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Design of an automated system for temperature and humidity control in a *Pleurotus Ostreatus* mushroom culture cell

Diseño de un sistema automatizado para el control de temperatura y humedad en una celda de cultivo de hongos Pleurotus Ostreatus

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Abstract: This article presents the results obtained in a culture cell through the automated management and control of temperature and relative humidity, variables relevant to the quality of Pleurotus Ostreatus mushroom cultivation, in such a way as to minimize the impact of climate and ensure a quality product for consumption. The article describes the engineering process applied to obtain the control system that interacts with the cell, as well as the results obtained by comparing the control group under normal environmental conditions with the culture that uses technology supported by the Internet of Things (IoT)

Keywords: culture cell, internet of the things, mushroom, temperature, humidity, automation system.

Resumen: El artículo presenta los resultados obtenidos en una celda de cultivo mediante el manejo y control automatizado de la temperatura y humedad relativa, variables relevantes en la calidad del cultivo del hongo *Pleurotus ostreatus* de tal manera que minimicen el impacto del clima y aseguren un producto con calidad para su consumo. Se indica el proceso de ingeniería aplicado hasta obtener el sistema de control que interactúa en la celda y los resultados obtenidos comparando el grupo de control bajo condiciones ambientales normales y el cultivo en el cual se hace uso de la tecnología apoyada en Internet de las Cosas IoT, por su acrónimo en inglés – *Internet Of the Things*.

Palabras clave: celda de cultivo, internet de las cosas, hongos, temperatura, humedad, sistema automatizado.

1. INTRODUCTION

Nariño is considered an agricultural region based on smallholdings, where small farmers grow different varieties of products thanks to the variety of thermal floors in the department. However, sometimes due to climate changes, these crops are affected either by excessive heat or cold, causing the loss of at least 30% or more of the crop, generating economic instability for the farmer, their families, until starting again with a new crop whose harvest can take at least 4 months and that generates a rise in the prices of products. Faced with this situation and taking advantage of existing technology that allows the generation of crop cells and basically the *Pleurotus ostreatus* fungus, an automated control system has been developed to maintain the temperature and humidity required for cultivation in optimal conditions of the product in question, through the combination of electronics and IoT-based systems, it is possible to minimize the impact of climate on the crop and in turn ensure a quality product that when harvested allows ensuring the economic sustainability of small farmers dedicated to these crops.

To this end, use is made of an embedded system based on an Arduino Wi-Fi microcontroller, with Internet access, which can make decisions on the actuators to stabilize the temperature and relative humidity, key factors for obtaining a quality product.

The project therefore arises as a support from the technological point of view towards agriculture with social sense and with a low production cost that is accessible to those communities that wish to make use of this technology. Moreover, according to [1] to promote intelligence and automation in agriculture, it is a trend to apply IoT technology and any environmental monitoring system based on IoT can meet the requirements of fast, accurate and continuous measurement in precision agriculture, whose vision is what is intended to be addressed through the development of further research in this area.

This paper shows the results that have been achieved so far with the implementation of the system in a crop cell.

2. METHODOLOGY

For the design of the automated control system, the methodology based on software engineering called XP (*Xtreme Programming*) was applied, considered an agile development methodology, which defines the development stages according to [2] cited and adapted by [3] as follows:

● Phase I - System Requirements Analysis: During this phase, the control and management of a large amount of processes and information is required, for such reason, it is necessary to acquire sufficient information to determine all the functional requirements of the type of crop, the product to be cultivated and the cultivation cell, in addition to that information on the optimal conditions for the cultivation and harvesting process to be considered satisfactory and whose product has the minimum quality conditions for its commercialization.

● Phase II - Project Planning: With the requirements defined, the project is planned taking into account the guidelines established by the methodology to analyze and design the automated module, as well as the programming language to be used for both the interface and the system that generates the data.

● Phase III - System Design: From the previous phase, the designs of the system's web interface, the adequacy of the service that hosts the system, the design of the database and the definition of access policies are developed.

● Phase IV - Documentation: All the documents that provide support to both users and developers are generated; the final documentation includes the user's manual for the personnel training stage and the documentation of the expected results.

2.1. Phase I - System Requirements Analysis

For this stage, two sources of information were defined, the primary one through direct observation and interviews with specialized personnel on the cultivation of the Pleurotus ostreatus mushroom and it was found that the optimal environment for this crop is a temperature between 23 and 28 degrees Celsius, with a relative humidity above 90%, key information for the system to receive the data and if one of these parameters varies outside the normal range, an alert is sent and an electrovalve or the heaters are activated.

Another observation made in the field work is the inspection of the site where the cultivation cell will be located, in order to determine the characteristics of the radio link and thus ensure the optimal signal for sending data over the Internet. The second source of information called secondary takes as references some research on mushrooms, to determine alternative substrates as raw materials on which mushrooms grow, in addition to the above we have the datasheets of the Arduino PCB [4] and its Wifi components [5] and microcontroller [6], the DHT11 sensor and the 2-way relay [7], whose technical characteristics facilitate the connection scheme of each device for the design of the complete system.

Similarly, the autonomous robotic system for fire detection and extinction, presented by [8], was taken as a reference, where the importance of wireless communications in the operation of autonomous robots to safeguard the integrity of people is highlighted, in this case it is a reference point to make the system autonomous in decision making to control the variables that may affect the quality of the crop, as well as the remote monitoring of sensors and actuators.

Another important reference for the development of the project from the point of view of agriculture and IoT is the design of a monitoring system based on Internet of Things for an experimental farm, whose discussion and results are presented by [1], where an IoT architecture is presented from a layer of sensors that captures data from the environment, which pass to a second layer of communication, in which is the wireless communication system that for the case that concerns the project would be at the level of WLAN, The system will be hosted on the Internet to access the application layer where, through the mail and web servers and a database manager, the system will be remotely accessed by the end user of the system for control and monitoring purposes, although the system presented by the authors in their article is a network of sensors and ad-hoc wireless communications, it is possible to adapt the proposed architecture.

2.2. Phase II - Project Planning

With the information collected in the previous item, the control variables shown in the following table were defined:

***Table 1:** Variables to be controlled*

Variable	Unit	Minimum acceptable value	Maximum acceptable value
Temperature	°C	23	28
Relative humidity	%	90	98

***Source:** own elaboration*

It is necessary to keep in mind the IoT architecture, proposed by [9], which has the layers of perception, network and application, where the perception layer for this project is made up of temperature and humidity sensors that are located at various points of the crop cell and the device that receives the signal, the network layer, which allows to re-establish the connection between the IoT device and the Internet access through the local network by means of the radio link and finally the application layer, in which the user interacts through the web interface, presenting the data to the user that are stored in the database.

The sensor that allows obtaining the information of the variables to be controlled is the DHT11 or the DHT22, for the project the DHT11 is used, whose characteristics are available at [10]. Likewise, the PCB to be used was defined, in this case an Arduino Wi-Fi Demos R2 was chosen due to its cost and the signal coverage provided by the antenna.

The system is designed through a free tool for prototypes such as Tinkercad. It is also necessary to store the collected information in a database, visualize the records through a web-based system, implement a

communication system and an alert system when the control variables are outside the normal range, with these specifications we proceed to the next phase which is the design.

Apart from the above, it is necessary to have the planning for the link budget, this item is taken into account and developed in the next phase, taking into account the equations and the use of RadioMobile, which according to [11] is a free distribution software that allows designing Telecommunications networks composed of radio stations and predicting the behavior of the system by simulating the radio links to be established in it and according to [12] was developed by Roger Coudé and the program simulates the Radio Frequency propagation and is free to use and implements with good performance the Longley-Rice model, tropospheric prediction model for radio transmission over rough terrain in long-medium range links. In addition to having multiple utilities to support the design and simulation of telecommunication links and networks [13].

In the same way, the parameters to be introduced to perform the simulations allow to faithfully reflect the real equipment to be used in the installation for which they would be intended. RadioMobile uses for the evaluation of the links, the geographical profile of the working areas. These maps can be obtained directly from a software option that allows downloading them from the Internet. Three types of maps are available: SRTM, GTOPO30 and DTED [13].

Like the propagation model on which it is based, it allows working with frequencies between 20MHz and 40GHz and path lengths between 1 and 2000 Km.

2.3. Phase III - System design

For the design of the system there is an Arduino microcontroller device, with internet connectivity via WiFi, this device can be Arduino Wifi Demos R2 or the better known ESP3286, as mentioned above in the project the first one is used.

According to the information collected, the fungus requires in its incubation or cultivation stage a temperature ranging between 18 and 22 degrees of temperature, with a relative humidity of 95%, for this a digital DHT 11 sensor is used, which according to [14] has an accuracy of ±2.0 °C and a humidity range of 20% to 95% relative humidity with an accuracy of 4%. The sensor captures the surrounding air and temperature through a reading pin and is calibrated to provide approximate information with a minimum percentage error.

The system consists of two parts, the first is the electronic part, composed of a sensor and an actuator whose data is processed through the Arduino microcontroller, whose schematic is shown in Figure 1:

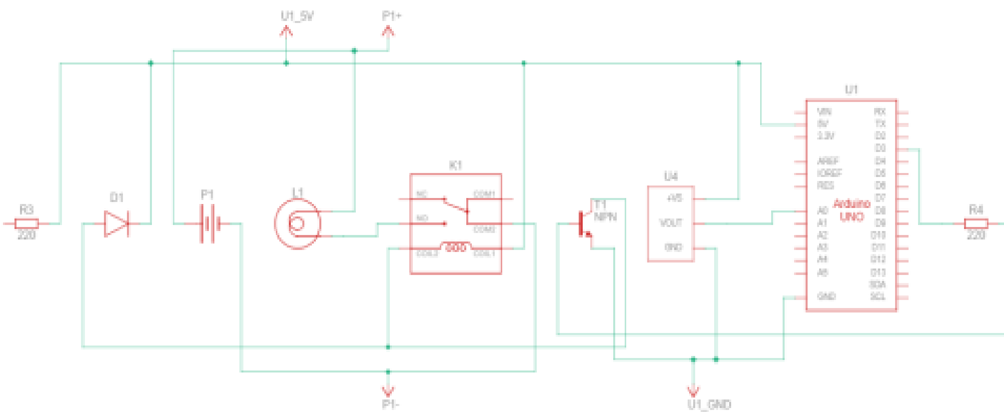

Fig. 1. *Scheme electronic part of the system.*
Source: *own elaboration.*

In the data acquisition process, these values are processed to determine the function of an actuator, which in this case is a relay, which upon receiving a signal activates the passage of energy so that the solenoid valve can be turned on in case an action is required to counteract the relative humidity or high temperatures or turn on the heaters in case the temperature is low.

The second part of the system is the software, developed in Arduino's own language for information processing, whose data is sent to a system through the internet, where it is housed in a database, this is done in order to graphically visualize the historical behavior of the relative humidity and temperature captured by the system throughout the day or month.

The database manager used is MySQL of free use and it is hosted in a hosting with an Apache web server that supports PHP as programming language for dynamic pages and the use of the plugin for graphics that is compatible with PHP.

Figure 2. shows the database design, which consists of an authentication system for tracking purposes and is composed of standardized tables.

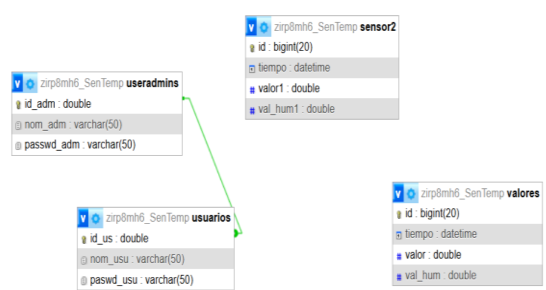

Fig. 2. *Database Scheme*
Source: *own elaboration.*

The system also has an alert system that warns the client of changes outside the range in the variables under study, for this purpose a free email is used, in this part it should be noted that the client must have active in his mobile device the mail application through which the message will arrive. According to the above, and taking as a reference the scheme of [15] on the design of a system with humidity, temperature and photo detection sensors, the flow diagram of the system is shown in Figure 3:

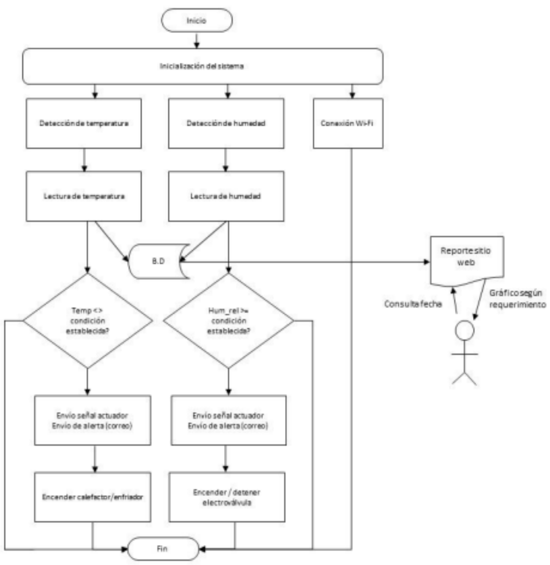

Fig. 3. *Automated system flow diagram and monitoring.*
Source: *own elaboration.*

As it is a system that requires an internet connection and due to the fact that the cultivation cell is located in a different place from the house, a wireless connection is needed that has line of sight from the place where the internet service is provided and a range with an optimal signal strength in the cell where the device is located. In case of being close, according to the Arduino datasheet, the receiving and sending data values are at the threshold of 18 dBm, at a frequency of 2.4 GHz with a distance range between 400 and 500 m in free space, according to the specifications [5] therefore, if connectivity cannot be achieved with the conventional router that the user at home, it would make use of a radio link, through which signal coverage can be guaranteed, for

the project carried out, the location was taken into account in the village of Obonuco whose geographical coordinates are: 1.1887651 north latitude and 77.3073162 west longitude, and with the field visit the location of the house and the crop is located more precisely and the radio link is calculated.

For the calculation of the radio link, use is made of the Radio Mobile software, parameterized with the frequency and power data of a Loco M5 nanostation radio, whose specifications are available at [16], being a low-cost solution with good range and taking into account the recommendations of [17] on the design of a system at the level of reliability, line of sight, design of the communications system. The geolocation data of the radio link between the site where the Internet connection is located and the cultivation cell can be seen in Figure 4:

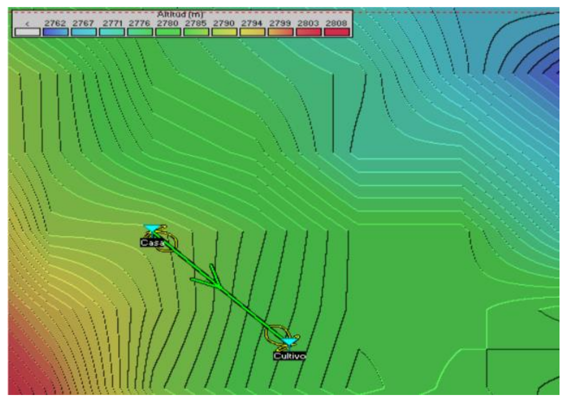

Fig. 4. *Geolocation of the radio link.*
Source: *own elaboration.*

At the site where the system and the cultivation cell are currently located, the use of the radio link was necessary, using the equation of the link budget quoted by [18] indicated in (1)

$$\text{Pot Rx[dBm]} = \text{Pot Tx[dBm]} + \text{Ganancias[dB]} - \text{Pérdidas[dB]} \tag{1}$$

To find the values of (1), it is necessary to break down the gains and losses in a radio link, for this purpose use is made of (2), mentioned by [19]

$$P_{Rx} = P_{Tx} - L_{Tx} + G_{Tx} - L_P + G_{Rx} - L_{Rx} \tag{2}$$

For the project the radio link seeks to expand the WiFi coverage radius and as indicated in Figure 4, it is not a great distance, but it is required to improve the signal quality to avoid attenuation and losses in free space, therefore, no losses are considered in connectors or in the line, since the antenna height does not exceed 3 m, therefore: $L_{Tx} = 0.5$ and $L_{Rx} = 0.5$. The antenna gain of the radio is 13 dBi and the output power of the radio, with a value of 23 dBm according to [16], the antenna gain of the

Arduino Wifi antenna according to [5] is 3 dB. For the free space loss is calculated in (3):

$$L_P = 20 \log_{10}(d) + 20 \log_{10}(f) + K \tag{3}$$

Since the radio frequency is 5.8 GHz and the distance is 180 m, then K = 92.4 gives (4):

$$L_P = 20\, log_{10}(0.18) + 20\, log_{10}(5{,}8) + 92.4 = 92.77 \tag{4}$$

With the above data, the value of the power or sensitivity in the receiver can be calculated taking as reference (1) and calculated in (5):

$$\text{Pot Rx[dBm]} = 23 + 13 + 3 - 93.29 - 0.5 - 0.5 = -54.77 \tag{5}$$

The solution of the equations and results presented are compared with the calculations made with the help of RadioMobile, which are presented in figure 5:

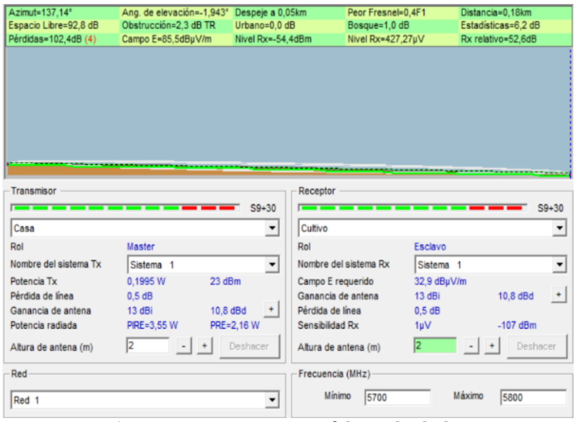

Fig. 5. *Parameterization of the radio link.*
Source: *own elaboration*

As can be seen, the values found are similar from the mathematical and software perspective, therefore, we proceed to configure the radio link in this way, ensuring the availability and quality of the Internet signal.

At the level of the web-based system for visualization of graphs and records, its friendly, simple and intuitive interface allows the farmer with basic knowledge in the use of the Internet to enter the system with his credentials and monitor the crop cell. Figure 6 shows the interface that is presented to the farmer so that he can verify the behavior of the system in his crop, once he enters with the access credentials, which are the identification and a password:

Fig. 6. *User interface for system monitoring and verification.*
Source: *own elaboration.*

2.4. Phase IV - Documentation

For this phase of the project, the system user's manual was delivered, taking into account that the user is a farmer, a minimalist design was made, based on the simplicity of the system that is easy to use for him, likewise the system manual was delivered and the necessary support is provided for 6 months, accompanying the people involved in the project.

3. RESULTS

The system in the prototype showed an adequate monitoring of the temperature, at the date in which the results are delivered, the effects of the climate are not considered very far from the acceptable condition and in some cases it sent the alerts, together with the required actuator activation, being the most used the activation of the electrovalve. The temperature record at 2800 meters above sea level where the culture cell is located is shown in Figure 7:

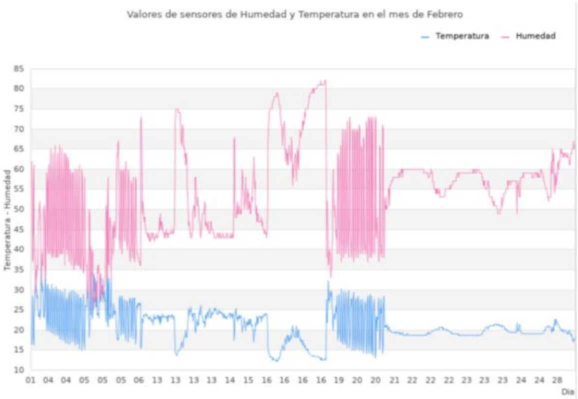

Fig. 7. *Temperature and humidity records in the month of February in the incubation process.*
Source: *own elaboration.*

Figure 8 shows the records in the fruiting process, showing that the differences are significant because the temperature and humidity values are different between the two culture chambers. It is also evident that thanks to the automatic control system, it is possible to stabilize the variables when there is a difference in the temperature or humidity range, since the system captures the values every 10 minutes, enough time to take the necessary corrective measures in case of low or high temperature that may affect the crop, as well as the percentage requirement of humidity.

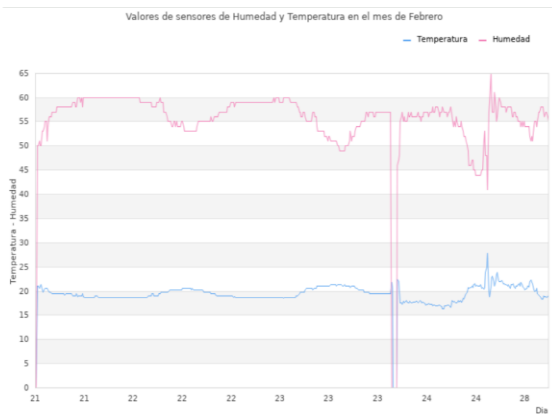

Fig. 8. *Temperature and humidity records in February during the incubation process.*
Source: *own elaboration.*

Figures 9 and 10 show that the humidity parameter did not reach the desired threshold in the first two months, this is due to the fact that various irrigation mechanisms were used to counteract the necessary humidity, as well as the calibration of the electrovalve.

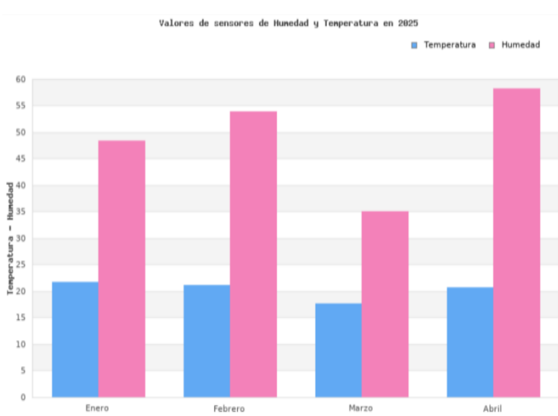

Fig. 9. *Average temperature and humidity records between January and April during the incubation process.*
Source: *own elaboration.*

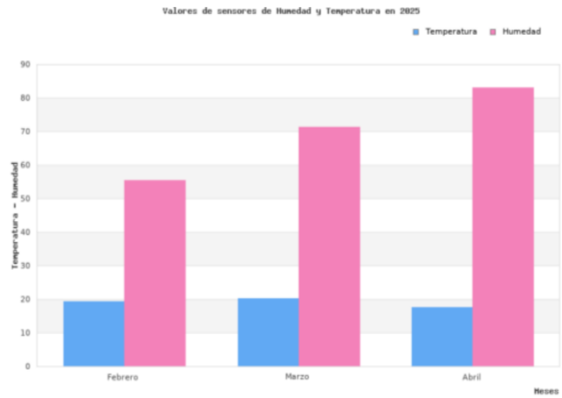

Fig. 10. *Average temperature and humidity records between January and April in the fruiting process.*
Source: *own elaboration.*

These values are presented in Table 2:

Table 2. Average temperature and humidity during the incubation and fruiting stages.

Stage	Month	Temperature	Humidity
	January	21.7	48.42%
Incubation	February	21.17	53.81.%
	March	17.7	24.99%
	April	20.67	58.2%
	February	19.27	55.3%
Fruiting	March	20.19	71.18%
	April	17.61	83.07%

Source: *own elaboration.*

The system at the humidity level was evaluated, including scenarios of high temperature generated by heaters and low irrigation pressure, where the reading for a random day is shown in Figure 11 and the effect produced when it is regulated after some time thanks to the automation:

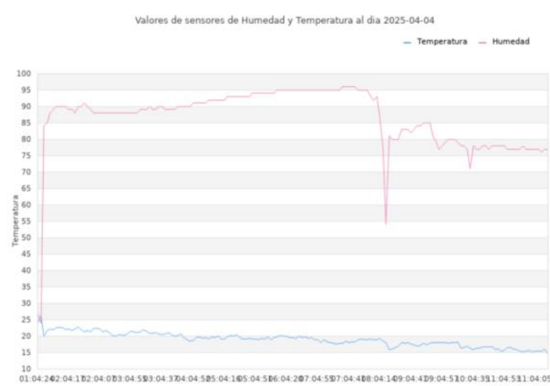

Fig. 11. *Daily temperature and humidity records with intentional variation of parameters.*
Source: *own elaboration.*

It can be seen that the system seeks to recover the parameterized state as soon as possible, those peaks with low values indicate the existence of an external factor such as heaters, activated intentionally to measure the system response, and in the case of values between 75 and 80, indicate that despite having a low water supply to the solenoid valve, the system seeks to compensate the action of the high temperature, protecting the crop, as long as there is water supply, as well as the system sends a message to the registered mail, in order to alert the variation outside the established parameters as shown in Figure 12.

***Fig. 12**. Alert sent from the project's email to the user.*
***Source:** own elaboration.*

By regulating the variables that affect the crop, it was possible to improve the efficiency of the germination and fruiting processes, reducing the time of 2 days for germination and 4 days for fruiting, without affecting the quality of the product. Water consumption is reduced by activating irrigation by means of an electrovalve, with adequate pressure, supplying the necessary amount of water so as not to waste the precious liquid.

The results obtained can be taken as a contribution to the development of intelligent agriculture, an alternative that [20] in its study concludes as a solution to the challenges faced by the food industry due to the growing demand for food production, the decrease in rural labor and the increase in production costs.

On the other hand, it was shown that implementing an automated system in small agriculture, besides being an innovative solution, allows to obtain better results in crops, minimizing some risk factors such as climate change, counteracting its effect with actuators that compensate in this case the temperature or humidity, but applicable to other factors that may be present, as stated by [21] "currently, the implementation of various wireless sensors and IoT sensors has led to numerous innovations for crop improvement. These new emerging technologies address a variety of traditional crop problems, such as disease management, efficient irrigation, cultural practices and drought response."

4. CONCLUSIONS

The temperature and humidity monitoring and control system for a Pleurotus ostreatus cultivation cell improves the quality of life of farmers who choose to implement these mushroom cultivation cells, since they do not have to be aware of weather variations, especially if the distance between home and cultivation is considerable, as well as avoiding the interruption of their rest, when phenomena such as frosts are approaching.

Being systems susceptible to failures, it is necessary to take preventive measures, therefore, the user of the system is sent an alert in order to verify proper operation of the same in case of reading parameters outside the normal range and thus can have a manual control in case it is deemed necessary.

The intelligent control and communications system for small cultivation cells based on the Internet of things, allows collecting, processing and controlling the temperature and humidity in the cultivation space in real time according to the variability of the two factors that can affect the quality of production and sending data via Wi- Fi in real time, in addition to monitoring and keeping the user or farmer informed about the temperature data and relative humidity in the cell through alerts to email and on the website with access from any device with a browser and internet connection ensuring real-time monitoring.

The application of the intelligent control system of a cultivation cell for Pleurotus ostreatus mushroom improves work efficiency for the farmer and offers a guarantee to obtain the desired results in the harvest.

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