Design and implementation of an electronic system to monitor and record agroclimatic variables in greenhouses

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ABSTRACT

Objective: To describe the development of a low-cost electronic device that can monitor, track, record, store, export, and interpret climatic variables of greenhouse-produced crops.

Methodology: An Arduino UNO board was used, along with specific sensors, to measure the agroclimatic variables under study. A Raspberry Pi® 3B+ board was also used to store and export the recorded information. The previously assembled device was installed in a greenhouse located in San Agustín Calvario, municipality of Cholula, Puebla, from March to July. Finally, graphs were developed to interpret the variables according to the agroclimatic requirements of native cucumber.

Study Limitations/Implications: Greenhouses must have access to an electrical supply, regardless of their geographic location or the crop they produce.

Findings: A low-cost electronic system and device were successfully developed, allowing each sensor to monitor, record, store, and export the following agroclimatic variables: minimum and maximum temperature, relative humidity, carbon dioxide (CO_2) concentration, and light intensity in a greenhouse with electrical supply. Regarding data interpretation, graphs were developed for the agroclimatic variables in the greenhouse, based on the needs of the native cucumber plant.

Keywords: protected agriculture, weather station, hardware, software.

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INTRODUCTION

According to the November 2022 census of the United Nations, the global population reached 8 billion people, which involves an increasing demand for abundant, quality, and varied food [1]. Meanwhile, climate change has caused an increase in the demand for food, which has resulted in uncertainty regarding rainfed crops. Therefore, a search to increase the safety and volume of greenhouse food production has begun.

Simultaneously, recent technological advances have made it possible to replace the rigid structure of traditional systems with a more flexible one, supported by computing, conditioning circuits, data transmission, and data acquisition hardware and software [2]. One of the most significant technological advances in the evolution of electronics has been automation and agriculture is one of the areas it has had a major impact on [3].

Greenhouse crop production stands out among the techniques currently used in agricultural production. This recently-developed technique enables the cultivation of crops out of season and during the winter, without the risk of the plants dying due to low temperatures [4].

In order to address this situation, the crop area in protected agriculture must be increased to face decisive situations for crop growth —such as higher temperature, light intensity, relative humidity, and a greater water requirement—, all of which must be managed within optimal ranges [5]. Several efforts have been made to manage agroclimatic variables [6].

Consequently, the objective of this research was to design a low-cost electronic system for the recording, storage, and export of data on the agroclimatic variables with the greatest impact on crops grown in non-technified greenhouses that nonetheless have electric power.

MATERIALS AND METHODS

This section describes the main components used in the construction of the monitoring system. It also explains in detail the design and development of the software used to monitor the variables in the greenhouse, covering everything from the code to the connection of the components.

Design of the monitoring system and data collection

The goal of this project was to build a system that could monitor the agroclimatic variables that affect crops. For this purpose, a Raspberry Pi® 3B+ board was used as the interface. An Arduino UNO board was employed as data collection nodes. Both devices allow the acquisition and storage of data about various agroclimatic variables. The variables were selected based on their importance for the growth and development of crops during the operation of a greenhouse. The following variables were taken into consideration: maximum and minimum temperature, relative humidity, light intensity, and carbon dioxide concentration. Table 1 shows the measuring instruments used and their costs as of 2022.

Circuit Assembly

The circuit assembly is defined by the presence of a solderless breadboard. Jumper wires were used to connect the breadboard, the sensors, and the Arduino UNO board. Additionally, the sensor connections were made as follows: the signal pin of the DHT22 sensor was connected to the Arduino board's digital input module. The same procedure was made with the BH1750 sensor, which is also digital. The capacitive humidity sensor —which is an analog sensor— was connected to the analog input module. Finally, the two communication pins of the MH-Z19 sensor were connected to the digital inputs.

Table 1. Electronic components costs.

Equipment	Cost/Unit (USD)
DHT22 temperature and relative humidity Sensor	3.00
BH1750 light intensity Sensor	2.00
MH-Z19 CO_2 Sensor	40.00
Soil moisture Sensor %	10.00
Arduino board	27.00
Raspberry 3B+ board	35.00
Touch screen for Raspberry pi 3B+	12.00
Total	129.00*

*Prices in USD, calculated at an exchange rate of $20.00 MXN per dollar.

Figure 1. shows the sensors connected to the assembled circuit. The connection between the Arduino board and the Raspberry 3B+ board, which is done via a USB cable, is not included.

Programming phase

The programming environment used for the Arduino UNO board is found in the Arduino platform. Regarding the Raspberry Pi® 3B+ board, various programming languages are typically used, but Python was chosen for this study. The first part of the programming was done with the Arduino UNO board. The libraries for the sensors were included, because they are essential for their operation (Step 1, Figure 2). The Wire library was used for the BH1750 sensor, because it works through the I2C bus.

Meanwhile, the uart library was used for the MHZ19 sensor, because it works through the UART bus, which consists of two communication lines (TX and RX). Variables were declared to store the data obtained from each sensor (Step 2, Figure 2). The sensors were subsequently initialized (Step 3, Figure 2). In the final stage, the data obtained by the sensors was printed through the serial port. A 10-minute delay (sampling time) was defined. For the lines of code which manage data printing through the serial.print function, the values

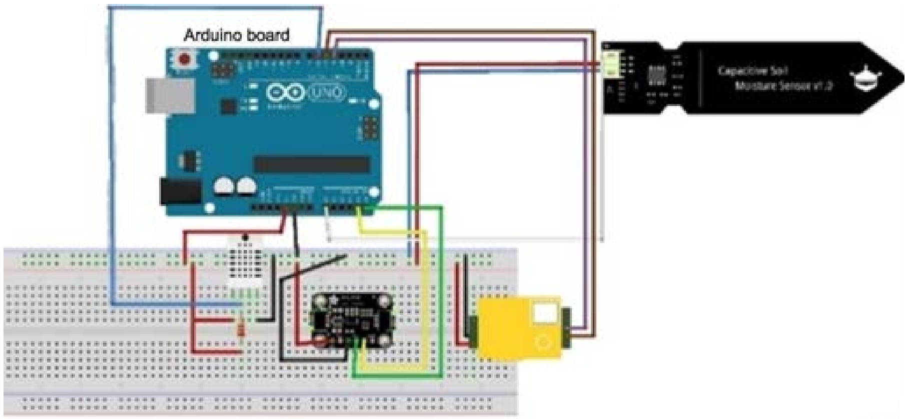


Figure 1. Sensor connections to the Arduino board.

Step 1

```
#include "DHT.h"
#include <BH1750.h> // incluye libreria BH1750
#include <Wire.h> // incluye libreria para bus I2C
#include <MHZ19_uart.h>
```

Step 2

```
#define DHTPIN 6
#define DHTTYPE DHT22   // DHT 22  (AM2302), AM2321
const int rx_pin = 5; //Serial rx pin no
const int tx_pin = 4; //Serial tx pin no
const int dry = 563; // valor del sensor seco
const int wet = 214; // valor del sensor mojado
int temperatura, humedad;
DHT dht(DHTPIN, DHTTYPE);
BH1750 sensor;    // crea objeto con nombre sensor
MHZ19 uart mhz19;
```

Step 3

```
void setup() {
  Wire.begin();   // inicializa bus I2C
  sensor.begin(); // inicializa sensor con valores por defecto
  Serial.begin(9600);
  mhz19.begin(rx_pin, tx_pin);
  mhz19.setAutoCalibration(false);
  dht.begin();
}
```

Step 4

Step 5

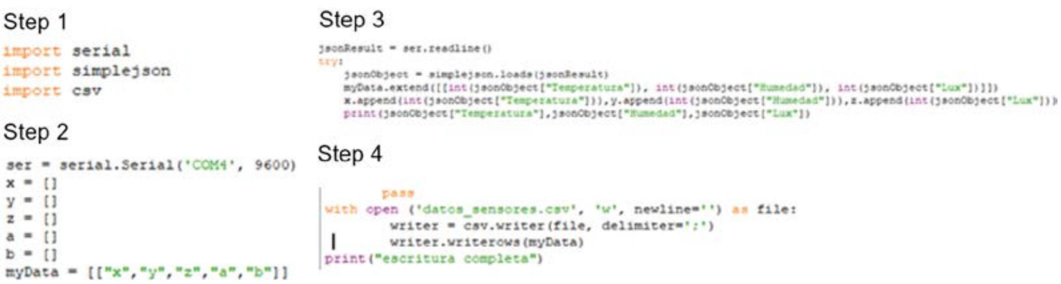
Figure 2. Arduino Code.

are converted to String to avoid programming errors (Step 4, Figure 2). Once the code was implemented for the four sensors, a test was performed opening the serial port from the Arduino platform to verify data reception (Step 5, Figure 2).

Therefore, a Python script was developed within the system of the Raspberry Pi® 3B+ board to enable communication, as well as to store and export data obtained by the sensor network of the Arduino board. In the first lines of code, the following libraries were included: "serial," which establishes communication between Python and Arduino; "simplejson," necessary for the program's execution; and finally, "csv," which stores data in a CSV file (recognized by programs like Excel) (Step 1, Figure 3).

For the next part, the connection port and the variables used were specified. In this case, they were declared and, in turn, stored in the MyData variable (Step 2, Figure 3). A name was assigned to each variable, after they had been defined according to the definitions established in the Arduino program (Step 3, Figure 3). To finish the script, the following lines of code created a CSV file named "datos_sensores" (Step 4, Figure 3).

A test was conducted to verify the effectiveness of information storage on the Raspberry Pi® 3B+ board. Once the programming phase was completed, the system was installed in the greenhouse.



Step 1

```
import serial
import simplejson
import csv
```

Step 2

```
ser = serial.Serial('COM4', 9600)
x = []
y = []
z = []
a = []
b = []
myData = [["x","y","z","a","b"]]
```

Step 3

```
jsonResult = ser.readline()
try:
    jsonObject = simplejson.loads(jsonResult)
    myData.extend([[int(jsonObject["Temperatura"]), int(jsonObject["Humedad"]), int(jsonObject["Lux"])]])
    x.append(int(jsonObject["Temperatura"])),y.append(int(jsonObject["Humedad"])),z.append(int(jsonObject["Lux"]))
    print(jsonObject["Temperatura"],jsonObject["Humedad"],jsonObject["Lux"])
```

Step 4

```
        pass
with open ('datos_sensores.csv', 'w', newline='') as file:
        writer = csv.writer(file, delimiter=';')
        writer.writerows(myData)
print("escritura completa")
```

Figure 3. Python code.

Collection of agroclimatic variables

The monitoring system was installed in a greenhouse located in the community of San Agustín Calvario, in the municipality of Cholula, Puebla.

The monitoring was conducted for almost five months (from March to July). The equipment was installed in the middle of the greenhouse for better data recording [7] (Figure 4). Subsequently, the device was programmed to record the data of the variables every ten minutes. Given the large amount of information involved, the decision was made to analyze the recordings every hour, starting at 11:58 hours, identifying the optimal periods of each variable and the coldest and hottest hours of the day.

On the one hand, the hottest period of the day inside the greenhouse occurs between 11:00 and 15:00 hours. On the other hand, the coldest temperature occurs between 05:00 and 08:00 hours. Considering the optimal periods for each variable, graphs were developed based on monthly averages. Data was manually exported once a week using a USB drive. The data was transferred to the desktop and input into an Excel spreadsheet.

RESULTS AND DISCUSSION

This section presents the results obtained according to the information captured by the monitoring system about the agroclimatic variables.

Temperature

Temperature was recorded every hour and, from this data, the monthly average temperatures were calculated to obtain a representative value of the entire data universe. The collected information was used to develop the graph shown in Figure 5, illustrating the behavior of the "temperature" variable over the 5 months a horticultural crop would last; the resulting three stages describe the optimal and extreme conditions of greenhouse crops. The red and blue dotted lines show the optimum maximum temperatures of the day (28 °C) and the optimum minimum temperature of the night (15 °C), respectively (Figure 6). The lowest temperature of the day in the greenhouse is recorded at 05:58 hours. Consequently, the average minimum optimal temperature is not reached in any of the months and always remains below 15 °C. Nevertheless, March stood out with the

Figure 4. Installation of the monitoring system in the greenhouse.

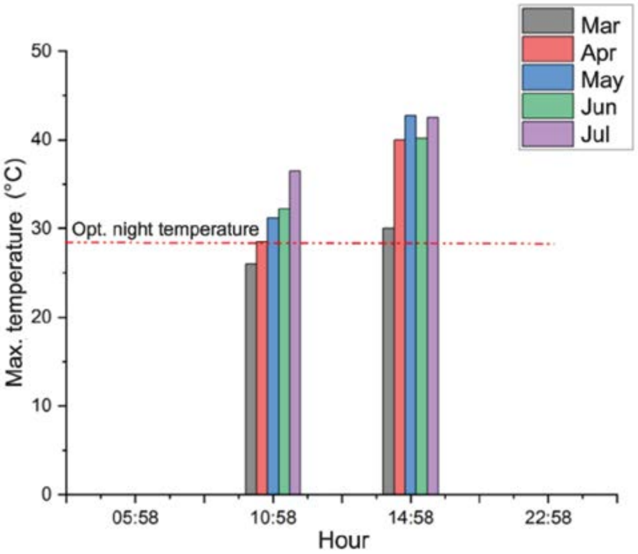


Figure 5. Maximum temperatures in the greenhouse.

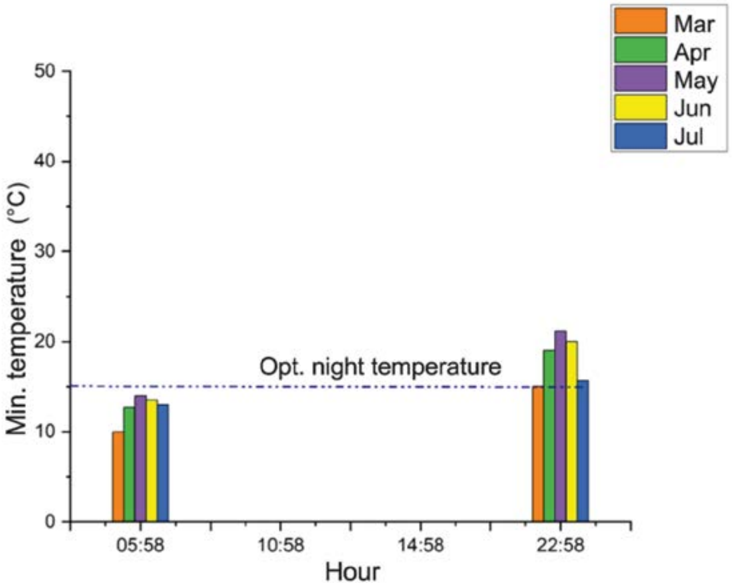


Figure 6. Minimum temperatures in the greenhouse.

lowest temperature (10 °C), followed by April (15 °C). Likewise, at 14:58 hours, all months exceed 28 °C, while at 10:58, only April falls within the optimal conditions [8]. Under these conditions, the decision should be made to lower the greenhouse temperature using a cooling system.

Relative Humidity

The relative humidity sensor shows the percentage of humidity in the environment (Figure 7). The graph is divided into three sections by two dotted lines. The blue dotted line shows the optimal relative humidity for crops during the night (90%). This condition is met

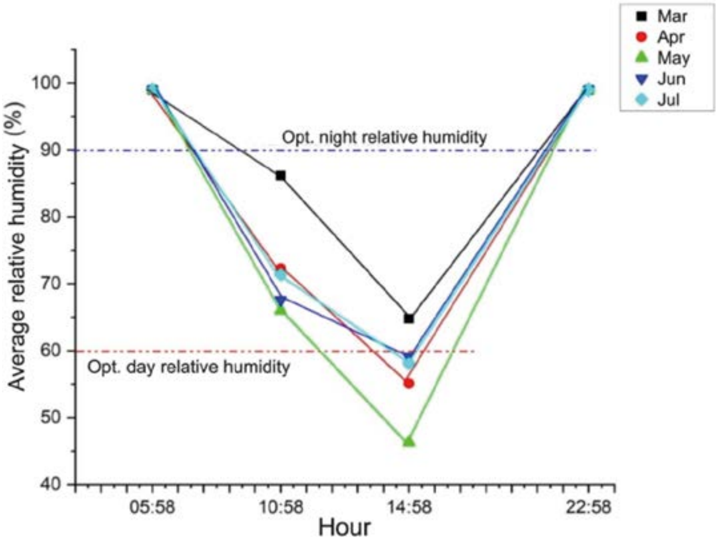


Figure 7. Relative humidity behavior.

in all months, as temperature does not affect it [9]. The red dotted line shows the optimal relative humidity during the day (60%). This condition is only met in June. In April, May, and July, the humidity falls below 60% due to the high temperatures recorded at 14:58 hours, when the maximum temperature is reached.

Light intensity

Figure 8 shows that all months meet an optimal light intensity, which is suitable for crops. Light intensity is clearly distributed throughout the day, with noticeable differences in March, when the days were shorter. For April, May, and June, light intensity distribution was affected by the daylight-saving time change in April, resulting in longer days. In July, light intensity was affected by the high frequency of afternoon storms.

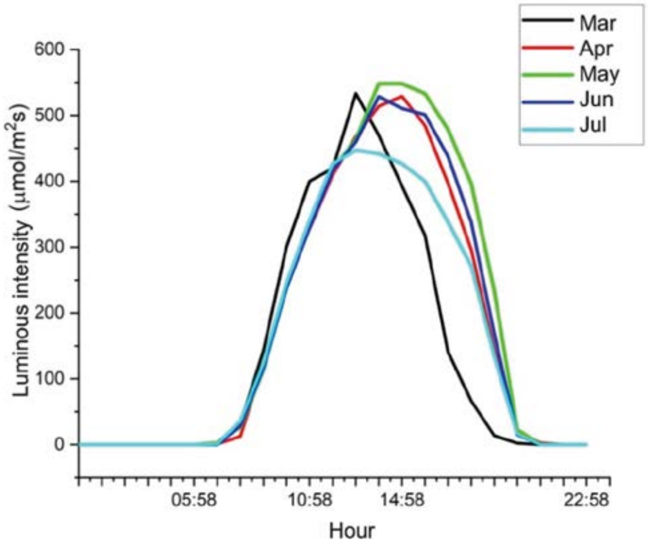


Figure 8. Behavior of light intensity in the greenhouse.

Carbon dioxide (CO_2)

This variable was measured in the greenhouse environment with an emissions sensor. As photosynthesis takes place, the plant absorbs the largest amount of CO_2. The inverse process occurs during the night: the plant no longer absorbs CO_2 and instead releases it into the environment [10].

Figure 9 shows a considerable increase in the concentration of CO_2 at night, expressed in ppm. The optimal CO_2 concentration in a greenhouse ranges between 600 ppm and 1,000 ppm [11]. In this case, the concentration fell below the 600-ppm threshold during the day and it exceeded 600 ppm at night. This is a very logical and normal phenomenon, because, during the day, the plant absorbs CO_2 and releases oxygen, while at night, the reverse process occurs.

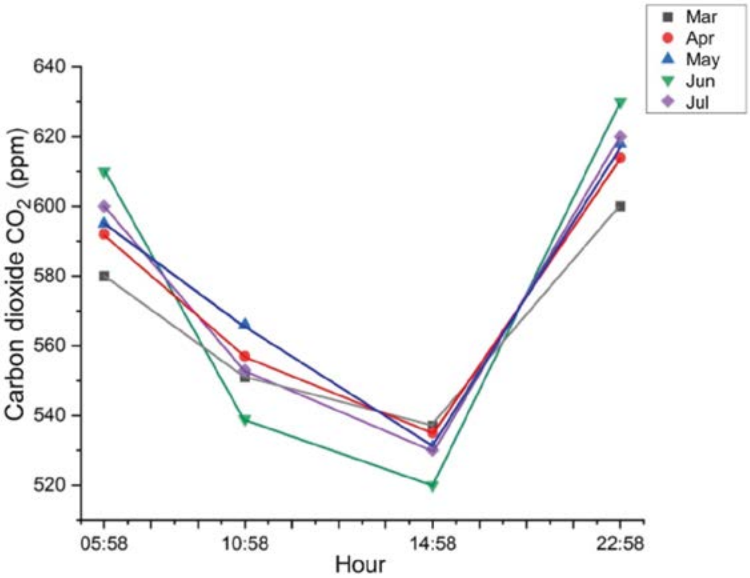


Figure 9. behavior inside the greenhouse.

CONCLUSIONS

The research team was able to design and build a low-cost electronic system and specific software for monitoring, recording, storing, and exporting agroclimatic variables that impact the development and production of crops in medium- and low-technology greenhouses. The graphs developed from the studied variables provided timely agroclimatological information that will be useful for decision-making in greenhouse crops.

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