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Industry 4.0 and Fire Safety: Proposal for a Low Cost Security Monitoring System

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Abstract

The travel and accommodation sector were one of (and not the most) affected during the pandemic by COVID-19. Hotels and inns struggle to remain operational and not to close permanently. Even with this situation, security issues in the accommodation are still essential and mandatory. This research demonstrates the permeability of industry 4.0 in the security sector of hosting environments. Based on tools such as microcontrolled devices, Cloud Computing, Mobile applications and the Internet of Things, the paper presents a prototype of a microcontrolled fire monitoring system capable of detecting not only signs of events in an advanced stage, but also the first moments of suppression to avoid further damage. With the growing number of incidents and tragedies with deaths related to fires in accommodation environments, the proposed project demonstrates a relevant alternative for this scenario. With these resources, an attempt was made to develop a monitoring device with access via the mobile interface. Such devices use low cost microcontrollers, with the objective of making them accessible to people of low or modest purchasing power, so that it can be a proposal that can be disseminated on a large scale.

Keywords: internet of things; cloud computing; mobile application; fire safety; accommodation sector

1. Introduction

By integrating technologies such as Cloud Computing, Internet of Things and microcontrollers with the advent of the industry 4.0, it is possible to carry out the construction of a fire-safety monitoring system for the hosting sector. Through the access of information in real time and accessible through the internet, it is possible to prevent fires and check for smoke or temperature rise.

Although there are solutions on the market focused on fire prevention, this article brings the question: if such solutions present an effective behaviour, how is it possible that tragedies, such as that occurred with the sportsmen of the Clube de Regatas do Flamengo in 2019, may be present in society (Brazil, 2019)? It is based on this case and on the countless possibilities of application with the aforementioned technologies, that this work aims to present a prototype focused on the safety of environments, aimed at places of hosting, such as hotels, houses, and apartments.

Normative data on security were raised, mainly in hosting environments, to trace the operating parameters of the monitoring system, which has sensors capable of detecting events that offer risks to physical integrity. Such devices can enable remote access to data and the storage of monitored information. Thus, tests were carried out to prove the effectiveness of the system and to select the best way to implement it in practice.

Thus, a prototype was developed and tested that integrates the technologies previously-mentioned: Cloud Computing (for access and treatment of online data); IoT (for the integration of several micro controlled elements via the Internet); and mobile technology, to enable both access to information and the monitoring and administration of processes (Varghese & Buyya, 2018; Minchev & Dimitrov, 2018; Batista et al., 2020).

The structure development, in addition to making automation compact and accessible, uses low-cost microcontrollers from the family called ESP (ESPRESSIF), with the characteristic of enabling a WIFI connection (Souza et al., 2019). Parallel to this, the impact of the pandemic by COVID-19 was considerable for the tourism and travel sector. This service sector, due to the lack of resources and drastic drop in demand, needs solutions that can be efficient and affordable to maintain its services and the safety of its customers (Gostin & Wiley, 2020).

With these characteristics, a solution was designed that integrates a security monitoring centre to safeguard the physical integrity of people in a hosting environment. During the validation experiments, to guarantee the reliability of the system, parameters that can characterize life-threatening factors were considered, such as: sudden change in temperature and concentration of harmful gases.

2. Methodology

This experimental study included an analysis of the fire process and the reference parameters and a definition of the materials and environment for testing the prototype. The consolidation of the research was established according to: definition of the project costs, assembly of the experiment structure, development of the electronic monitoring structure, implementation of the cloud structure, the mobile monitoring solution and the experimentation process.

2.1 Analysis of the Fire Process and Reference Parameters

This research focuses on human security and integrity. Thus, the acceptable / harmful levels of carbon monoxide, described in Table 1, were surveyed.

Table 1: Exposure time and amount of CO present in the environment and its effects

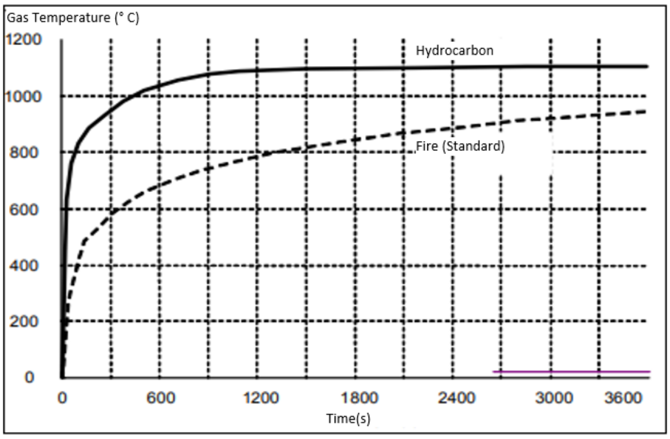
Approximate amount of CO (ppm - part per million) in the environment			
1h	8h	% COHb	Effects
0	0	0.3-0.7	Physiological pattern in non-smokers
55-80	15-18	2.5-3	Decreased cardiac function in debilitated individuals, changes in the bloodstream and after prolonged exposure hemopoietic responses
110-170	30-45	4-6	Decreased visual capacity, reduced vigilance and decreases in maximum work capacity
280-575	75-155	10-20	Weak headache, tiredness, dyspnoeal on exertion, cutaneous vasodilation, electrophysiological changes and general psychomotor problems
575-860	155-235	20-30	Severe headaches and nausea
860-1155	235-310	30-40	Muscle weakness, nausea, vomiting, dark vision and severe headaches.
1430-1710	390-470	50-60	Syncope, seizures and coma
1710-2000	470-550	60-70	Coma, impaired heart and respiratory activity, sometimes fatal
2000-2280	550-610	70-80	Respiratory failure and death

Source: Peres, 2005.

The temperature of the environment was also raised as a study variable and the maximum temperature that a place can reach to be considered a fire was not evaluated. In general, elements in combustion, after the ignition point (where the fire starts), the temperature rise is exponential (Figure 1), reaching 200 ºC in the first seconds after the start (Heidari et al., 2019).

As a premise of the tests, it is considered that temperatures in hosting environments are controlled. Thus, it was empirically defined as a maximum temperature value of 50 ºC, knowing that, exceeding this value, the system considers a possible fire event. This value is below the sprinkler operating temperatures.

Figure 1: Fire curves (standard) and 'H'.

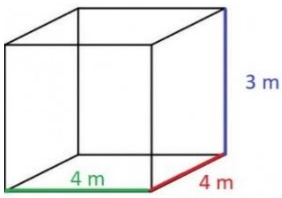


Source: Kaefer & Silva, 2003.

2.2 Definition of Materials and Testing Environment

For the measurement and experimentation process were used: Microcontrollers: ESP-32; ESP-12; Arduino nano; Sensors: MQ-7 (Carbon Monoxide); MQ-2 (Flammable and Smoke); DHT22 (Humidity and Temperature Sensor); DHT11 (Humidity and Temperature Sensor); External 3.3V and 5V power supply; For burning: paper and vegetable oil. The tests were performed on a 1:10 scale. The base taken as a reference for the area was, according to Figure 2.

Figure 2: Average volume of a room taken as a basis for carrying out the tests



Source: Authors, 2020.

3. Results

3.1 Cost Evaluation

The cost assessment was carried out and shown in Table 2. In a large-scale production the price tends to decrease, since the whole assembly would be carried out on a printed circuit board, which would save some types of materials and reduce the dimensions of the project.

Table 2: Estimated average cost for the prototype

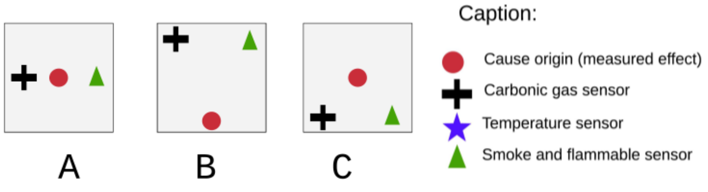
Quantity	Description	**Brazilian Reals (R$)**
1	Dht22 / Am2302 Humidity and Temperature Sensor	42.9
1	Dht11 Humidity and Temperature Sensor	9.9
1	Nano V3.0 + USB Cable for Arduino	39.9
1	MQ-2 Flammable and Smoke Gas Sensor	14.9
1	Carbon Monoxide Gas Sensor MQ-7	18.9
1	ESP8266 NodeMcu ESP-12E Wi-Fi Module	49.9
1	ESP32 Bluetooth 30-pin Wi-Fi module	64.9
1	Adjustable Power source for Protoboard	7.9
1	Wires	15
	Welding	5
	TOTAL	269.2*
	* Values based on Eletrogate (2020), disregarding labour	

Source: Eletrogate, 2020.

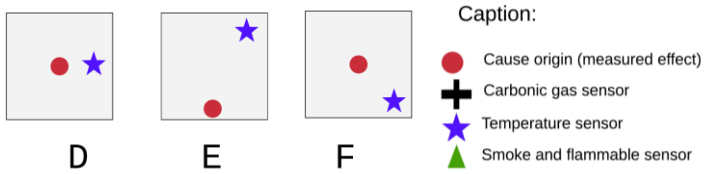
3.2 Experimentation Structure

For the tests, the scale 1:10 was used, that is, the test box will have a dimension of 40 cm x 40 cm x 30 cm. The types of sensors vary according to the desired measurement. For burning, MQ7 and MQ2 were used to detect carbon monoxide and flammable gases, and for temperature detection the sensor DHT22. A sequence of measurements was carried out, which was divided into three parts, according to the origin of the effect to be measured: firing, temperature and firing + temperature. Thus, according to each effect, specific sensors and measurement positions were used, as shown in Figure 3 (a-c).

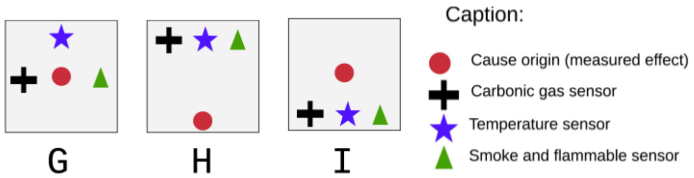
Figure 3: View of the Test Box



(a) Position of the sensors for measuring the flare (top view of the test box)



(b) Position of sensors for temperature measurement (top view)



(c) Position of sensors for measurement of flare and temperature with sensors together

Source: Authors, 2020.

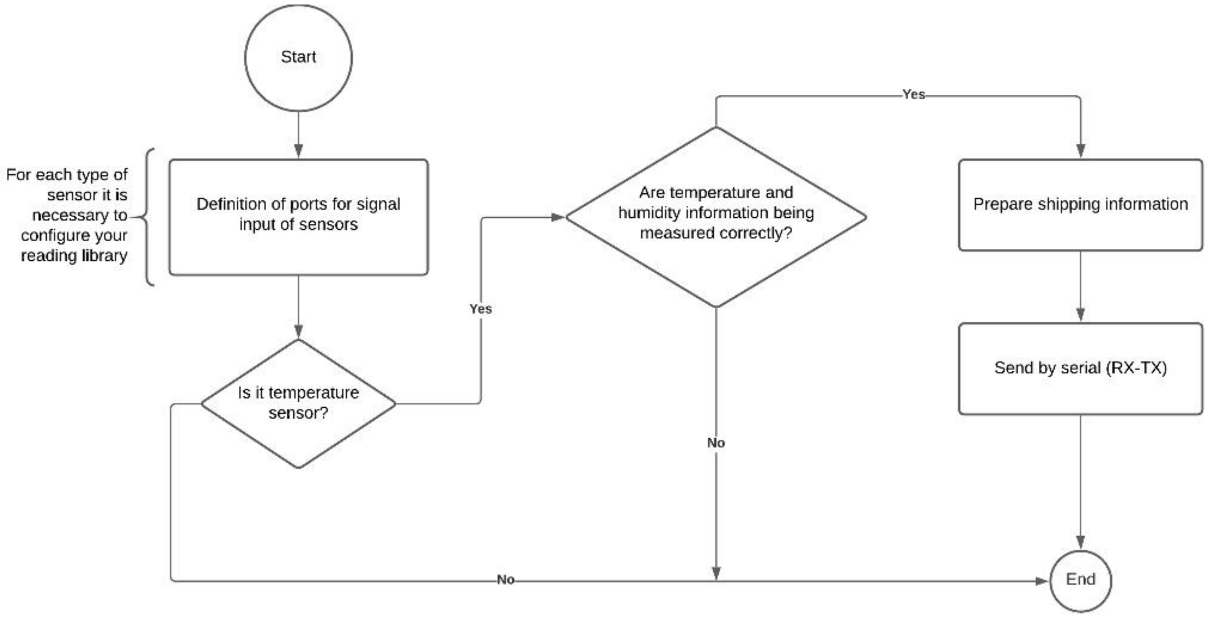
With these scale tests, data were obtained that approximate what would happen in an event of the size of this room in real size.

3.3 Electronic Monitoring Structure

The prototype uses 3 microcontrollers, the ESP-12, ESP-32 and Arduino nano. The information is collected by 4 sensors, which is composed of two sensors for temperature and two for humidity (DHT11 and DHT22). DHT22 is more accurate but has a slower response. There is also the CO sensor, named mq7, and a smoke and flammable gas sensor, named mq2. Regarding compatibility, the existing libraries and drivers for the sensors were not compatible with the ESP-12 microcontroller.

Another limitation was that the ESP-12 has only one analogic input port, which limits the installation of more than one sensor per microcontroller. In relation to cost-benefit issues, the ESP-12 has the benefit of having wireless communication. In relation to Arduino, its operating logic is seen in Figure 4.

Figure 4: Arduino nano working structure



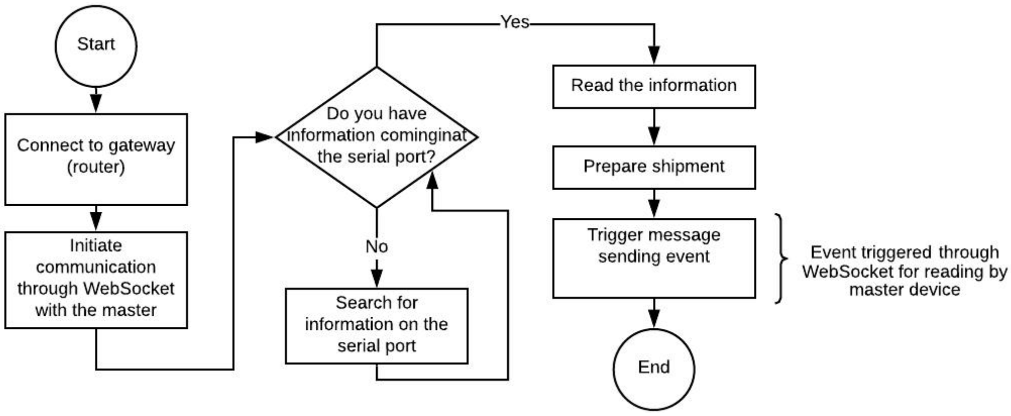
Source: Authors, 2020.

To transmit the information from the sensors to the control panel, Wi-Fi is used. For this reason there was a need to connect the Arduino via serial with the ESP12 so that it transmits the information to the ESP32 microcontroller. As described in Figure 5, the function of ESP12 is to capture the information received and prepare it to be sent via Wi-Fi to ESP32. Initially the objective was to promote an independent system, in such a way that it would be possible to connect to ESP 32 and control all the information through it (Figure 6).

However, after some tests, it was not possible to build this system completely independent of an external network because the communication protocol itself depends on the existing network. The definition of the transmission protocol was relevant to the interoperability and quality of transmission of the system information. HyperText Transfer Protocol (HTTP) has a high processing capacity, since the generated packages are large and there is a need for the system to have constant communication with the client.

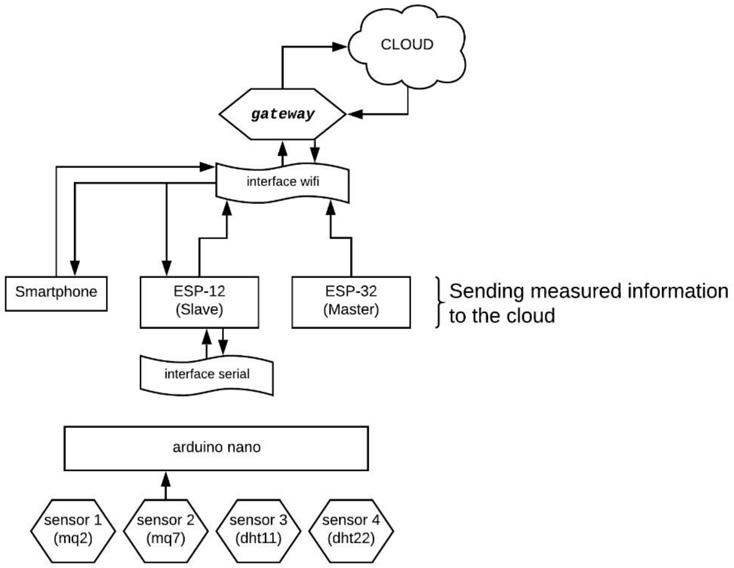
As IoT devices, they only present measurement data, so the WebSocket was used. It makes it possible to open an interactive communication session between the user's browser and a server. With this it is possible to send messages to a server and receive event-oriented responses without having to consult the server to obtain a response, as in an HTTP request. Via WebSocket, the ESP32 microcontroller receives such information and treats it so that it is sent to Cloud storage using a service called Firebase®.

Figure 5: ESP12 operating structure



Source: Authors, 2020.

Figure 6: Sensor structure and its communication

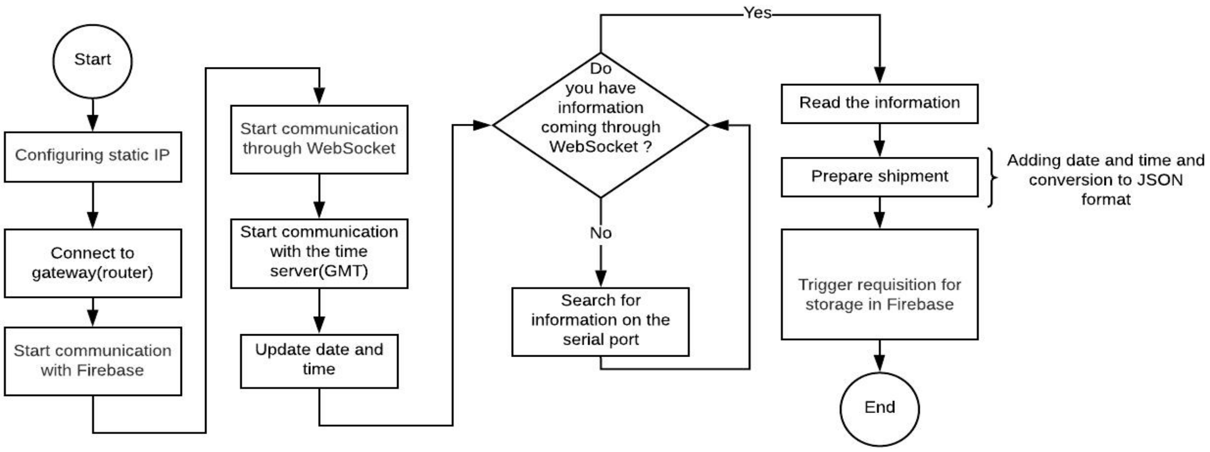


Source: Authors, 2020.

An advantage when working with WebSocket and ESP, is the existence of libraries, which make their integration possible, and have functions that enable the configuration of the verification time between connection of the devices and the possibility of reconnection in case of loss of signal. The operation of the ESP-32 is depicted in Figure 7.

Upon receiving this information, the ESP32 converts this information to be sent in an HTTP request and stored in Firebase®.

Figure 7: Communication protocol structure



Source: Authors, 2020.

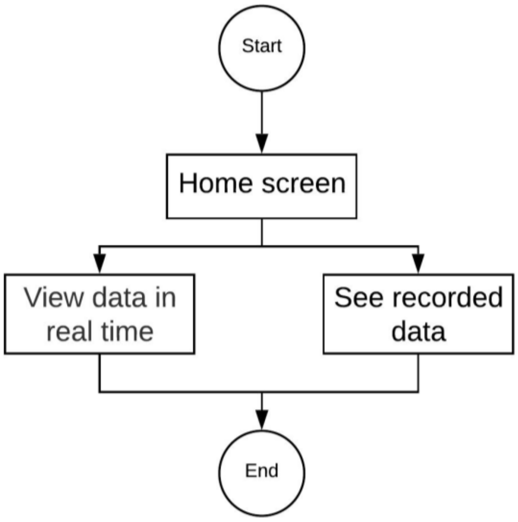
3.4 Cloud Structure and Mobile Solution

The devices are connected to the local network of the establishment, through the wireless router. The system is composed of a “master” who will be responsible for centralizing the information that comes from the sensors and transmitting the information to the cloud, each one with its ESP, called “slaves”.

WebSocket technology will be used to communicate the sensors with the master as it allows, among other things, bidirectional and low latency communication. Each ESP and sensor set sends information to the master. This transmits the information to the cloud through the local gateway connected to the internet provider.

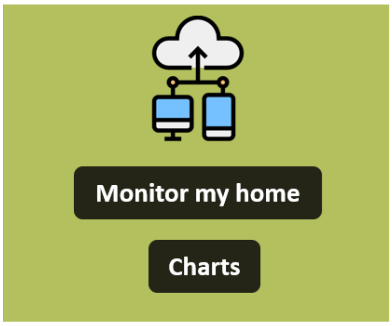
The system used to store such information in the cloud was Firebase® which provides a database in real time and accessible. For instance, through a smartphone, which can act on the local system, whether to turn on the hood, send an alert , or contact an external agent (family members, public security agencies). Figures 8 and 9 demonstrate the mobile application, in the design of its working flow and interfaces (screens).

Figure 8: Application structure diagram

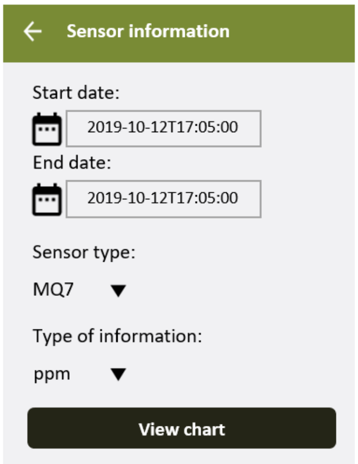


Source: Authors, 2020.

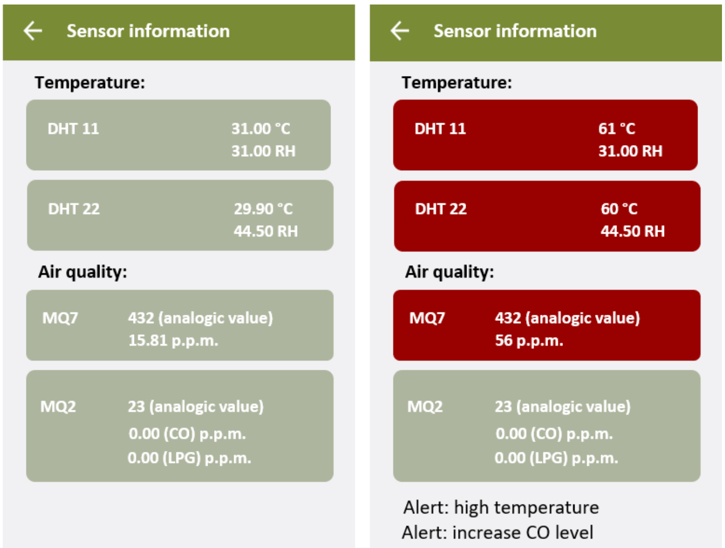
Figure 9: Application screens



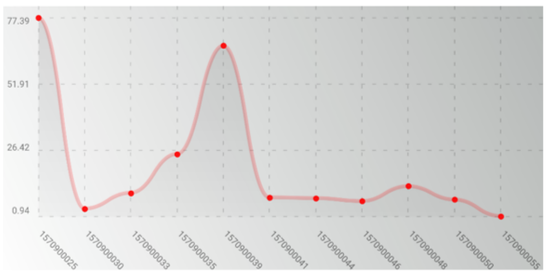
(a) Home screen



(b) Parameters for chart



(c) Measured data in real time without and with alert, respectively



(d) Bezier Line Chart showing sensor info

Source: Authors, 2020.

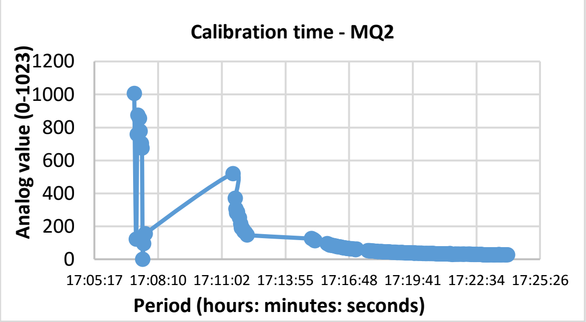
3.5 Experiments

The experiments were limited to a period of 5 minutes for security reasons and in order to obtain the data, with a sampling index that faithfully represented a real situation.

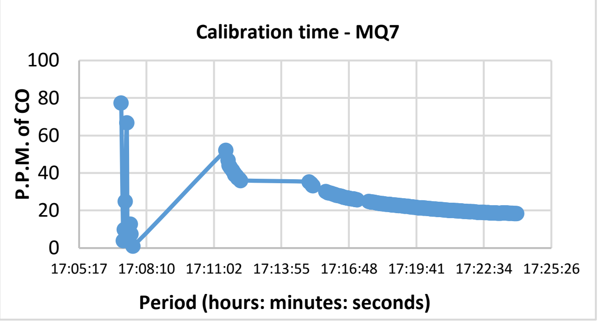
It was found that, for an environment with the dimensions of a 4x4x3 m room, the position of the sensors does not affect the measurement, as long as they are at the top of the site. Since it is working with the situation of a fire in which the gas expansion is very fast, so that the reading of the sensors is uniform within the sensitivity range of each type. However, the study of sensor allocation in large, more widely spaced environments is essential, since each sensor has a radius of coverage that must be observed so that there are no blind spots in the system, thus minimizing the possibility of failure.

Three tests were performed, and the results obtained were proportional on a 1:10 scale to a real fire and the type of fuel that was available to burn. It is worth mentioning Figures 10a-c that correspond to the calibration period that lasts around 16 to 20 minutes, this range will not be observed in the following tests, because after this period it stabilizes and starts to represent the reality of the environment. In the first test performed in the environment, it was done only with a paper ball going into partial combustion and then the flames were extinguished, but as it can be seen in Figures 11a, 11b the carbon monoxide emission continued to rise even when the temperature stopped rising as illustrated in Figure 12.

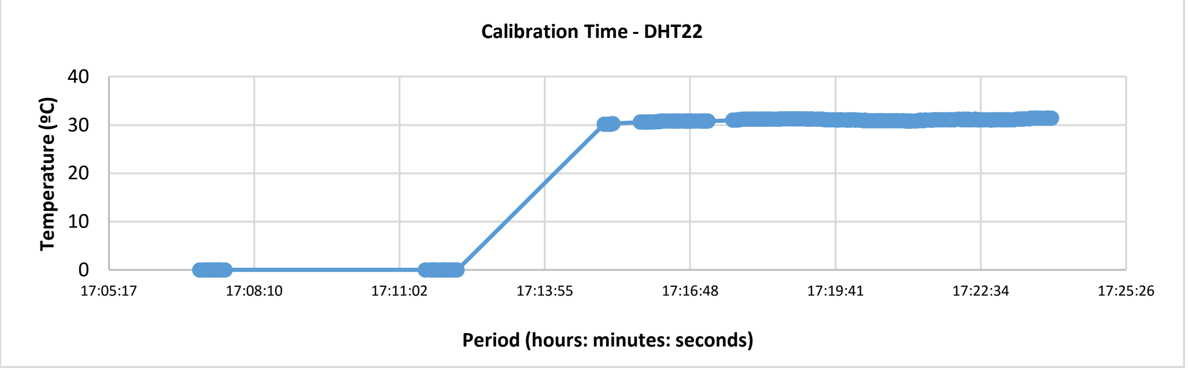
Figure 10: Sensor Calibration Time



a) MQ2 sensor calibration time



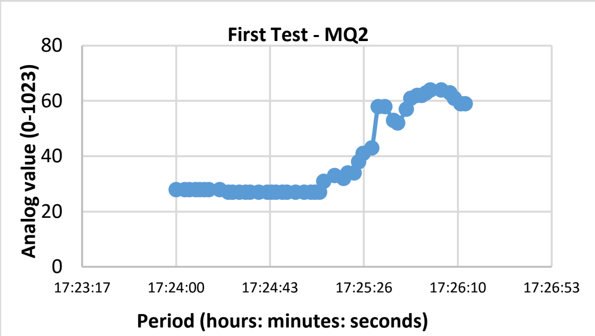
b) MQ7 sensor calibration time



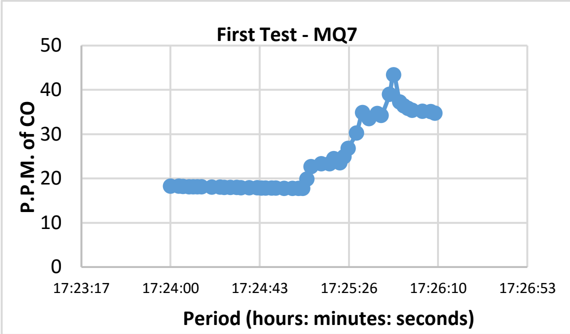
c) DHT22 sensor calibration time

Source: Authors, 2020.

Figure 11: Concentration data (First Test)



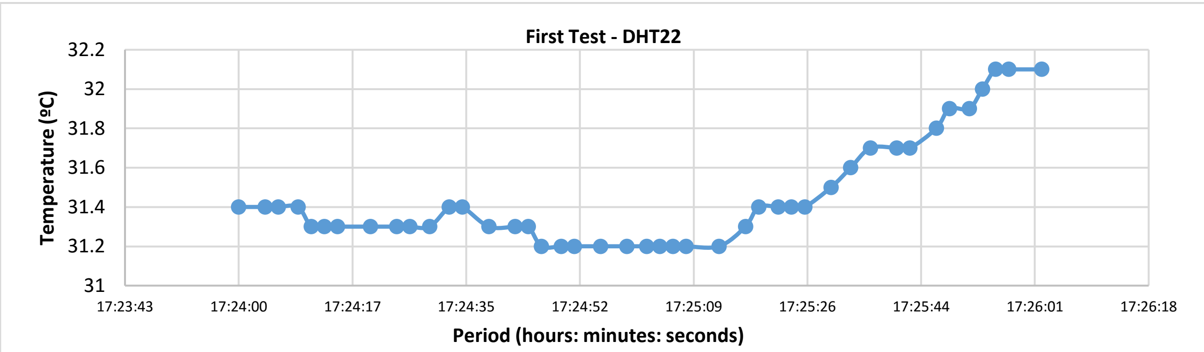
a) flammable gases sensor MQ2



b) carbon monoxide sensor MQ7

Source: Authors, 2020.

Figure 12: DHT22 sensor temperature data (First Test)

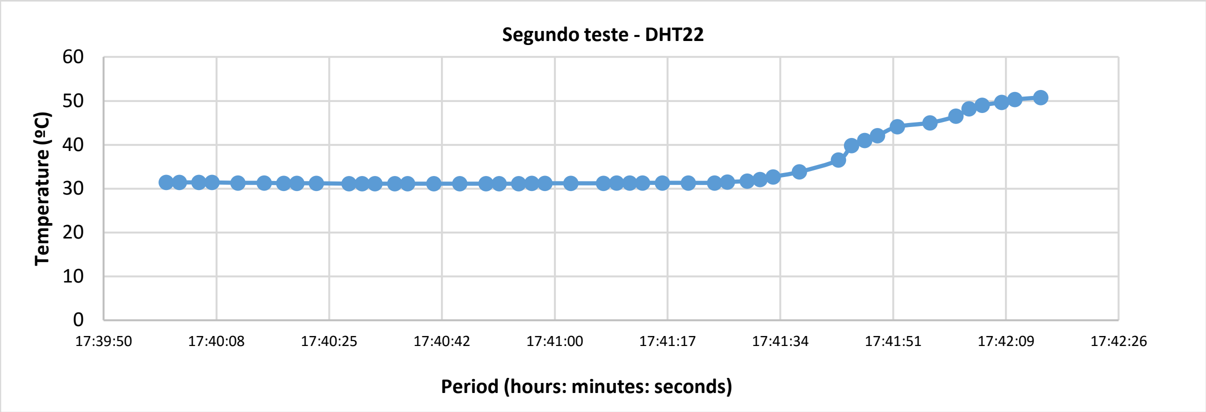


Source: Authors, 2020.

In test two, a larger burn was carried out, where the flame was kept on for a prolonged time. Figure 13 represents how much the temperature increased within the environment, exceeding the aforementioned limit that was chosen as the limit temperature to not be considered a fire. Figures 14a, 14b represent the increase in carbon monoxide at the time of this test, which has a higher rate of increase because the amount of material in combustion is greater.

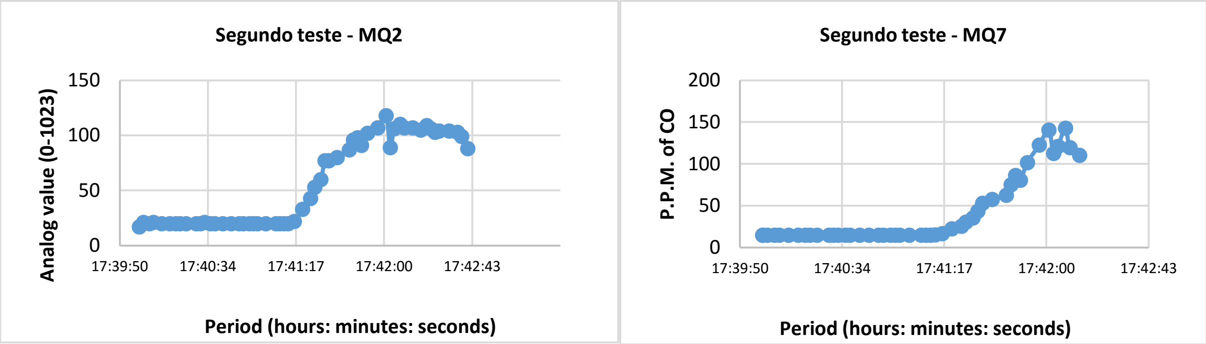
In test three, a vegetable oil fuel was introduced, instead of keeping only paper. This represented an increase in the flames and their durability. The temperature test was interrupted to avoid damage to the test environment. However, the results collected were satisfactory, since the peak obtained showed, in addition to the drastic increase in temperature, the perception of new components due to the change in fuel.

Figure 13: DHT22 sensor temperature data (Second Test)



Source: Authors, 2020.

Figure 14: Concentration data (Second Test)

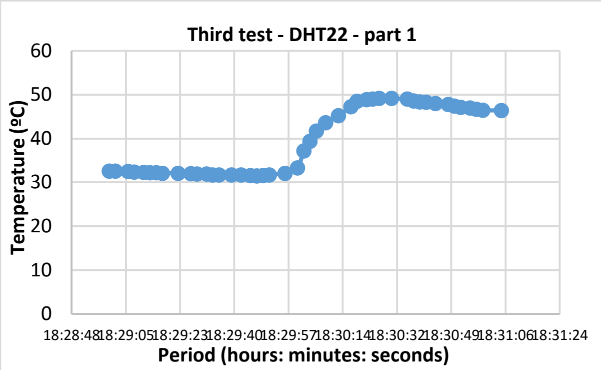


a) flammable gases sensor MQ2 b) carbon monoxide sensor MQ7

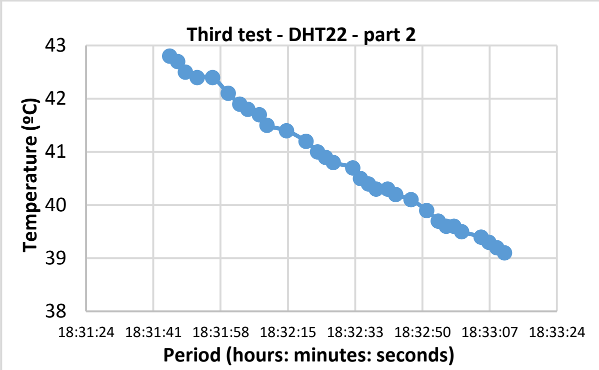
Source: Authors, 2020.

In Figures 15a and 15b it is shown the temperature representation in this test, and in Figures 16a, 16b, 17a, 17b, the graphs of the amount of carbon monoxide. After the exhaust fan goes into operation, all graphs show a decrease, since the exhaust fan is removing the air mass with the analysed components, which justifies the decrease, and proves the expected effect of minimizing the consequences of this gas in the environment.

Figure 15: DHT22 sensor temperature data



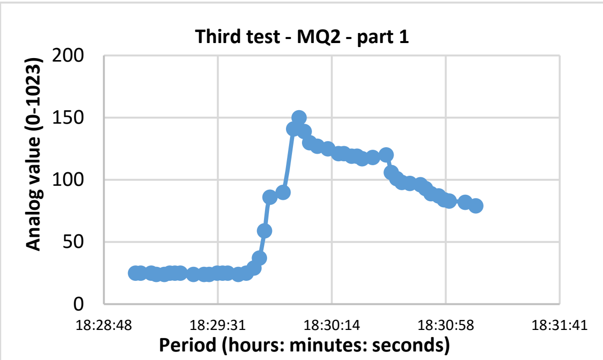
a) First DHT22 test



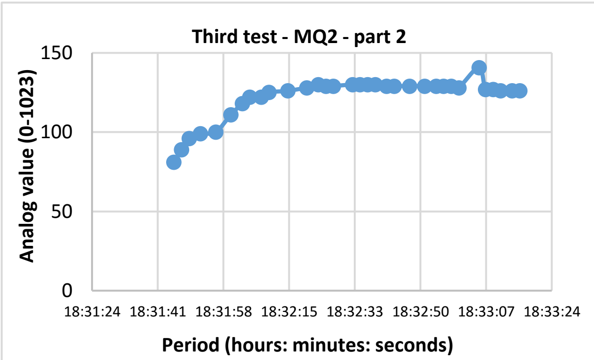
b) Second DHT22 test

Source: Authors, 2020.

Figure 16: Concentration data for flammable gases MQ2 sensor



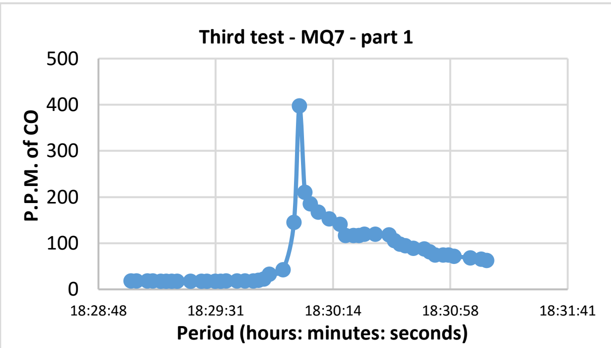
a) First MQ2 test



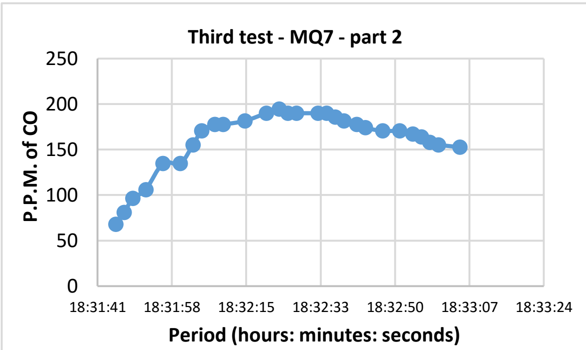
b) Second MQ2 test

Source: Authors, 2020.

Figure 17: MQ7 sensor carbon monoxide concentration data



a) First MQ7 test



b) Second MQ7 test

Source: Authors, 2020.

4. Conclusion

The relevance of the research is showed by the proof that the prototype, with the association of the evaluated technologies, could present a structure capable of meeting security demands, in addition to providing relevant information to the security demands of a living / lodging environment. The experiments attest to the effectiveness (given to the coherent responses of the architecture) and efficiency of the micro controlled system, where the response of the sensors proved to be satisfactory. The reaction time of the system is around 2 to 4 seconds after the detection of the problem, which for human safety is an acceptable speed, since carbon monoxide, even in conditions of high concentration, takes around one hour to cause attenuation of senses and more severe damages.

Improvements can be implemented, which would allow greater autonomy of the environment to be controlled, such as: service for sending messages (SMS) and pre-recorded calls to security agencies. In addition to a possible expansion, with the implantation of an artificial intelligence capable of managing the system, taking the necessary measures to safeguard human life.

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