Monitoring System for Amaranth Cultivation Using Temperature and Humidity Sensors

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***Abstract*—Amaranth is a highly nutritious crop with significant agricultural potential. However, maintaining optimal growth conditions is challenging due to environmental factors such as temperature and soil moisture. This study presents the development of an monitoring system designed to track and visualize key environmental parameters essential for amaranth cultivation. The system integrates an ESP32 microcontroller with DHT22, HD-38, and DS18B20 sensors to measure air and soil temperature, as well as humidity levels. The collected data is processed and displayed through real-time graphical representations, facilitating decision-making for optimal crop management. Experimental results demonstrate the effectiveness of the system in monitoring environmental conditions, highlighting its potential to enhance agricultural productivity and sustainability. Future improvements include refining sensor calibration and expanding the system's capabilities to include additional environmental variables.**

***Index Terms*—Agriculture, Amaranth, Sensors, Temperature, Humidity, Monitoring, DHT22, HD-38, Ls18b20.**

I. Introduction

In the field of agriculture, an urgent need has arisen to find foods with more nutrients, as well as to improve the quality and quantity of crops, due to the accelerated growth of society. As a result, studies have been conducted in Mexico on various species of plants suitable for cultivation, including Amaranth. The Amaranth plant is a millenary species that has played a fundamental role in both nutrition and cosmovision in Mexico [1]. Its origins can be traced back to Mesoamerican civilizations, particularly Aztec culture. Its pre-Columbian name is Huatli, which means immortal, because the seed does not rot, while its current name comes from greek, where it means to not wilt; the Aztecs implemented amaranth in their alimentation due to its high protein content, they also employed it in their religious rituals, recreating their deitys silhouettes [2]. In the current time, Amaranth is mainly cultivated in Puebla, State of Mexico, Morelos, Tlaxcala, Mexico City, Jalisco and Oaxaca [3].

It is an annual crop plant; its life cycle spans approximately 30 to 55 days from germination to harvest when they reach a height of 0.6 meters, under optimal conditions [4]. It can grow up to 3 meters in height and has broad foliage with lilac-colored flowers. This plant thrives in temperate and pseudotropical climates. It produces a grain classified as a pseudocereal, which is used as food [5].

According to the Secretary of Agriculture and Rural Development, Amaranth is the best natural food source for human consumption. It is beneficial for health as a result of its high protein content. The average protein content in amaranth grains from species in Mexico ranges between 16% and 18%, while its leaves, which can also be used as food, contain 3.5% protein. Proteins include albumin, tryptophan, threonine, and valine. In addition, it has a high content of monounsaturated and polyunsaturated fats. Consuming amaranth is recommended for people suffering from cardiovascular disease because it lowers hepatic cholesterol levels and decreases arterial pressure [3].

We intend to develop an IoT monitoring system specifically designed for the tracking of amaranth, analyzing the environment in which the plant develops, using sensors that measure humidity and temperature in soil and air. World Meteorological Organization (WMO) defines temperature as the physical quantity that characterizes the mean random motion of molecules in physical bodies [6].Humidity is understood as a property that describes the water vapor content present in a gas, according to Martínez [7].

The concept of the Internet of Things was first used by Kevin Ashton in 1999. This concept refers to the connection between objects in the physical and digital planes. Today, the Internet of Things has become a popular term for describing scenarios in which Internet connectivity and computing capabilities extend to a variety of objects, devices, sensors, and everyday items [8].

II. METHODOLOGY

One of the main challenges in the amaranth cultivation field is root rot, which represents the 19% of the issues related to this species, according to a survey conducted in the community of Temoac, Morelos [9].

Root rot is primarily associated with two factors: excessive soil moisture and inefficient root oxygenation. These conditions lead to stomatal closure, reduced root growth, inhibition of photosynthesis, and impaired nutrient transport. In the long term, these effects contribute to root decay and consequently, plant death. [10].

As we have already mentioned, amaranth grows in specific conditions. This species flourishes in temperate climates, with an ideal temperature range between 13.1°C and 28.9°C, although it can endure temperatures reaching up to 38°C . However, air temperatures above 25°C are essential to ensure optimal development [11]. According to Díaz, in terms of soil requirements Amaranth cannot grow on substrates under 31.5% of moisture content; 49.8% of soil moisture promotes adequate root hydration and nutrient absorption, additionally, Amaranth does not tolerate substrates above 80% of moisture content [12].

The purpose of the investigation is the development of an electronic device that integrates sensors and information processing technology to address the identified issues. The system will be connected to an ESP32-WROOM-32 microcontroller, which features integrated Wi-Fi 802.11 b/g/n, dual-mode Bluetooth version 4.2, and a range of peripherals [13]. The ESP32-WROOM-32 is responsible for processing the data collected from the DHT22, HD-38 and Ds18b20 sensors. Those sensors are responsible for measuring the two ambiental factors mentioned before, humidity and temperature on both air and soil. The components will be soldered onto a copper prototyping board. The setup begins by connecting the ESP32-WROOM-32 to two 3.7V Li-ion batteries, which will supply power to all sensors. Additionally, four LEDs will be connected to indicate the status of each monitored variable: soil moisture, soil temperature, air humidity, and air temperature. As can be seen in figure 4.

The DHT22 sensor measures temperature and humidity using a polymer capacitor, converting data into digital signals. It offers advantages in terms of quality, speed and precision, with an average error value of 1.96% [14] in displaying the data it collects regarding temperature and humidity [15] . It operates within a voltage range of 3.3V to 6V and features low energy consumption, making it ideal for our sustainable project. [16].

The HD-38 sensor measures soil moisture, operating with a voltage range of 3.3V to 12V and a temperature range of -20°C to 75°C. It consists of a probe with two spaced terminals that are resistant to oxidation. When current passes through the soil, when in higher water levels it has in better conductivity, leading to lower resistance; conversely, in dry soil, there is no conduction, resulting in high resistance. Thus, the percentage of moisture can be determined. [17].

The DS18B20 is a digital device used to measure temperature in various environments, both domestic and industrial. This sensor is chosen for its small size, ease of avoiding signal interference, and accuracy in measuring temperature [18]. It has a range of -55°C to +125°C, with an accuracy of ± 0.5°C in the interval of -10°C to +85°C. [19].

To create the graphs, is necessary to divide the code into two sections. The first section is the one that reads and interprets the data directly from the sensors, for which we will rely on Arduino.

The Arduino Flowchart in figure 1, follows a continuous cycle. First, the system sets up the sensors and LEDs, then it starts reading the air temperature and humidity, the soil temperature, and the soil humidity. If the data is correct, it sends it to the serial monitor. Then, the system compares these values with set limits and turns the LEDs on or off depending on whether the values are within the range. This cycle repeats continuously.

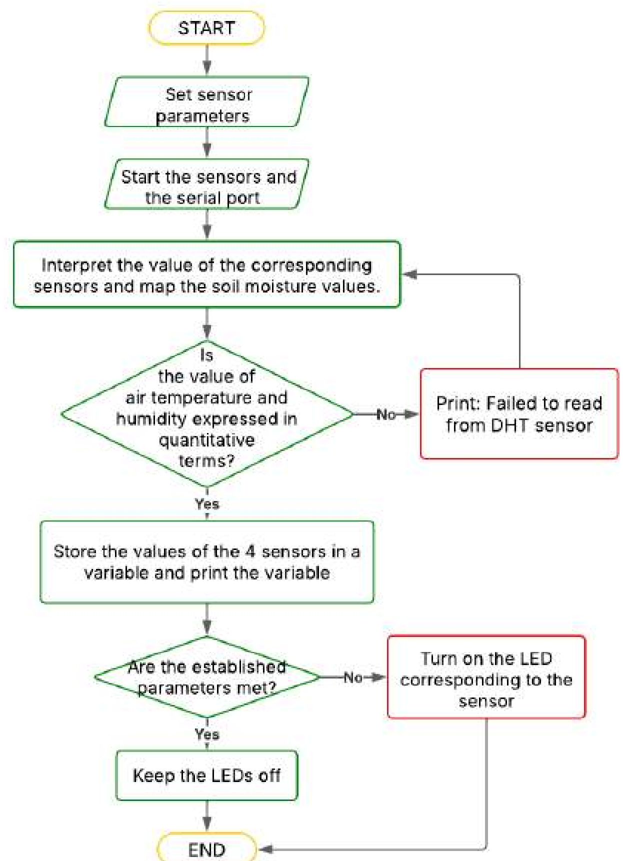

Fig. 1: Arduino Flowchart

And another that transforms that data into graphs of the data with respect to time (samples), for which we will rely on Phyton:

The Python Flowchart in figure 2, follows a continuous cycle to read and plot data in real-time from a serial port. First, the system connects to the serial port and sets up a graphical interface with four charts to display air temperature and humidity, as well as soil temperature and humidity. Then, the system starts reading data from the serial port. If the data is correct, it adds it to the corresponding lists and updates the charts on the screen. The charts update every so often, showing the last 3000 data points. The cycle repeats, and old data is removed when the sample limit is reached. If any error occurs, the system displays it in the console.

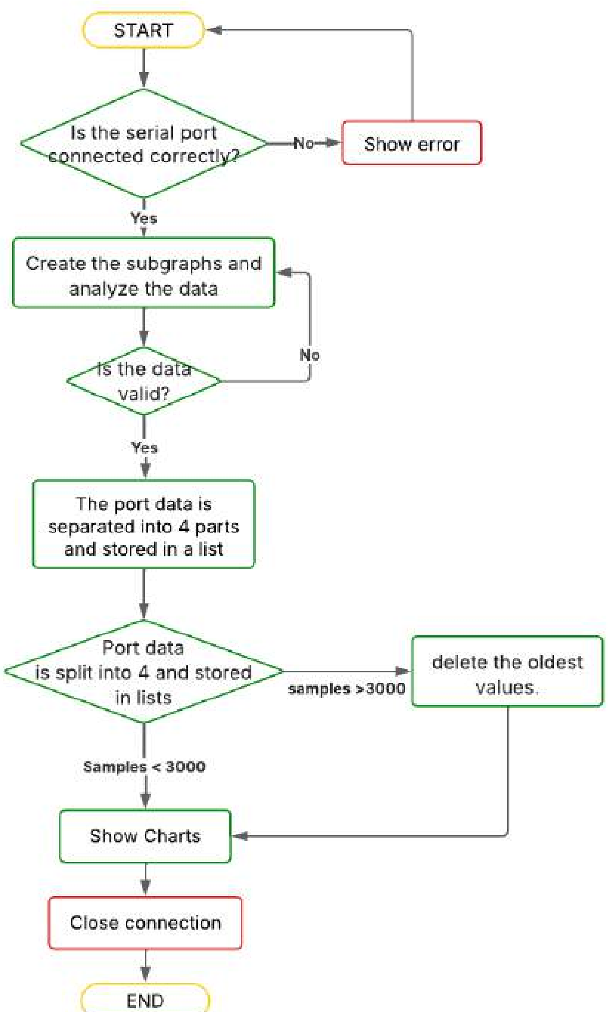

Fig. 2: Python Flowchart

III. Experimental Work

Once the foundations of the problem are well established, we proceed to divide the project into: manufacturing the parts, assembling the circuit, mounting the board in the casing, coding to display graphs, and testing in three different terrains, looking for any variation or error in the code.

A. Manufacturing of the casing

We started by designing the parts in SolidWorks2024®. In this case, we used four different parts:

1) parts:

- Container
- Body
- lid
- sensor module

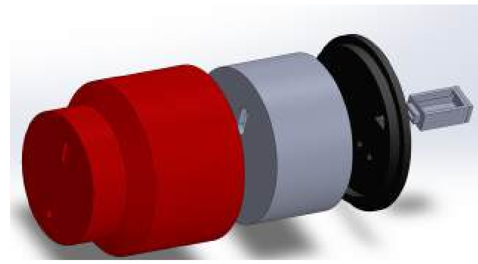

Fig. 3: Assembled prototype

To manufacture the pieces, we will use Polylactic Acid filament (PLA), a polymer composed of natural materials. Since it is made of natural components, it does not alter the ecosystem's balance or affect plant growth [20]. In addition to being biodegradable and easy to recycle, PLA is a low-cost option that does not release harmful substances into the soil, making it completely safe for plants [21]. The pieces will be manufactured using a 3S-1-Ender® plastic filament 3D printer and then set aside.

B. Circuit connection

The first step to integrate the system is to assemble the circuit. This involves connecting the cables of the DH-38, DHT22, and DS18B20 sensors to ports 4, 15, and 16 on the ESP32, respectively. The GND of these sensors and the four LEDs in the circuit, as well as the VCC of the sensors, should also be connected. The positive legs (anodes) of the LEDs are connected to ports 23, 22, 21, and 19 on the ESP32 to show the air humidity and temperature, and the soil temperature and humidity. Finally, the ESP32 is powered by two 3.7V lithium batteries, connected directly to its USB-C port. All of this is soldered onto a copper board that was designed earlier, like the Fig. 1: Diagram of connections.

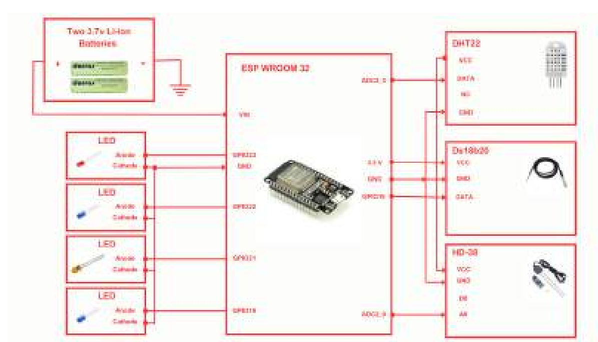

Fig. 4: Diagram of connections

C. Embedded system code

Now let's explain the code. In this case, the Arduino IDE was used, which is a development environment based on C and C++ that makes it easier to interact with electronic boards like the ESP32 [22]. To enable communication between the board and the sensors, we need to use libraries, which are like extra tools that allow us to reuse code. In this project, we used three key libraries to manage the temperature and humidity sensors.

The DHT22 sensor, which measures air temperature and humidity, requires the DHT.h library. This library helps interpret the data from the sensor and converts it into values the program can use. Additionally, we used the OneWire library, designed to work with sensors that use a single pin for data transmission. This is essential for accurate readings in this project. Finally, the Dallas Temperature library helps interact with Dallas brand sensors, making it easier to gather and process data.

In the code, the initial setup is done in the setup function, where the pins for the sensors and LEDs are defined, and initial values are set to zero. This section of the code runs only once at the beginning to prepare everything for the program to function properly. After that, in the loop function, which runs continuously, the code reads data from the sensors and processes it.

To measure air temperature, we use the dht.readTemperature function, which returns the temperature in Celsius and stores it in the corresponding variable. For soil temperature, communication with the sensor is done via the OneWire library, allowing us to detect the temperature and use the data for various applications, like generating graphs. Soil humidity is measured using the analogRead function, which processes the data from the sensor and converts it into a numerical value within an established range, allowing us to assess the moisture level in the soil where the plant is located.

To prevent errors in data transmission, the code includes a check function to verify the validity of the values received from the DHT22 sensor. If invalid data is received, the program shows an error message until the issue is corrected. Once the data are validated, they are stored in specific variables for air temperature, soil temperature, soil humidity, and air humidity. All of this information is then printed on the serial monitor, allowing real-time visualization and making it easier to monitor the plant's environmental status.

To ensure proper growth, optimal temperature and humidity ranges have been established. If the environmental conditions are not within these predefined values, the indicator LEDs are activated, signaling the need for intervention. Air humidity should be kept between 40 % and 60 %, while soil humidity should range from 49.8 % to 70 %. The air temperature should be between 25 ° C and 38 ° C, and the soil temperature between 13 ° C and 28 ° C. These values were chosen to create the best environment for plant growth, ensuring a proper balance between temperature and humidity.

D. Python code

The code presented aims to read data from a serial port and update a graphical visualization in real-time using the matplotlib library. According to the official matplotlib.org website, it is "a comprehensive library for creating static, animated, and interactive visualizations in Python. Matplotlib makes easy things easy and hard things possible." [23].

This is possible because the code first imports the necessary libraries: serial for serial communication, matplotlib.pyplot to generate the graphs, and FuncAnimation from matplotlib.animation to animat the graphs. The main function, read_serial_and_update_graph, is responsible for opening a serial connection on the specified port and baud rate.

Then, four subplots are configured in a figure to display four variables: air temperature, air humidity, soil temperature, and soil humidity. Each subplot has its title and axis labels accordingly. After that, an array is created to store the data lists for each variable.

The update-graph function, called at regular intervals by FuncAnimation, reads data from the serial port and processes them. The data, expected in CSV format (comma_separated values) [24], are split and assigned to their respective lists. If the number of samples exceeds a certain limit (num-samples), the code removes the oldest samples to maintain the dataset size constant. The graphs are then updated with the new data.

The process of updating the graphs involves clearing the axes of each subplot (axs[i].cla()) and then plotting the data, while adjusting the titles, labels, and legends. Finally, the FuncAnimation function updates the graphs every 100 milliseconds. The program displays the resulting figure with plt.show() and closes the serial connection once finished.

Once the circuit was assembled and the ESP32 configured, various tests were performed under three different conditions, from which the corresponding measurements were obtained.

E. Research cases

To summarize, we have four variables to analyze (air humidity and temperature, soil humidity and temperature), which are key to the growth of amaranth. These values must be within the following limits:

- Air humidity: 40% to 60%
- Air temperature: 25°C to 38°C
- Soil temperature: 13°C to 28°C
- Soil humidity: 49% to 70%

Subsequently, tests were done in three different scenarios: Plant in pot, unwatered plant and recently watered plant. The next results were obtained.

1) Air humidity: According to what was discussed in the methodology section, air humidity is crucial for amaranth growth, as it is linked to several key physiological processes in the plant, such as: transpiration, water absorption, and photosynthesis.

Although that the experiments were conducted in different enviropments, the plants consistently mantained an average humidity level of 33%, which causes the plant to lose water quickly through transpiration, preventing it from absorbing the necessary nutrients from the soil due to this transpiration, and making it susceptible to pests or failing to achieve optimal development.

2) Air temperature: In the same way, the air temperature influences the photosynthesis, development, respiration, stress resistance, and pollination of the plant. In this case, since Puebla has a predominantly warm environment (around 25°C in the morning), it helps the growth and preservation of the plant in optimal conditions during this process.

3) Soil temperature: The soil temperature is crucial from seed germination, as it directly affects the speed of germination. On the other hand, the roots of amaranth develop better when the temperature is optimal, and in turn, this favors the production of microorganisms that break down organic matter and release essential nutrients for the plant.
By analyzing the samples (with a temperature around 25°C, which is within the optimal growth range), we can determine that the samples are out of danger in this case.

4) Soil humidity: The data show that the soil in which the samples are planted is semi-moist, as it falls within a range between 48% and 52%, placing it below the lower limits of optimal cultivation. This could lead to water stress and wilting, as well as limit photosynthesis. However, despite all this, since it is close to the ideal range, the plant will be more resilient to adverse conditions, such as droughts or excessive rainfall, making it easier for the plant to adapt and develop under diverse conditions.

IV. Conclusions

The study on the monitoring system for amaranth cultivation, using humidity and temperature sensors, demonstrated significant potential to improve growing conditions and optimize the production of this pseudocereal. By integrating sensors such as the DHT22, HD-38, and DS18B20 with an ESP32 microcontroller, it is possible to monitor, in real time, the environmental conditions affecting the plant.

In addition, the system includes a mechanism for detecting when variables fall outside acceptable ranges, which supports timely decision-making to maintain optimal growth conditions.

This approach takes into account key environmental factors essential for the development of amaranth, including air and soil temperature and humidity. The sensors enable both the collection of data and its graphical representation, providing a clearer understanding of the plant's environment and needs.

According to the results obtained from the tests carried out in the previous section, it was observed that the average air humidity around the plants was 33%, which causes the plants to lose water rapidly due to transpiration. This hinders their ability to absorb all the nutrients necessary for proper development. Regarding soil moisture, it was noted that the specimens were within a range of 48% to 52%, placing them at the minimum threshold required to maintain optimal growing conditions.

Air temperature remained within an ideal range, as the measurements consistently showed values above 25°C and below 38°C. Similarly, soil temperature varied depending on humidity and time of day; however, it stayed within an appropriate range.

The system functioned correctly. However, during the execution of the tests, some data accuracy errors were detected. These were resolved by adjusting the preset intervals of the variables.

Despite this limitation, the precision of the crop monitoring mechanism promises a future of greater autonomy in agriculture, with the potential to improve efficiency and reduce costs in agricultural production.

Fig. 5: Some tests of the prototype

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