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IoT Based Environmental and Water Monitoring System for Sterilization Units in Honduras

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Abstract. Sterilization is a crucial process in healthcare. The environment in which it is performed plays a critical role and any change in temperature and humidity of the environment can compromise the process. In addition, the water quality is also fundamental since its contamination and hardness can cause high impact damage to surgical material and medical equipment. It is difficult for public hospitals in Honduras to control these processes, environments, and water, possibly due to factors such as limited budgets or lack of knowledge of international guidelines. It is proposed to develop a monitoring system capable of measuring environmental and water quality parameters through the implementation of IoT for sterilization units. A vast literature review and the support provided by experts in the field allowed to establish the success criteria for the development of the prototype. The V methodology was used for the mechatronic design to obtain a complete product. By means of experimentation and finally field tests were carried out to determine the components that would integrate the system and the validation of their measurements. A monitoring system was developed to measure relative humidity, temperature, dust particles and total dissolved solids in the water. These measurements were displayed on a web based Ubidots dashboard for data visualization, storage, and export. Once the measurements were obtained, a comparison with international standards was carried out to demonstrate the importance of environmental monitoring in this area.

Introduction

Sterilization plays a fundamental role in the field of healthcare, as it involves the elimination of pathogens and other microorganisms present in equipment and materials used in surgical procedures. Therefore, it is vitally important to ensure that the environment where sterilization is performed is highly safe and controlled. [1].

The environment in which the sterilization process is carried out is a critical factor that affects its effectiveness. Any change in the environment can impair the quality of sterilization. [2]. In addition, the quality of the water used in the sterilization process is also essential, since its contamination can cause major damage to the material and equipment. [3]. The Internet of Things (IoT) provides an effective solution to monitor these parameters, as it allows the collection of data in real time and the immediate identification of any deviation from normal values. [4].

The Honduran health system has several deficiencies, this could be reflected in the effectiveness of the sterilization process of surgical materials in a Sterilization and Equipment Center (SEC). Public hospitals find it difficult to control processes, controlled environments and water quality, possibly due to factors such as limited budgets or lack of technical knowledge.[5].

Environmental parameters, such as temperature, humidity and the presence of dust particles in the air, are crucial elements that should be monitored at all times in order to have an essential environment that does not compromise the sterility of the materials.[6]. Water quality is another crucial factor to consider because it also affects the lifespan of materials and equipment. [7].

During visits to a public hospital in the country, it was observed that there is a lack of adequate separation between the different areas. This situation generates unfavorable environmental conditions and facilitates the free movement of dust particles, which increases the risk of material contamination in these areas. [8]. It is important to take measures to avoid this contamination and guarantee a safe environment free of harmful particles in the SEC. [9].

This research aims to improve the verification of environmental parameters and water quality in a sterilization plant through the implementation of a monitoring system. The objective of this paper is to develop a monitoring system capable of performing the measurement of environmental and water quality parameters by implementing IoT for this area in a public hospital in Honduras.

In the following sections the state of the art and the methodology used in the research will be discussed. In addition, the part of results and analysis will be addressed, where the results obtained in the validations, the elaborated tests and final tests will be seen. Likewise, the IoT connection and the results obtained from the platform measurements will be explained. Finally, the conclusions and thanks to the people involved in the project will be presented.

State of the Art

Environmental quality monitor in an SEC: Evidence from a cancer center. In India, the concept is used that quality is related to the degree of excellence of a product. In addition, a large amount of time is required to develop, implement and monitor processes for quality control. This reduces unnecessary costs and increases the useful life of instruments and equipment. Therefore, a monitoring system was developed that would analyze four environmental parameters such as water quality, air quality, carbolization and sterility tests [10].

This system may be inefficient, but it is what some hospitals manage. The others choose to hire external companies to carry out a study of the different variables that they want to study. The cost of a study like this can be high and will depend on the area where it is intended to be carried out.

Low-cost in-hospital environmental monitoring system. In Mexico, a study was carried out on environmental factors that could influence the quality of patient care. To this end, we sought to implement a monitor of environmental parameters in medical unit facilities. Which would allow the real-time measurement of five values: temperature, relative humidity, light intensity, sound intensity and carbon monoxide concentration. [11]. Various sensors were used to measure environmental parameters, which were strategically positioned. For data capture and transmission, a PIC16F877 microcontroller was used, which is considered low cost in all areas.

IoT-based environmental monitoring system for intensive care unit in Honduras. In Honduras, not all hospital institutions have the ability to integrate a monitoring system for environmental parameters in their facilities, therefore, this must be done manually by the staff or it is something that some institutions are completely unaware of.

In Honduras, not all hospital institutions have the ability to integrate a monitoring system for environmental parameters in their facilities, therefore, this must be done manually by the staff or it is something that some institutions are completely unaware of [12]. Operating rooms are classified as critical areas due to the fact that invasive procedures are performed on patients, therefore, they are exposed or vulnerable to microorganisms entering the body, causing what is known as a nosocomial disease. Thus, due importance and attention must be given to the environment within the facilities.

To carry out the monitoring, the environments within the different areas of the hospital were studied, reaching the conclusion that the focus area would be the Intensive Care Unit (ICU). The information collected would then be transmitted through the Internet of Things for the study of the final results, obtaining the desired guide for the applicability of the system. In this way, this project demonstrates how crucial it is to have a monitoring system that validates the environmental conditions for an area as critical as the ICU. Concluding that the introduction of IoT and the ability to fully exploit a network of sensors would achieve favorable results for monitoring within complex environments. [12].

Regulations

The following section presents the regulations considered for the design of the prototype developed for the research.
AAMI ST 79: 2017. This association created ”The Comprehensive Guide for Steam Sterilization and Sterility Assurance in Health Care Facilities (ST79)”, which provided guidance on recommended temperature and humidity levels for different areas of the sterile processing department. In 2017, due to disagreements by SEC staff, regarding the difficulty in achieving the recommended levels, the environmental parameters for each department now follow a version of ASHRAE 170.[13]. This regulation has served as a basis for the development of ideal standards depending on the conditions of the hospital.
AAMI TIR34:2014. Establishes that the water used in the cleaning, disinfection and sterilization processes of medical devices must meet certain quality criteria and recommends the use of high quality purified or demineralized water. It is recommended to regularly monitor the quality of the water used to prevent contamination of medical devices. In addition, different parameters must be taken into account to ensure water quality. [7].
ASHRAE 170-2017. Standard that establishes the minimum requirements for the design, construction, and operation of ventilation and filtration systems in health care facilities. It is widely used for the conditions that must be met within a SEC [14]. The standard’s requirements for sterilization units include: air change rate per hour, indoor air quality, location and size of air intakes and discharges and differential pressure between processing areas and adjacent areas.
ISO 14664. This standard refers to a series of international standards that establish requirements and guidelines for the classification, monitoring and control of air quality in controlled environments. For example, clean rooms or areas and controlled atmosphere zones. [15]. It establishes an air cleanliness classification based on the maximum number of airborne particles allowed in a given particle size in a controlled environment. It also provides guidelines for continuous monitoring and control of air quality.

Methodology

After establishing the main idea of the problem to study, we proceeded to conduct a literature review for the collection of information and the analysis of the system requirements, which allowed us to define the feasibility of the project. In addition, to make sure that it was possible to develop it in a public hospital, a field study was carried out with several visits in which the origin of some problems were observed.

The investigation continued by interviewing personnel to learn more about the infrastructure and processes carried out at the site. In this way, a complete picture of the design was obtained and compliance with the corresponding regulations or quality standards was understood. The mission was to collect as much information as possible in order to determine the implementation of the system at the plant. This led to the conclusion that two prototypes should be implemented, one to measure environmental parameters inside the clean area and the other outside the CEYE to measure water quality, which came from a well adjacent to the plant.

In addition, a system analysis was carried out to review the different sensors that could be used in the project. With the related research obtained in the elaboration of the state of the art, it was possible to determine a feasible way to develop the project, taking into account the experience of previous researchers. It was determined that the parameters to be measured would be temperature, relative humidity, air quality (concentration of dust particles) and water quality (hardness). At the conclusion of the literature review, the modules (sensors and microcontrollers) to be used were selected to start testing. Codes were programmed in Arduino IDE for each of the modules and tested individually to avoid problems at the time of integration of the entire system. Having all the corresponding materials and the appropriate research to build the system, individual tests were to be performed with them.

Subsequently, experiments were carried out with the sensors in different locations, for example, with the TDS sensor, the transducer was immersed in water brought from the hospital and then in drinking water, comparing the values with those of a conductimeter. For the temperature and humidity sensor, the industrial engineering laboratory booth was used, which had an instrument capable of measuring the corresponding parameters. In the case of the dust particle sensor, there was no feasible way to check if its values were correct, since only the manufacturer's reference was available, which was obtained through the technical data sheet. Subsequently, we proceeded to integrate the corresponding sensors with each ESP32, in one the TDS sensor for water quality was installed. The other microcontroller was mounted with the dust particle sensor and the HTU21D, each prototype with its corresponding LCD display.

The system had to have a robust and reliable aesthetic, so a 100x200mm bakelite PCB was adapted for system integration to improve communication and census. Then, the whole system was tested to verify its accuracy. Once the system was integrated, the values measured by the sensors were checked again using the controlled environment cabin of the industrial engineering laboratory.

Once the final system tests were completed, the communication protocol that would be used to connect the system to a cloud platform was programmed. Then, the housing parts were designed in Solidworks and exported to DFX format to be used in RDWorks. Then, we proceeded to cut the parts with a Corvus laser cutter. Subsequently, the parts were fixed together with glue and support units were installed at the base of the housing to prevent the cables from touching the base of the housing. Then, validation tests were performed with the previously mentioned sensors. With all this verified, we proceeded to perform the tests in the public hospital. At the hospital, the corresponding measurements were performed at the locations mentioned at the beginning. Data was collected for approximately one hour and stored in the cloud using Ubidots, which is a platform known for its implementation with IoT systems.

Results and Discussion

For the development of the system, the monitoring of four factors considered crucial to guarantee the effectiveness of the sterilization process was established: ambient temperature, relative humidity, presence of dust particles in the air (these in one prototype) and the level of dissolved solids to determine the quality of the water (in a second prototype). The integration of components such as microcontrollers and sensors available in the national market was fundamental for the design of the prototype.

It was possible to design a system integrated by two prototypes with different electronic components. An environmental prototype had: HTU21D temperature and relative humidity sensor, SDS011 dust sensor, ESP32 microcontroller and 20x4 LCD screen. On the other hand, the water quality prototype had: TDS sensor, ESP32 microcontroller and 16x2 LCD screen.

In this way, we proceeded to establish the connection with the IoT platform, in the case of the prototype for monitoring environmental parameters.The dashboard is shown in Fig. 1. Thus achieving the implementation of this technology in the facilities of a sterilization unit, an area of vital importance for any hospital. The system underwent a field test lasting one hour and thirty minutes. The system was subjected to a field test lasting one hour and thirty minutes as shown in Fig. 2.

During this test, revealing information was obtained indicating that the conditions under which this procedure is carried out are not suitable. High temperature values, acceptable levels of relative humidity and sharp fluctuations in dust particles were observed. (See Fig. 3, Fig. 4 and Fig. 5).

Regarding humidity, it was constantly maintained in a range of 49-58%. These values could be considered acceptable according to the regulations established by AAMI. It is also relevant to take into account that this area of the plant lacks an environmental conditioning system.

However, the temperature values turned out to be in a high range when considering what is established by international standards. The readings were maintained in a range of 27-29°C for the reason

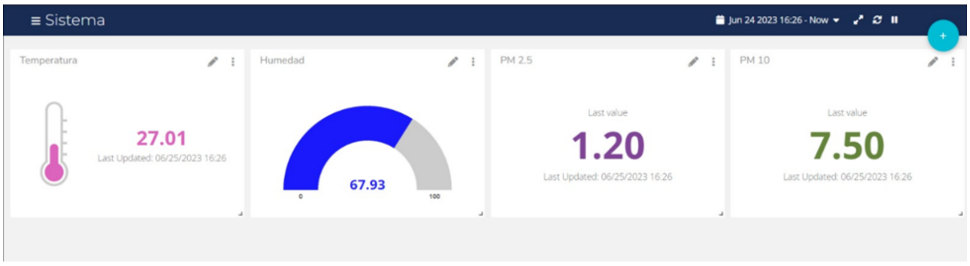

Fig. 1: Dashboard in Ubidots platform.

Fig. 2: Area where the packaging of washed material takes place.

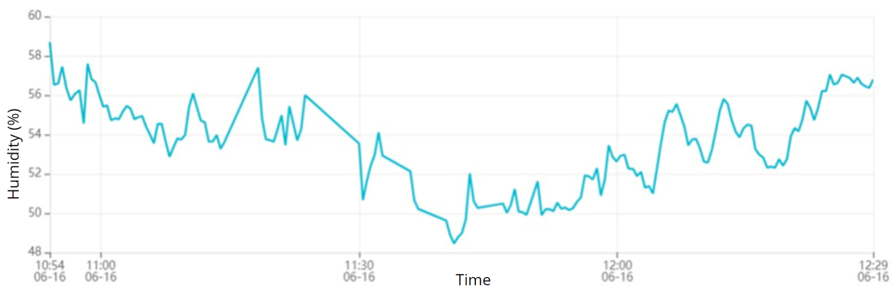

Fig. 3: Relative Humidity Graph in IoT platform from 10:54am to 12:29pm

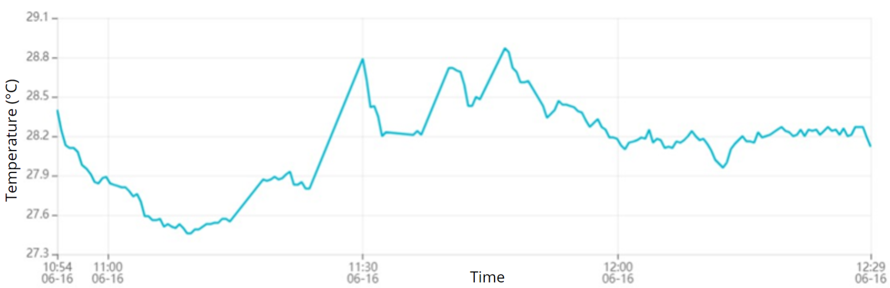

Fig. 4: Ambient Temperature Measurement Graph in IoT platform from 10:54am to 12:29pm

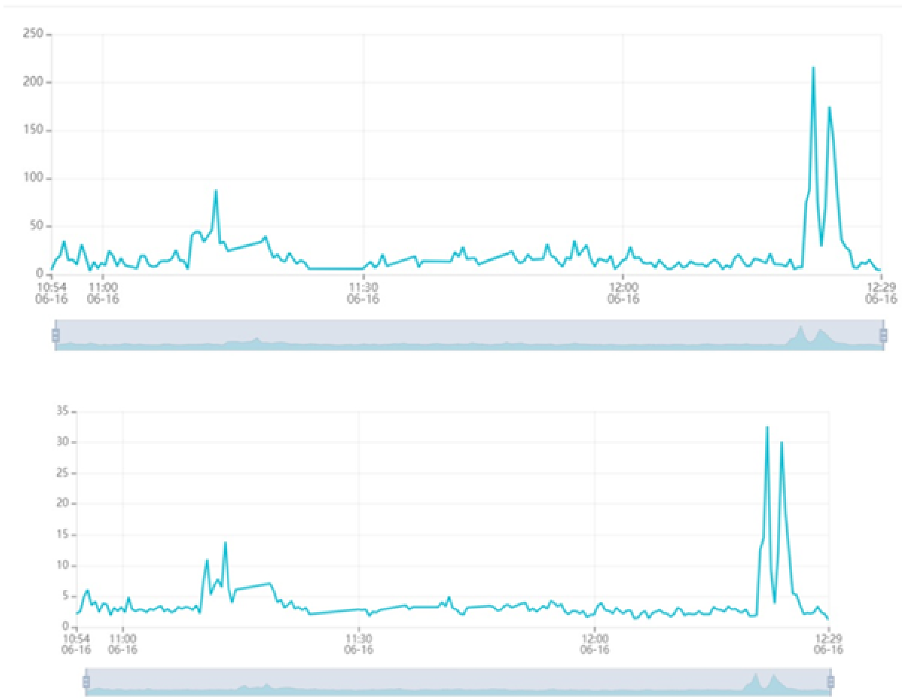

Fig. 5: PM 10 (top) and PM 2.5 (bottom) particulate matter measurement graphs in IoT platform.

mentioned above. This indicates that the environment contains conditions that favor the proliferation of microorganisms that benefit from high temperatures.

The most significant results were obtained from the suspended particulate measurements. Noticeable changes in PM 2.5 and PM 10 levels were observed during the morning hours (8:00 AM to 12:00 PM), matching with a greater presence of personnel. These changes were evident at specific times, such as during the transfer of washed material for packaging.

Having mentioned the above, this research proposes the following system which has been developed to better control the variables to be monitored in a sterilization plant. Fig. 6 shows the connections used to build the system.

Fig. 7 shows a block diagram of the environmental parameters prototype. The microcontroller is powered with a 5V voltage, and thus provides 3.3V to power the SDS011 (S1) and HTU21D (S2) sensors. These sensors collect information on ambient temperature, relative humidity and the concentration of PM2.5 and PM10 particles. Once they perform the measurements, they send the data to the R(s) microcontroller. The latter is responsible for processing the information obtained and then sending this data to be displayed both on an LCD screen and on the Ubidots platform.

Fig. 8 shows the block diagram of the water quality monitoring prototype. The microcontroller is powered with a voltage of 5V, and provides 3.3V to power the TDS sensor (S1). When the TDS sensor performs measurements, it sends the collected information about the total dissolved solids (R(s)). The ESP32 then processes this data and sends it for display on the LCD.

The shortcomings related to the coding and quality of the TDS sensor model meant that it was not possible to establish an effective connection with the IoT platform. This made it impossible to obtain data through the sensor, so it was decided to perform manual monitoring.

To evaluate the accuracy of the sensor, tests were used with distilled water as a reference, since it is considered ”pure water” due to its lack of electrical conductivity. This is because distilled water does not contain charged ions, such as dissolved minerals, which are normally responsible for conducting electrical current through water.

This was performed for a 10-minute interval with a sample of the water used in the hospital sterilizers. In this case, a field test was not possible due to the installation of new equipment in the sterilization

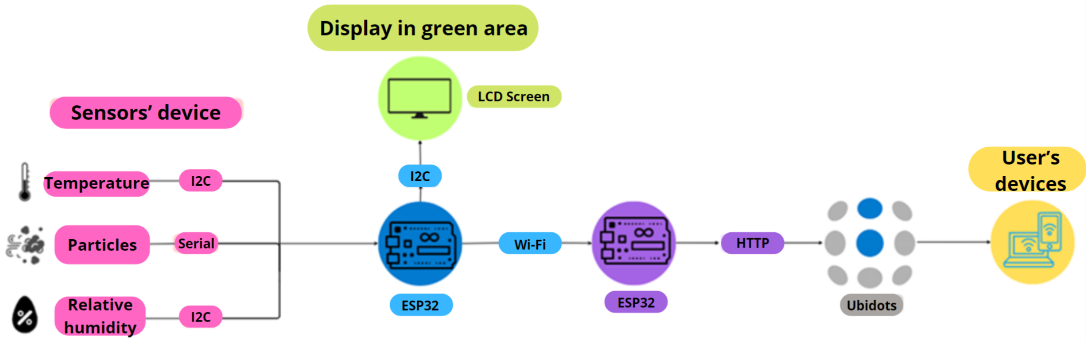

Fig. 6: Diagram of the IoT connection of the environmental parameters prototype.

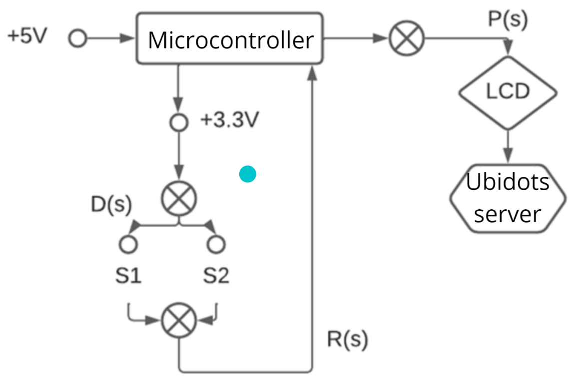

Fig. 7: Block diagram of the environmental prototype

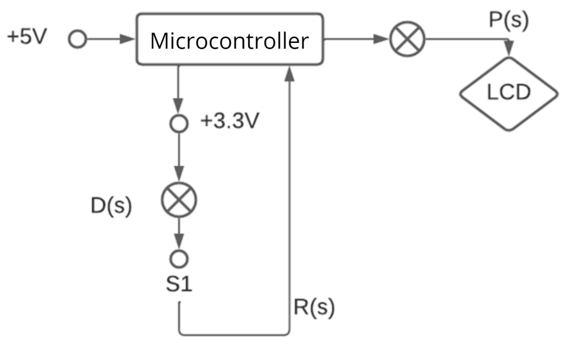

Fig. 8: Block diagram of the water prototype

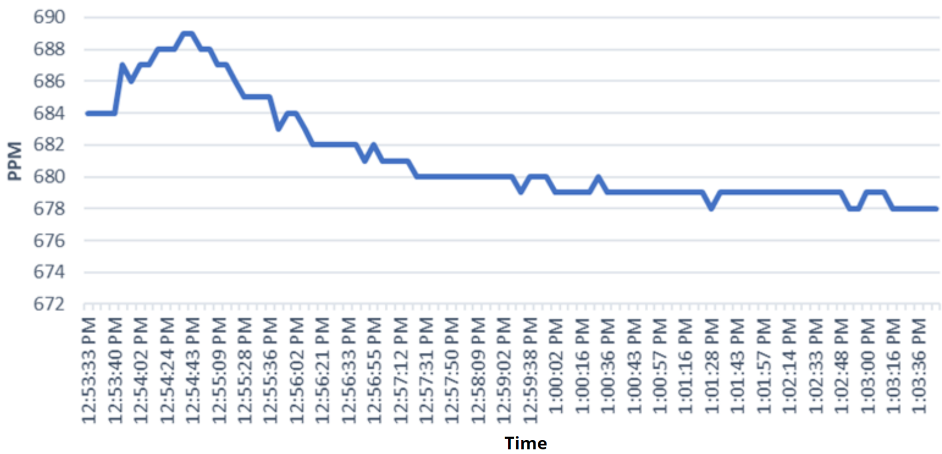

Fig. 9: Measurements of the TDS sensor for water quality monitoring in the IoT platform.

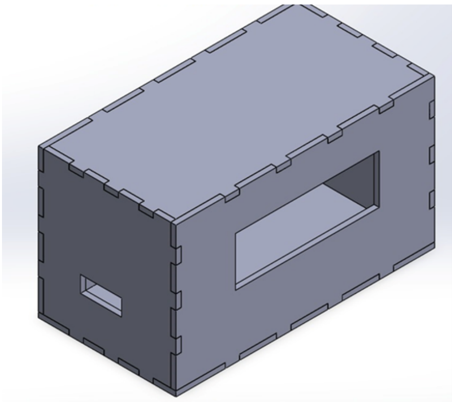

Fig. 10: Final housing design in SolidWorks

area and the integration of the reverse osmosis system. Nevertheless, the test was carried out and its operation was effectively verified for an extended period of time. Obtaining the values shown in Fig. 9. The sensor data were compared with a calibrated Thermo Orion model 145 conductivity meter. The data between them showed a significant difference indicating that the sensor is not accurate.

It is recommended to use the Gravity TDS sensor, since the supplier provides a library compatible with DFROBOT that facilitates the use of the sensor. The sensor used in this project was of the Keyestudio brand, with which there were connection problems, because when connected to the server, the sensor stopped working, providing very different data to the conductivity meter. In addition, with the Gravity V2 sensor it is possible to measure TDS and electroconductivity simultaneously.

In order to integrate the two devices, the decision was made to design a housing using SolidWorks software. Acrylic, a material recognized for its durability and transparency, was implemented. To ensure the accuracy of the cuts, a laser cutting process was employed, which ensured high quality results and perfect fit in each component of the housing. This design choice and manufacturing method enabled the creation of a rugged case, providing adequate protection for the devices in question. (See Fig. 10). Both prototypes are shown in the Fig. 11.

Conclusions

An IoT monitoring system was developed to measure environmental parameters in a green area of a SEC. The TDS sensor could not be integrated into Ubidots due to coding issues and lack of compatibility with recommended protocols. The TDS sensor was used only for measurements and display on screen.

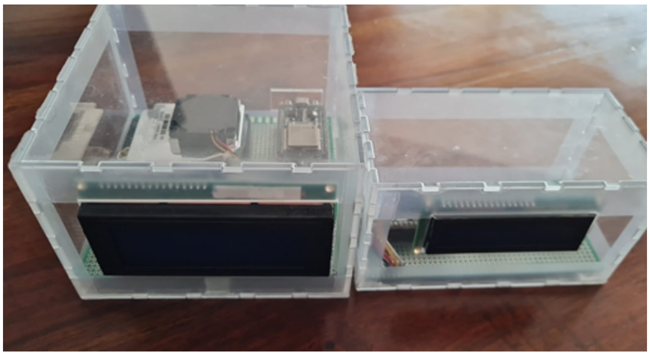

Fig. 11: Final prototypes

Two strategic points were found in the SEC for prototyping. The first was in the packaging area due to temperature, humidity and dust disturbances. The second point was the cistern where water is supplied for the autoclaves. However, the TDS sensor only works properly when the tank is almost full, as the measurements will be 0 otherwise.

The findings in airborne particulate measurements have generated particular interest due to the abrupt variations observed in particulate concentrations. These results indicate the possibility that the wrappings used for sterilization may not meet medical grade standards or may have lost their ability to act as a barrier against the entry of microorganisms. It is important to note that this type of packaging should have a controlled porosity of no more than 0.5 microns. This may open an opportunity to continue this study with further field tests in hospitals in the country.

It has been demonstrated that this type of system is efficient in different areas of the hospital such as operating rooms, intensive care units, isolation rooms, among others. All of them have in common that they are critical areas in a hospital and that they must have a controlled environment to ensure a safe environment for patients and health personnel. With a monitoring system, preventive or corrective measures can be taken quickly to help maintain an optimal environment that does not affect the integrity of patients or other people. IoT systems are of great benefit to hospitals, as they can help to efficiently manage resources and collaborate with the care of some equipment.

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