# Environmental variables monitoring system and irrigation control in a greenhouse (RIO)

# Sistema de monitoreo de variables ambientales y control de riego de un invernadero (RIO)

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**Abstract**

The waste of water in recent years in the world has been increasing drastically, such is the case of the irrigation systems of the different crops that exist in addition to the multiple conditions where they are operating either in the open field or in a greenhouse. 70% of the water used in Mexico is destined for agriculture where 60% of this destined water is wasted by irrigation systems either by infiltration or evaporation. In Guanajuato the construction of greenhouses throughout the state is very common with different crops. The main objective of the project is to reduce the consumption of water in the irrigation systems, as well as to reduce their operating costs. To achieve the goal, an embedded system will be developed using microcontrollers, which will measure the greenhouse temperature at different points and through radio frequencies, a multipoint network will be created implementing xbee modules where the temperatures obtained will be sent to a central device which will process the information and activate irrigation automatically. To achieve this, techniques such as serial communication, analog-digital conversion, multiplexing, data analysis will be used.

**Embedded system, Multiplexing, Micrcontrollers, Irrigation**

**Resumen**

El desperdicio de agua en los últimos años en el mundo ha ido aumentando de manera drástica, tal es el caso de los sistemas de riego de los diferentes cultivos que existen además de las múltiples condiciones en donde estos están operando ya sea a campo abierto o en un invernadero. El 70% de agua que se utiliza en México es destinada a la agricultura donde el 60% de esta agua destinada es desperdiciada por los sistemas de riego ya sea por la infiltración o evaporación. En Guanajuato la construcción de invernaderos a lo largo y ancho del estado es muy común con diferentes cultivos. El principal objetivo del proyecto es disminuir el consumo de agua en los sistemas de riego, así como, reducir costos de operación de estos para lograr la meta se desarrollará un sistema embebido empleando microcontroladores, los cuales medirán temperatura del invernadero en diferentes puntos y a través de radiofrecuencias se creara una red multipunto implementando módulos xbee donde la cual las temperaturas obtenidas serán enviadas a un dispositivo central el cual procesará la información y activara el riego de forma automática. Para lograr esto se emplearán técnicas como comunicación serial, conversión análogo-digital, multiplexación, Análisis de datos.

**Sistema embebido, Riego, Multiplexaxión, Microcontroladores**

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## Introduction

The Gran Bajío is a region of great socio-economic stability. Its fertile land supplies almost one third of the total production value of Mexico's most important vegetables. Among the states that make up the Gran Bajío, we find Guanajuato, which is why the main focus is on plants of this type. As living beings, plants need water to live. Crops absorb nutrients from the soil and perform various physiological functions in the presence of water. Irrigation is one of the activities in which much more water is wasted according to INEGI.

One of the main problems in a traditional irrigation system is the irrational use of water, which leads to water shortages in the area, with the consequence that the crops can be affected because the excess of water and the effect of high temperatures cause the asphyxia of the roots and eventually the death of the crop.

The irrigation system does not depend on different factors such as the type of soil and crop, water needed and economic resources, irrigation not only involves the cost of installation but also its maintenance. RIO aims to be water efficient and to reduce operating costs.

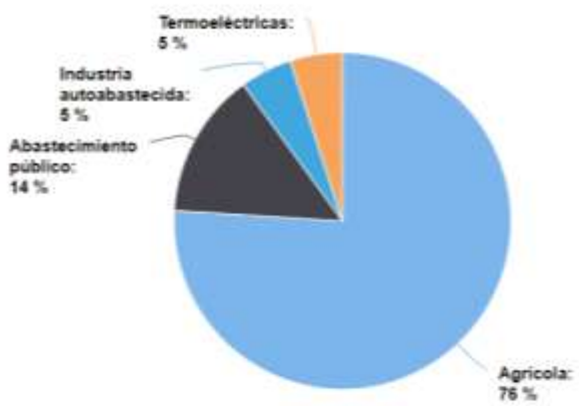


**Figure 1** CONAGUA. Water Statistics in México 2018
*Source: https://www.gob.mx/conagua*

## 2. Materials

For the development of the project, all the materials to be used were carefully and carefully chosen through research and comparisons previously carried out and documented and in this section the materials that will be used in RIO are presented.

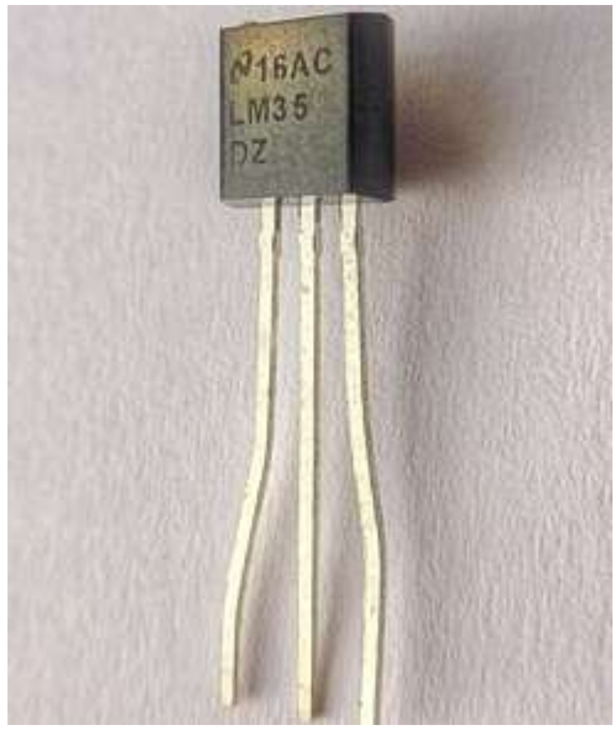


**Figure 2** Lm35 sensors
*Source: https://es.wikipedia.org/wiki/LM35*

Figure 2 shows one of the three sensors to be used, in this case the LM35 analogue sensor.

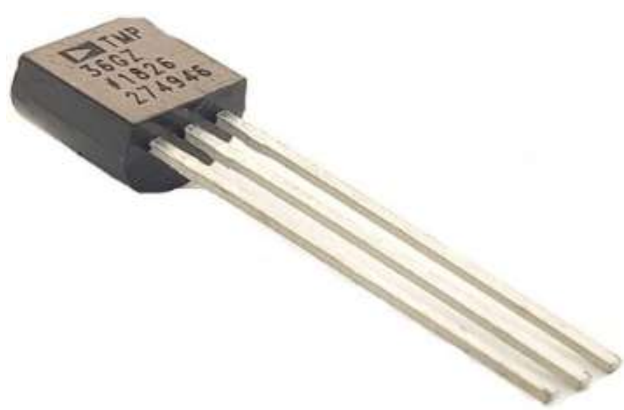


**Figure 3** TMP36 sensor
*Source:https://electronicaqueretaro.mercadoshops.com.mx/MLM-763963732-sensor-de-temperatura-tmp36-integrado-tmp36gz-5-piezas-_JM*

It is possible to appreciate the TMP36 analogue sensor in figure 3, another of the sensors with which the project will be developed.

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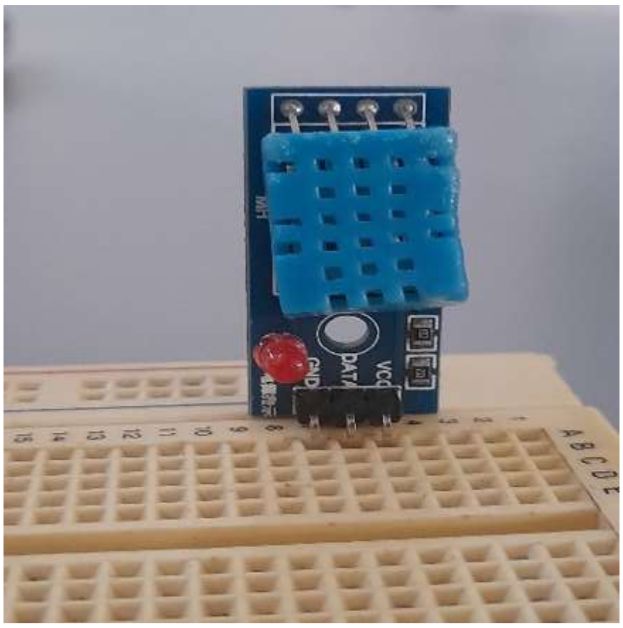


**Figure 4** DHT11 Sensor
*Source: Own Elaboration*

Figure 4 shows the third sensor to be used which is the temperature and humidity sensor dht11 where, unlike the previous sensors which are of the analogue type, this sensor is of the digital type.

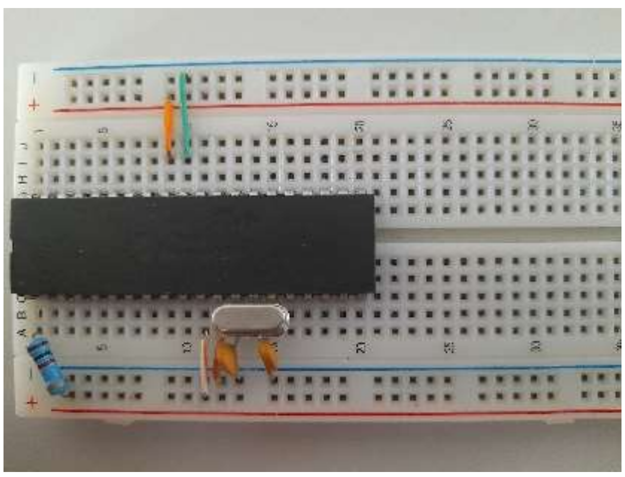

**Figure 5** PIC 16F877A Microcontroller
*Source: Own Elaboration*

Figure 5 shows the PIC 16f877a microcontroller with which the project will be developed for information processing and automation.


**Figure 6** XBEE S2B Radio Frequency Module
*Source: https://xbee.cl/xbee-pro-zb-s2c-th/*

For the wireless transmission of the environmental information of the greenhouse, the XBEE SERIES 2 radio frequency modules will be implemented, which can be seen in figure 6.

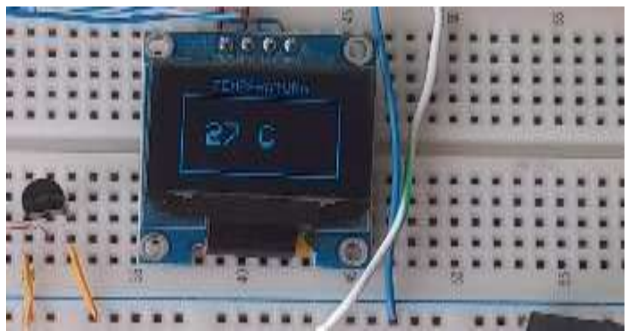


**Figure 7** i2c Oled display
*Source: Own Elaboration*

Figure 7 shows an oled screen which will be used to display the measurements that the plates inside the greenhouse are measuring by means of the sensors and the microcontroller.

**Figure 8** Oscillator
*Source: https://ipowerelectronics.com.mx/cristal-oscilador/1775-cristal-oscilador-de-cuarzo-mini-de-110592-mhz.html*

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In order to give a correct synchrony to the operations that the microcontroller is performing, it is necessary to implement an oscillator which will give enough synchrony and which can be seen in figure 8.

## Methodology

*Embedded System*

For the operation of the project an embedded system will be developed using microcontrollers, in this case we will be working with PIC microcontrollers. This will be in charge of information processing and irrigation automation when necessary**.**

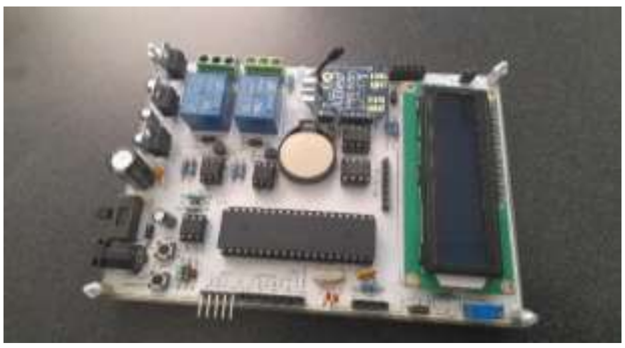

**Figure 9** Embedded System
*Source: https://doi.org/10.35429/jtp.2020.18.6.18.29*

In order to develop the embedded system it is necessary to create a block diagram, according to the characteristics of the microcontroller with which we are working in order to identify the resources that the system will have.

The first block indicated as RA5 refers to this port of the microcontroller on which the sensors will be used to activate the optical coupling in order to activate the irrigation pump according to the established parameters.

In order to carry out the measurements of the analogue type sensors, the ADC block refers to the converter (Analogue Digital) on which these sensors will be read.

## Formulas for reading temperature

Formula for calculating the resolution

$$\text{Res}= \frac{\text{Vref}-\text{Gnd}}{1024} = \frac{5\text{V}-0\text{V}}{1024} = 4.8mv \quad (1)$$

## Voltage to bit conversión

$$\text{Res}= \frac{\text{RV}*1024}{Vref} = \frac{0.21\text{v} * 124}{5} = 43.00\ bits \quad (2)$$

## Bit to temperature conversión

$$\text{Temp}= 100.0 * Vref\left(\frac{Bits}{1023}\right)$$

$$\text{Temp}= 100.0 * 5.0\left(\frac{43.00}{1023}\right) = 21.01 \quad (3)$$

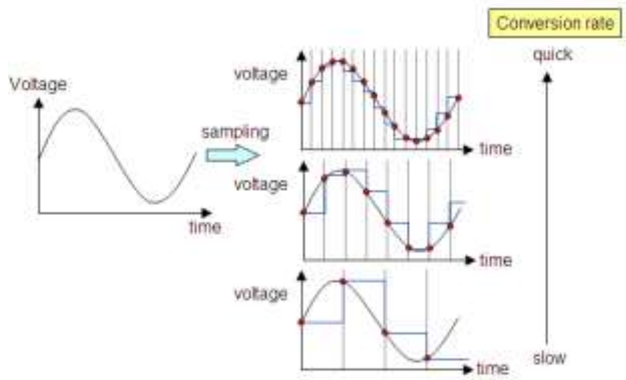


**Figure 10** Analogue-to-digital signal conversion
*Source: Analog-to-digital (A/D) conversion. Automatic Control Education*

The RC0-RC1 block is intended for the power circuit which will make use of the relays in order to make use of the alternating current for irrigation when necessary.

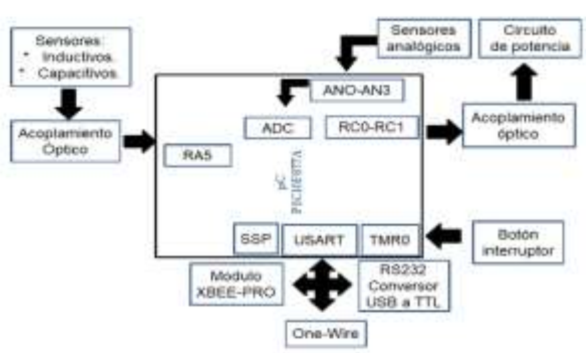


**Figure 11** Block diagram of the wireless electronic card for monitoring and control
*Source: https://doi.org/10.35429/jtp.2020.18.6.18.29*

In order to wirelessly transmit the collected information, the XBEE PRO MODULE is destined to the resources and protocols that the xbee module will be using, which, by means of the uart, ssp, rs232, will transmit the data in a multiplexed way and will also be in charge of creating the multipoint network.

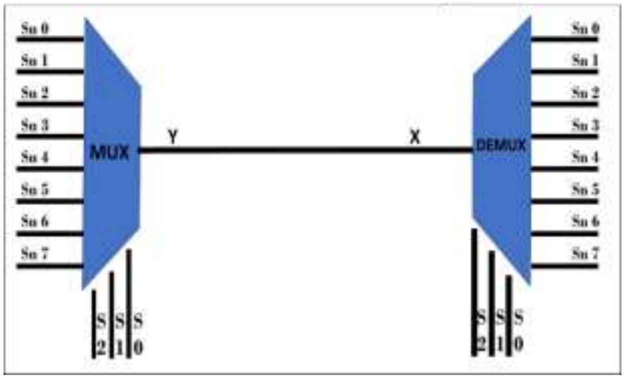


**Figure 12** 7-to-1 multiplexing diagram
*Source: Own Elaboration*

In order to transmit information from different sensors, multiplexing of sensor values will be implemented.

### Printed Circuit Board

As part of creating the multi-point network to be implemented within the irrigation system, several cards will be strategically created to measure temperatures at different points in the greenhouse.

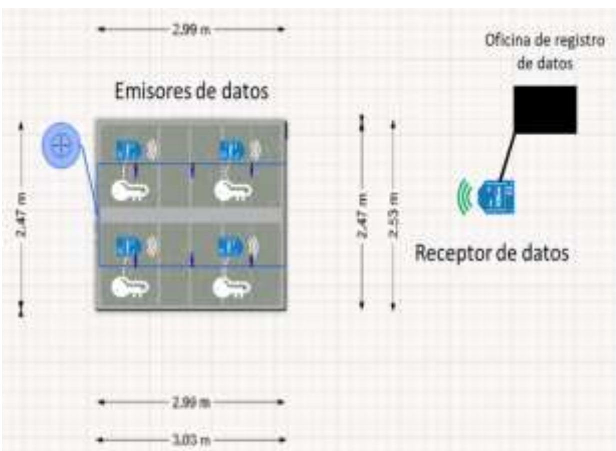


**Figure 13** Greenhouse network topology
*Source: Own Elaboration*

In order to develop the cards that will make up the multipoint network, the first step is to identify the elements with which these cards will be working, after identifying these components it is necessary to measure each and every one of the components with a vernier, to avoid that the pads are not of the correct size or that the footprints of the components are not the right ones.

| Compponent | Long | Width | Separation | Total, of pins |
|---|---|---|---|---|
| DC JACK | 1.9 cm | 9 mm | 6 mm | 3 |
| LED display | 2.2 cm | 2.8 cm | 2 mm | 4 |
| Oscillator Crystal | 8 mm | 6 mm | 2 mm | 2 |
| XBEE PRO Module | 32.94 mm | 22.00 mm | 0.079 mm | 20 |

**Table 1** Measurements of components to be used
*Source: Own Elaboration*

### Interface

In order to monitor the data that is being collected inside the greenhouse and also to store it, an interface was developed to be able to appreciate these points. Taking into account the requirements to be implemented.

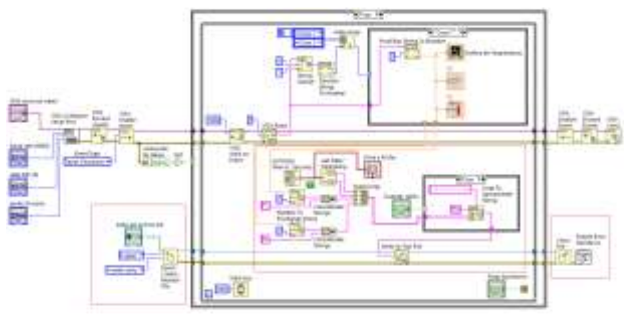

**Figure 14** Interface Block Diagram
*Source: https://doi.org/10.35429/jtp.2020.18.6.18.29*

### Results

### Sensors

In order to select the best sensor to implement within the project, tests were carried out on the previously mentioned sensors under the same conditions in order to gather information and carry out the relevant studies and thus determine which sensor is best suited to the project.

**Figure 15** Sensor measurement inside the greenhouse point a
*Source: Own Elaboration*

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As part of the tests carried out on each of the sensors, these were put to the test in different parts of the greenhouse in order to analyse the behaviour and precision at different points and thus determine the most suitable sensor.

**Figure 16** Sensor measurement inside the greenhouse point b
*Source: Own Elaboration*

## Embedded System

### Communication Tests

Based on the information gathered from the sensors and choosing the most suitable sensor for the project, the communication between two microcontrollers was implemented to verify the connectivity and efficiency of the xbee modules. Before transmitting information serially by implementing the XBEE radio frequency modules, the first wired tests were carried out to verify the functionality of the circuit.

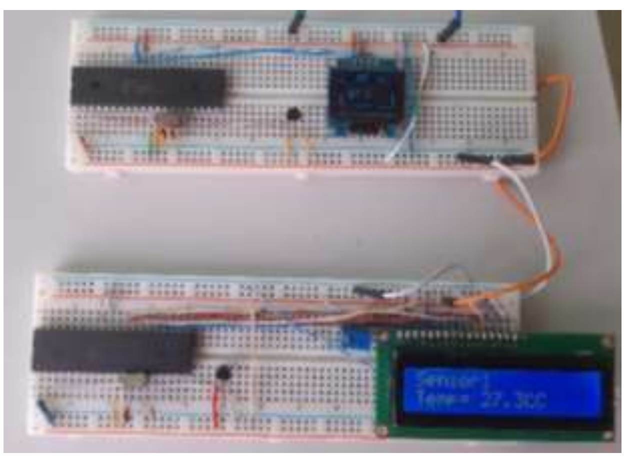

**Figure 17** Wired data transmission
*Source: Own Elaboration*

Figure 17 shows the sending of information from a sensor (LM35) from a transmitter to a receiver. It is worth mentioning that this test was only carried out with data from one sensor and for the following tests the signals from more sensors will be multiplexed.

Having verified the wired communication of the microcontrollers, we moved on to the wireless transmission of the information by implementing the xbee radiofrequency modules.

**Figure 18** Data transmission using xbee TRANSMITTER-RECEIVER modules
*Source: Own Elaboration*

As can be seen in figure 18, tests were carried out to send information wirelessly by implementing the xbee modules. This communication was only a transmitter and receiver, later on we intend to extend the topology.

### Sensor analysis

Once the sensors had been tested, the next step was to analyse and study the behaviour of the sensors by means of graphs generated from this data.

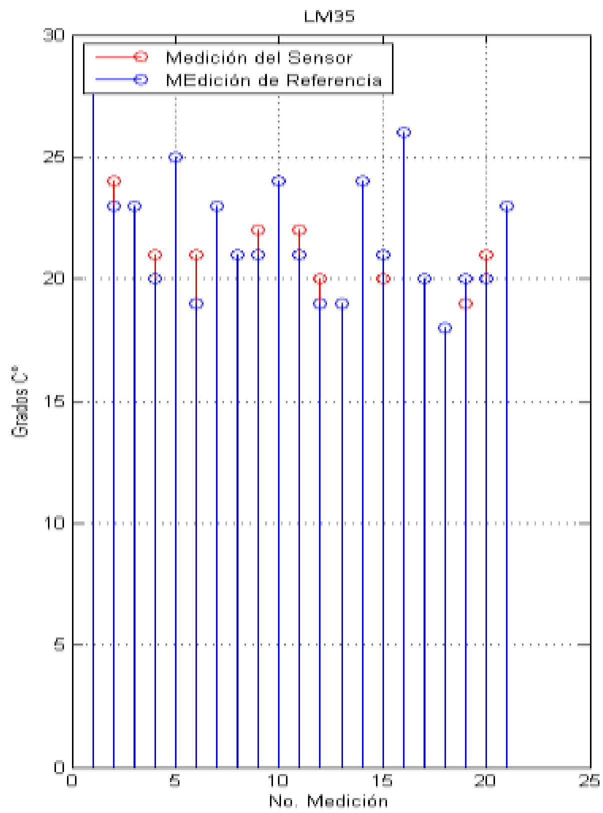


**Figure 19** Graph of the LM35 sensor behaviour
*Source: Own Elaboration*

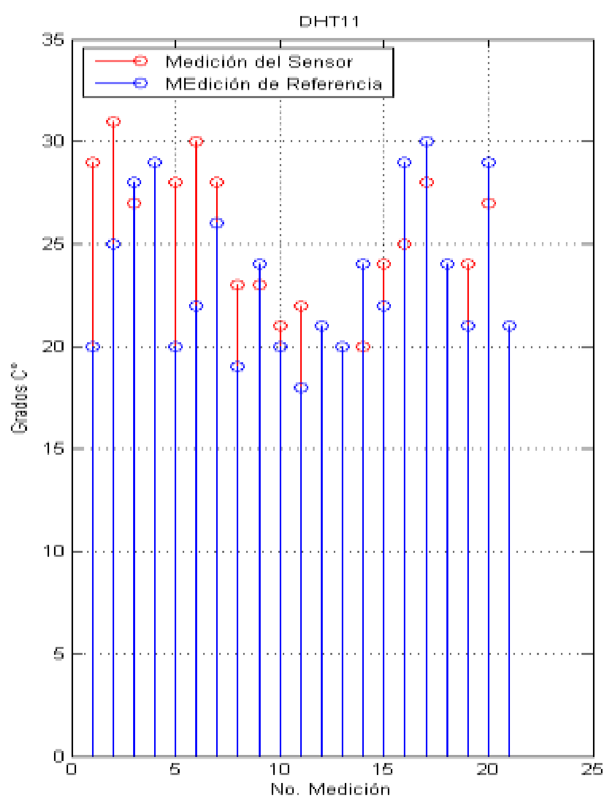


**Figure 20** Graph of the DHT11 sensor behaviour
*Source: Own Elaboration*

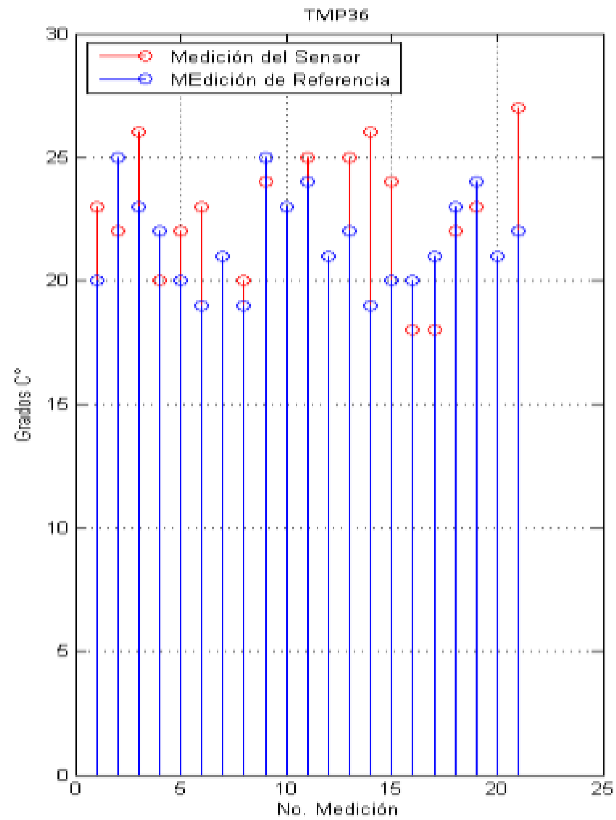


**Figure 21** Graph of the TEMP36 sensor behaviour
*Source: Own Elaboration*

In order to analyse the behaviour of the sensors through the graphs resulting from the data collected, it was decided to implement the LM35 sensor in the development of the project, in figures 19-21 it is possible to appreciate the graphs of the behaviour of the sensors.

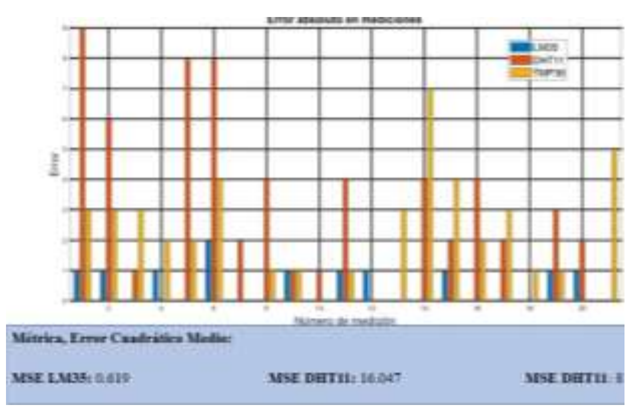

**Figure 22** Sensor error graph
*Source: Own Elaboration*

In addition to the study of the behaviour of each of the sensors that were implemented, the margin of error of each sensor was studied and the values of the different parameters are shown in Figure 22: Metric, Error, Quadratic Error, Mean Error, Mean Error.

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**Graphical interface**

Based on the block diagram shown above in the methodology section, we proceeded to develop the graphical user interface (GUI) for the embedded system in order to monitor the data acquired from the greenhouse and store it in a database for later analysis.


**Figure 23** View of the interface developed
*Source: Own Elaboration*

In figure 23 it is possible to observe the developed and working interface, which is receiving and displaying in graphs the data of the environmental variables sent by a microcontroller through the xbee pro module.

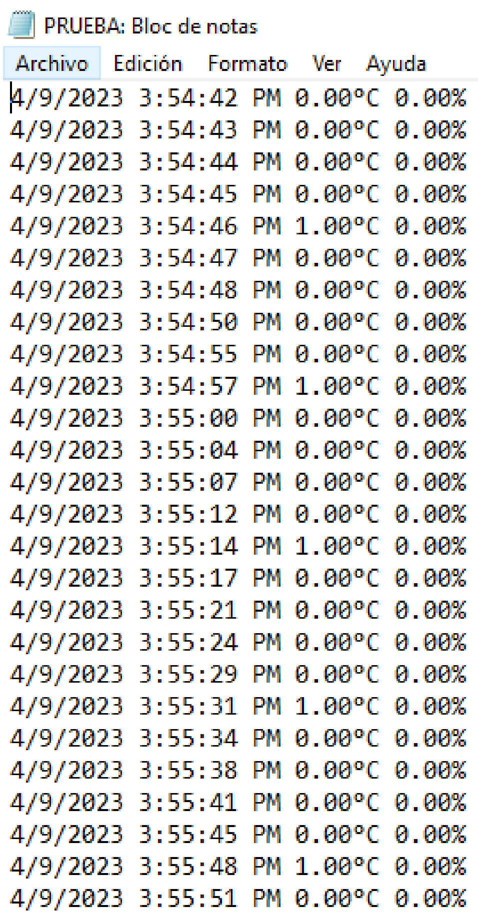
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**Figure 24** Data stored in a file through the developed interface
*Source: Own Elaboration*

**Development of the Embedded System**

Having obtained the measurements of the components to be used in the boards, we proceeded to the development of the pcb (Printed Circuit Board) with the help of electronic design software. First of all, the schematic design of the circuit to be developed must be created and then the corresponding footprints must be assigned.

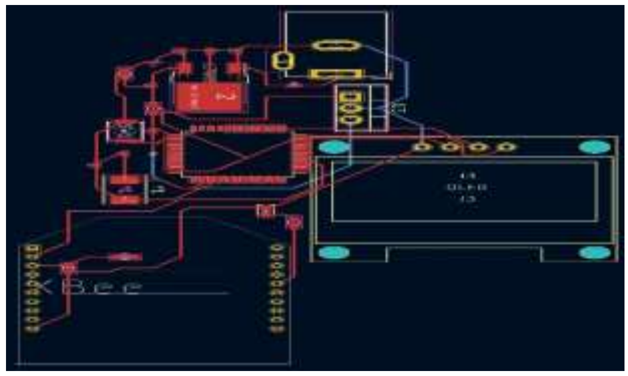

**Figure 25** Schematic diagram of the pcb
*Source: Own Elaboration*

Once the footprints had been assigned to the circuit components, the next step was to develop the component connections. It is worth mentioning that the components we are working with are surface mount.

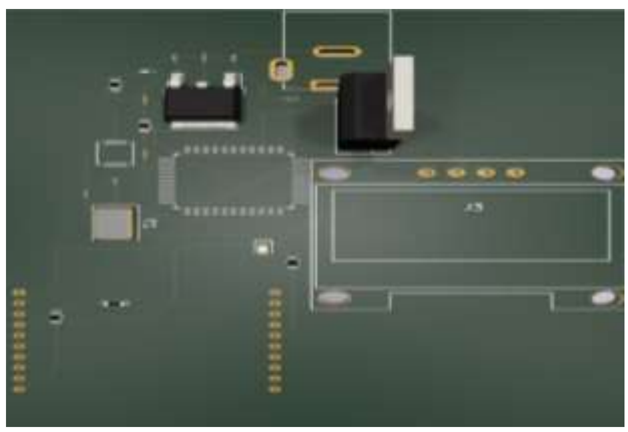

**Figure 26** 3D view of the final design of the pcb
*Source: Own Elaboration*

Figures 25-26 show the design of the pcb using surface mount technology.

**Broccoli and lettuce crops obtained**

While this article was being developed, plants were sown and transplanted from a tray where they germinated to the soil for their subsequent growth.

**Figure 27** Germinated lettuce plants in a tray
*Source: Own Elaboration*

**Figure 28** Lettuce plants transplanted into the ground
*Source: Own Elaboration*

## Conclusions

The implementation of the card inside a greenhouse allowed temperature measurement tests to be carried out at different points, so obtaining the graphs for the different sensors will allow comparison between sensors, at the same time it will help in choosing the best position inside a greenhouse for the chosen sensor, it is important to look for a sensor calibration and place from the statistics and obtaining the error, as well as knowing the behaviour of the electronic card with the different sensors and the data transmission error through Xbee, so the test has been successful in all senses.

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