended to provide value-added information for decision making by educational managers regarding the capacity of classrooms, based on the recommended reference values for CO2 levels.

Similarly, Fig. 4 shows the different processes developed in the functional view within the four layers of the IoT system architecture for monitoring and analyzing the CO2 level in educational environments.

Accordingly, in the capture layer through CO2 sensors, CO2 levels in volts are captured and sent to a free hardware board, which is responsible for converting the voltage levels into a value in parts per million (PPM) using a characterization curve provided by the sensor manufacturer. Once the CO2 levels are obtained, the capture board is responsible for creating a JSON message with the values obtained by the sensor in volts and PPM, so that these messages are served to the storage layer wirelessly and via WiFi.

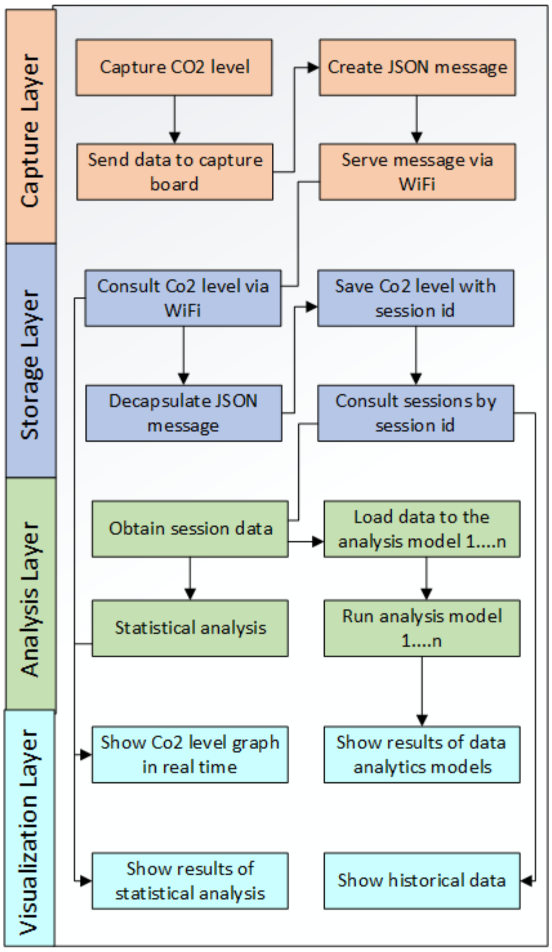


Fig. 4. Functional view

Thus, in the storage layer, the JSON messages generated by the capture board are periodically consulted using HTTP requests, so that once obtained, they are decapsulated and stored in a non-relational database by means of a session id that allows differentiating each set of captures performed. Similarly, this layer comprises a set of functionalities that allow the consultation of the data associated with a given capture session by the analysis layer. In the analysis layer, once the data from a particular capture session has been obtained, it is possible to perform a statistical analysis on the CO2 levels of the session in order to determine statistical measures such as mean, minimum value, maximum value and standard deviation. Similarly, it is possible to apply machine learning models based on unsupervised learning or clustering on the data of a given capture session, which allow to determine the distribution of the captured data with respect to the different CO2 levels presented in Table 1. Finally, in the visualization layer, the IoT system presents to the end user a graph showing the fluctuation of the CO2 level as a function of time. Likewise, in this layer the end user can consult both the history of session data and the results obtained in the statistical analysis and in the analysis based on machine learning models.

Continuing with the description of the architecture, Fig. 5 shows the implementation view of the proposed IoT system, which includes the different technologies and tools that allow the fulfillment of the processes described in the functional view of the architecture.

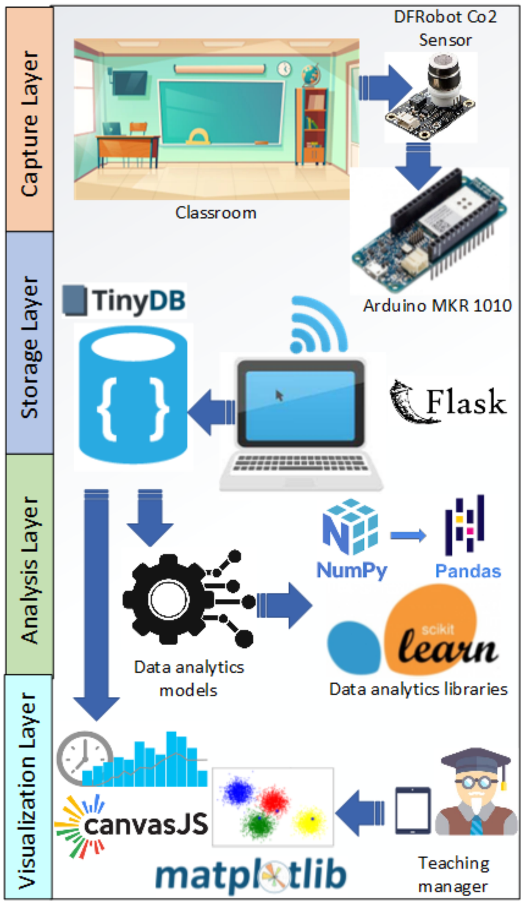
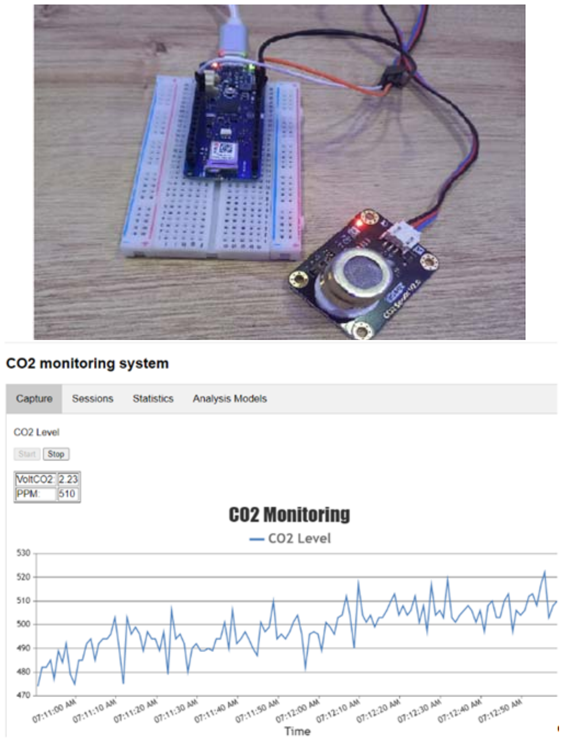


Fig. 5. Implementation view

According to the above, in the capture layer the IoT system is composed of the CO2 sensor DFRobot, together with the free hardware board Arduino MKR 1010, which supports WiFi communication and allows the implementation of a mini server that serves through JSON messages the CO2 level values captured by the sensor. Regarding the storage layer, the captures consulted to the Arduino board via HTTP requests are stored with a session id in the free NoSQL database manager TinyDB, which stores the records using the JSON format. From the data consulted in the TinyDB database, the IoT system allows statistical analysis using the numpy Python library, while for the application of machine learning models, the system makes use of the scikit-learn and Pandas Python libraries, which allow the implementation of supervised and unsupervised learning models. Regarding the visualization layer, the IoT system makes use of the CanvasJS Javascript library for the generation and display of the real-time graph with CO2 levels. Similarly, for the generation of the graphs resulting from the clustering analysis, the IoT system made use of the Python matplotlib library, which is easily integrated with the scikit-learn machine learning models. Finally it is worth mentioning that the four layers of the IoT system are framed in a client-server web application, which was implemented using the Python microframework Flask. Thus, the backend of the IoT system includes the capture, storage and analysis layers, while the visualization layer is linked to the frontend of the tool.

Once the different views of the proposed architecture have been described, the final graphical interfaces of the implemented IoT system are presented below. As previously mentioned, the IoT system was built using the Python microframework and its graphical interface consists of four tabs: "Capture", "Sessions", "Statistics", "Analysis Model" (see Fig. 6).


CO2 monitoring system

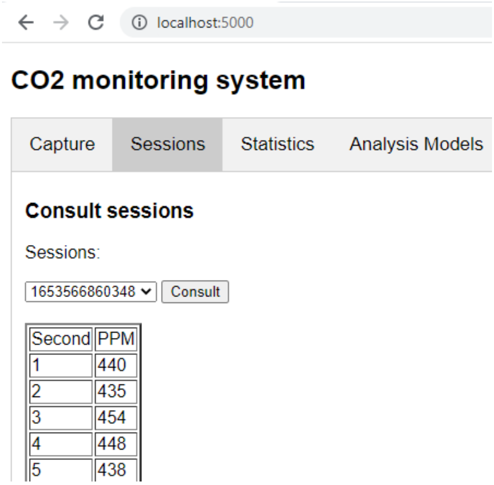
CO2 Level

VoltCO2: 2.23
PPM: 510

Fig. 6. IoT system implemented

In the "Capture" tab, once the user presses the "Start" button, HTTP requests are made periodically every second to the mini server deployed on the Arduino capture board, obtaining JSON messages in response with the values of CO2 levels in volts and PPM, which after being decapsulated are stored in the TinyDB database and presented in the interface of the web application that makes up the IoT system, through a real-time graph generated using the CanvasJS Javascript library. Thus, this graph includes the CO2 level values in PPM and the time stamp at which these were captured by the sensor. Similarly, the CO2 level values in volts and in PPM are displayed in an HTML table at the top left of the "Capture" tab.

Fig. 7 shows the graphical interface of the "Sessions" tab, in which the system displays the list of data associated with the CO2 level and obtained within a particular session by choosing a particular session ID and pressing the "Consult" button.


localhost:5000

CO2 monitoring system

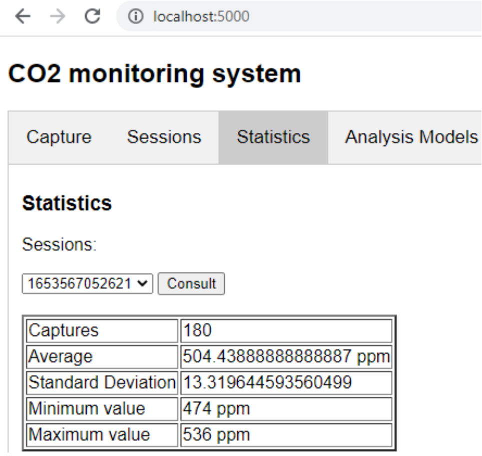
Consult sessions

Sessions: 1653566860348

Second	PPM
1	440
2	435
3	454
4	448
5	438

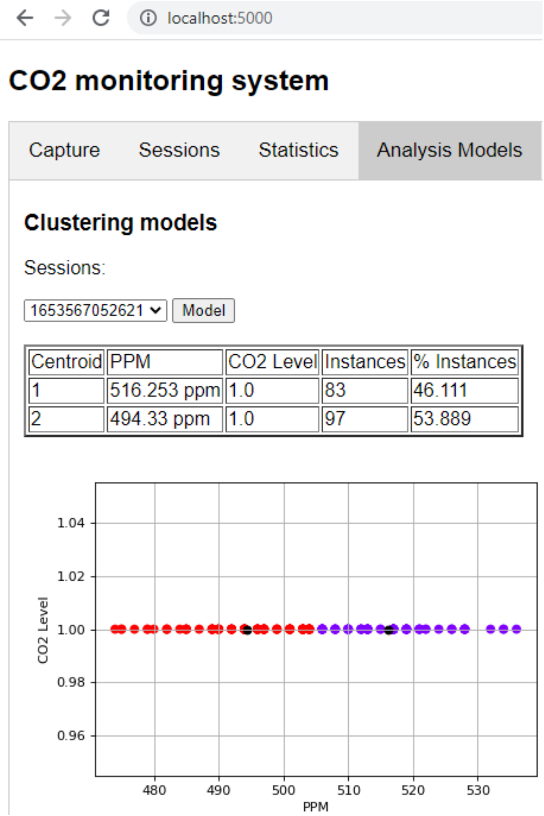
Fig. 7. “Sessions” tab of the IoT system

On the other hand, Fig. 8 shows the "Statistics" tab of the IoT system, which allows obtaining the statistical measures of average, minimum value, maximum value and standard deviation of the CO2 levels captured in a given session, which are presented in the web interface of the system by choosing the ID of a given session and pressing the "Consult" button. Thus, as an example, it is possible to observe in Figure 8 how for a given session, a total of 180 captures were made by the CO2 sensor, which have an average value of 504.4338 PPM, a standard deviation of 13.32, a minimum value of 474 PPM and a maximum value of 536 PPM.



Captures	180
Average	504.43888888888887 ppm
Standard Deviation	13.319644593560499
Minimum value	474 ppm
Maximum value	536 ppm

Fig. 8. “Statistics" tab of the IoT system



Centroid	PPM	CO2 Level	Instances	% Instances
1	516.253 ppm	1.0	83	46.111
2	494.33 ppm	1.0	97	53.889

Fig. 9. “Analysis Models" tab of the IoT system

Similarly, Fig. 9 shows the graphical interface of the "Analysis Models" tab, which allows the application of an unsupervised learning model or clustering, which relates the PPM values of the CO2 level with the classification obtained from Table 1.

Thus, as an example, Fig. 9 shows the results of the application of the clustering model for two centroids in a session of 180 captures, so that the purple color shows the instances that were classified in cluster 1, while the red color shows the instances that were classified in cluster 2. Likewise, the centroids determined for each cluster are shown in black, where C1={PPM=516.253, CO2 Level=1.0} and C2={PPM=494.33 CO2=1.0}. Additionally, it is possible to see how cluster 1 includes 46.111% of the total number of instances, while cluster 2 has 53.889% of the instances associated with it.

Once the design and implementation of the IoT system for CO2 level monitoring were presented, a case study that was developed within the elective course "Free Software" of the Systems Engineering Program of the University of Cartagena is presented below, in order to verify the functionality and usefulness of the proposed and built IoT system (see Fig. 10).

Fig. 10. Case study developed

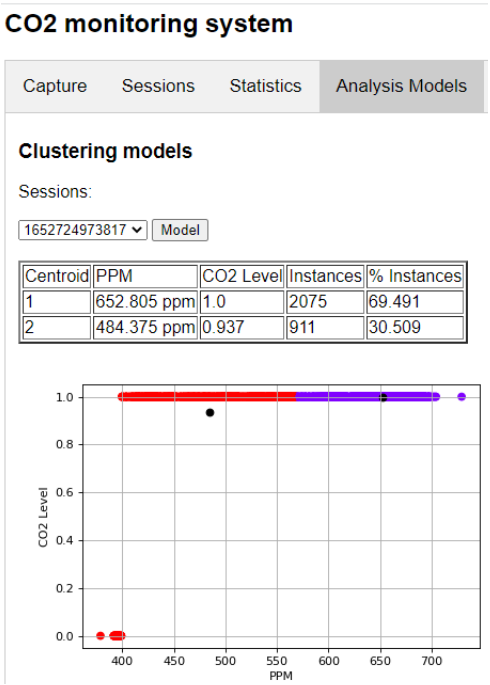
It is worth mentioning that for the development of the case study, a previous calibration of the sensor was performed in the empty classroom of 56 m2, obtaining a reference value of the CO2 level under these conditions. Once the sensor was calibrated, the CO2 level was monitored during the "Free Software" class of the Systems Engineering program of the University of Cartagena with a total of 15 people, obtaining the results presented in Table 2.

Table 2. Case study results

Measure	Value
Captures	2986
Average	601.419 ppm
Standard deviation	86.657
Minimum value	379 ppm
Maximum value	729 ppm

From the results presented in Table 2, it is possible to see how, on average, the captures made by the IoT system are within the "Good ventilation" level presented in Table 1. Likewise, although the maximum value obtained for the CO2 level is close to 800 ppm, it is also within the same level. In order to clarify the previous results at the level of data distribution around the levels defined in Table 1, Fig. 11 shows the results of the clustering analysis obtained with the implemented IoT system.

According to Fig. 11, it is possible to see how the IoT system obtained 2 clusters, each with two associated centroids (C1={PPM=652.805, CO2 Level=1.0} and C2={PPM=484.375, CO2 Level=0.937}). Cluster 1 is represented with purple color and includes 69.491% of the total number of instances, while cluster 2 is represented in red color and has 30.509% of the total number of instances associated with it. Likewise, it is possible to observe that although nearly 70% of the instances are concentrated around 652,805 PPM, both clusters of the model have been classified in level 1 of Table 1. Thus, it is possible to conclude that the conditions of the classroom in which the case study was conducted were adequate in terms of ventilation and for the number of students attending the class session.



CO2 monitoring system

Clustering models

Sessions:

Centroid	PPM	CO2 Level	Instances	% Instances
1	652.805 ppm	1.0	2075	69.491
2	484.375 ppm	0.937	911	30.509

Fig. 11. Clustering analysis of the case study

Discussion of Results

In this article it was proposed as a contribution an IoT system for monitoring the level of CO2 in academic classrooms, which is based on tools belonging to the field of free hardware and software, and is framed within a four-layer architecture: capture, storage, analysis and visualization, which is represented by three architectural views: business, functional and implementation. With respect to traditional IoT systems, the proposed IoT system not only allows the monitoring of the variable under study in this article, but also allows the automated application of descriptive statistics methods and machine learning models on the captured data. The functionality of the IoT system was validated in a case study developed within the classroom of the "Free Software" course of the Systems Engineering Program of the University of Cartagena, so that it was possible to determine the usefulness of the system in terms of obtaining indicators related to the distribution of CO2 levels with respect to the reference values presented in Table 1.

In accordance with the above, although there is evidence of works on IoT applied to CO2 level monitoring, proposals such as those presented in [22] and [24] describe the architecture of the IoT system without addressing the implementation and verification of the designed IoT system. Similarly, although the proposals presented in [8] and [23] develop case studies focused on the capture of CO2 levels and other environmental variables in classrooms, the data obtained in the capture layer are used to perform non-automated statistical analysis on the level of CO2 present in the classroom and its spatial distribution, so the system proposed in this article has the advantage of the automated application of both statistical methods and machine learning models, as well as the visualization of these results graphically. Likewise, as the architecture is independent of commercial devices and proprietary technologies, it facilitates the scalability of the system and its easy extrapolation to academic and other contexts of use.

Conclusions

Based on the need derived from the pandemic originated by COVID-19 regarding the development of academic activities in a face-to-face manner, respecting biosafety protocols and ensuring that the air quality in classrooms is adequate, in this article we proposed as a contribution the development of an IoT system for monitoring and analyzing the level of CO2 in academic scenarios, which was implemented from the use of hardware tools and free software, so that it can be extrapolated in educational institutions in order to make a diagnosis to support decision making in teaching managers about the conditions of educational classrooms and the relevance in terms of the number of students taking different courses. In the same way, this system is intended to serve as a reference to be extrapolated in the general organizational context in order to carry out air quality measurement studies in the post-pandemic context.

Unlike various IoT systems for measuring and/or monitoring variables of interest, the IoT system proposed in this article is framed in a four-layer software architecture: capture, storage, analysis and visualization, which is represented by three architectural views: business, functional and implementation. In this sense, the proposed IoT system, in addition to enabling the monitoring of CO2 levels in academic classrooms, allows the analysis through descriptive statistics and machine learning models on the data captured in a given session. The architecture that guides the development process of the IoT system presented in this article can be extrapolated to other application contexts for the measurement of indoor and outdoor variables of interest.

As previously mentioned, the proposed IoT system made use of different free hardware and software tools and technologies that were adequate to meet the functional requirements defined for the monitoring and analysis of CO2 levels in educational environments. Thus, in the capture layer, the IoT system made use of the DFRobot CO2 sensor and the Arduino MKR 1010 capture board, which has the advantage of implementing a mini server that allows consulting the captures made by the CO2 sensor through HTTP requests. Similarly, at the storage layer, the use of the free non-relational database TinyDB allows flexibility in data management, as well as extensibility and ease of loading data into machine learning models. On the other hand, in the analysis layer, the scikit-learn library allows the implementation and use of different supervised and unsupervised learning algorithms, which allow determining the trends and distribution of the captured data with respect to the reference levels considered and presented in Table 1. Regarding the visualization layer, the use of Javascript-derived libraries such as CanvasJS allows for compatibility in the presentation of monitoring graphs on different end-user devices. Likewise, the use of the matplotlib library allows the generation of graphs associated with the machine learning models generated with scikit-learn. Finally, as the four layers of the IoT system are implemented through Python's Flask microframework, it is possible to deploy the system in different embedded devices, which allows the portability of the system and its use in different application contexts.

The case study developed in this article allowed to verify the usefulness of the IoT system for monitoring and analyzing the CO2 level in academic classrooms and even in different types of organizations. In this sense, the case study developed within a classroom of the "Free Software" course of the Systems Engineering program of the University of Cartagena, allowed to verify that for the specific case of the course, the 2986 captures of CO2 level were classified within the "Good ventilation" level of Table 1. Likewise, through the clustering analysis developed, it was possible to determine that about 70% of the captures made by the system are concentrated around the CO2 level of 652,805 PPM. Thus, the proposed IoT system allows obtaining clear indicators for the development of diagnostics on air quality in educational classrooms, in order to support decision making in terms of academic planning by teachers' managers.

As a future work derived from the present research, it is intended to complement the architecture of the proposed system by including other artificial intelligence models for the analysis of CO2 level captures, using for example fuzzy logic, in order to enable the implementation of early warning systems for monitoring air quality.

Acknowledgment

The authors would like to thank the Universidad de Cartagena - Colombia and the Universidad Autónoma del Perú for their support in the development of this research.

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