Greenhouse Automation using ESP32: A Comprehensive Study on Monitoring and Controlling Environmental Parameters for Optimal Plant Growth

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***Abstract*— Greenhouse automation using ESP32 is a novel approach to achieving optimal plant growth by monitoring and controlling environmental parameters. This study presents the design, development, and implementation of an ESP32-based greenhouse monitoring and control system. The system includes sensors for temperature, humidity, soil moisture, and light intensity, enabling real-time data collection from the greenhouse. The ESP32 then processes and analyzes the data and controls the environmental parameters accordingly. This ESP32-based system offers better accuracy and reliability compared to conventional greenhouse monitoring systems. It can potentially improve crop yield and quality significantly and thus is an essential step towards sustainable agriculture.**

***Keywords*— Greenhouse Automation, ESP32, Optimal Plant Growth.**

I. INTRODUCTION

Greenhouses are controlled environments that provide optimal conditions for plant growth, regardless of the outside weather conditions, as shown in Fig. 1 [1]. Greenhouse measurement and control systems are used to monitor and control the greenhouse environment, ensuring that the plants have the right amount of light, water, and nutrients. By optimizing the greenhouse environment, growers can enhance crop yields, improve quality, and gain better control over the growth period of plants [2].

Key factors that exert an impact on plant growth include sunlight, soil water content, and temperature.

Temperature is an important factor affecting plant growth and development. It influences a wide range of processes, including photosynthesis, transpiration, absorption, respiration, and flowering. Typically, higher temperatures promote growth, while lower temperatures can impede it. However, at a certain temperature point, the growth rate does not continue to increase with temperature increase, as shown in Fig. 2. Each type of plant has a different temperature range in which it can grow. Below or above this range, enzymes become inactive and processes essential to life stop [3]. Therefore, the temperature must be kept at an optimal level whenever possible [4], [5].

Fig. 1. Example of greenhouse.

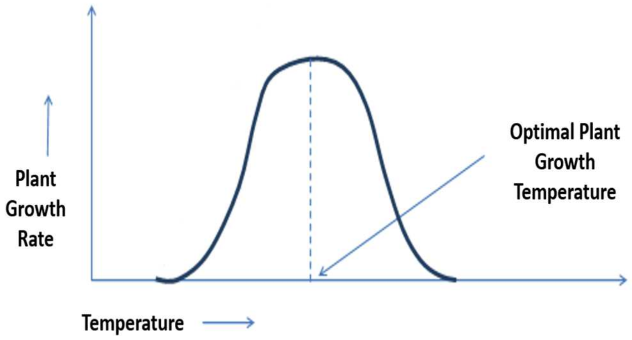


Fig. 2. The Relationship between plant growth and temperature.

Water vapor is one of the most important factors that significantly impact crop growth in a greenhouse. It plays a vital role in controlling the moisture loss from plant leaves. Plants have tiny pores on their leaves that allow carbon dioxide to enter while permitting oxygen and water to exit. The rate of transpiration, or water loss, decreases as the humidity of the air increases. This is because water diffuses from areas of high concentration to those of low concentration [6]. In contrast, plants in a dry environment experience greater moisture loss over time. Consequently, the difference in humidity can cause severe damage to plants. Humidity control is complex because it is inversely related to temperature. When the temperature changes, the relative humidity changes in the opposite direction. The same actuators control both temperature and humidity. However, temperature control is the main priority because it is the basic factor in crop growth [7], [8].

All living things need energy to grow. Humans and animals get energy from food, while plants get energy from sunlight through photosynthesis. This is how light primarily affects plant growth since, without light, plants cannot produce the energy they need to grow. In addition to its effect on photosynthesis, light also influences plant growth in other ways. Plants grown in the shade, as opposed to those in complete darkness, show different responses. Moderate shading tends to decrease water loss (transpiration) more than it reduces photosynthesis. As a result, shaded plants may be taller and have larger leaves because they have better access to water. On the other hand, increased shading leads to a more significant reduction in photosynthesis, ultimately resulting in weaker plants [9], [10].

Greenhouse monitoring and automation is a rapidly growing field in agriculture. It has the potential to increase crop yields, reduce labor costs, and improve the quality of agricultural products. While automation is already widely used in the industrial sector to improve productivity and quality, traditional farming methods still prevail in agriculture. Hence, implementing new science and technology in the agricultural sector is essential to increase yields [11].

The integration of Internet of Things (IoT) technology, which combines electronic devices, sensors, and the Internet to manage data, into greenhouse control systems can enhance the intelligence and coordination of greenhouse monitoring systems [12].

Microcontroller system Espressif Systems (ESP32) can be used for automatic monitoring and control of the greenhouse on an automatic or manual basis. An embedded system that records temperature, humidity, and other parameters that controls environmental conditions in the plant field can be developed. Moreover, the Blynk app is used in conjunction with the embedded system for effective control.

Numerous prior investigations in this field merit a comprehensive review to assist in formulating a greenhouse monitoring and control system. In [13], the authors developed an automated irrigation system that turns the pumping motor ON/OFF depending on the dampness content of the soil. Authors in [14] designed a system to monitor specific soil moisture levels to operate an automatic irrigation system inside the greenhouse. They implemented a sensing bit using a Soil Moisture Sensor (SMS YL-69) and used three light-emitting diodes (LED) and a Liquid Crystal Display (LCD) to display the three soil states to switch between the control and the irrigation systems. In this system, the control unit was implemented using Arduino. In [15], the researchers suggested the use of various sensors, including temperature and humidity sensors to assess the weather conditions suitable for a plant, soil moisture sensors to check if a field is dry or wet, and Light Dependent Resistor (LDR) sensors to check the lighting in a location. This mechanism ensures that soil quality is maintained, which is essential for optimal crop growth.

The objective of greenhouse monitoring and control using ESP32 is to create a system that can monitor and control various environmental factors within a greenhouse in order to optimize plant growth and yield. The ESP32, a cost-effective and low-power microcontroller, can collect data from sensors such as temperature, humidity, light, and soil moisture sensors and control actuators like fans and irrigation systems. By monitoring and controlling these factors, the system can ensure that the environment within the greenhouse is optimal for plant growth and health, leading to higher yields and better-quality produce. Additionally, the system can help reduce water and energy usage by automating the control of irrigation and climate control systems. Overall, greenhouse monitoring and control using ESP32 aims to create a more efficient and sustainable way of growing plants at a lower cost.

II. METHODOLOGY

Greenhouse monitoring and control using ESP32 is a system that enables farmers or gardeners to remotely monitor and control the environment of their greenhouse. This system involves the use of the ESP32 microcontroller, various sensors, actuators, and additional hardware components. Fig. 3 illustrates the proposed greenhouse design. It involves selecting appropriate sensors and actuators, connecting them to the ESP32 microcontroller, and programming the microcontroller to read data from the sensors and control the actuators. The system can also be connected to a mobile app or web interface to enable remote monitoring and control of the greenhouse environment. Collected data can be analyzed using algorithms to determine optimal conditions for plant growth and make necessary environmental adjustments. Additionally, the system can regulate actuators such as fans, and lights to maintain the desired environment for plant growth. Fig. 4 displays the proposed greenhouse system, which is composed of different units: the sensing unit, processing unit, driver components, and the actuators unit. Subsequently, the components of the envisioned greenhouse system underwent a sequence of activities, including design, simulation, implementation, fine-tuning, and integration.

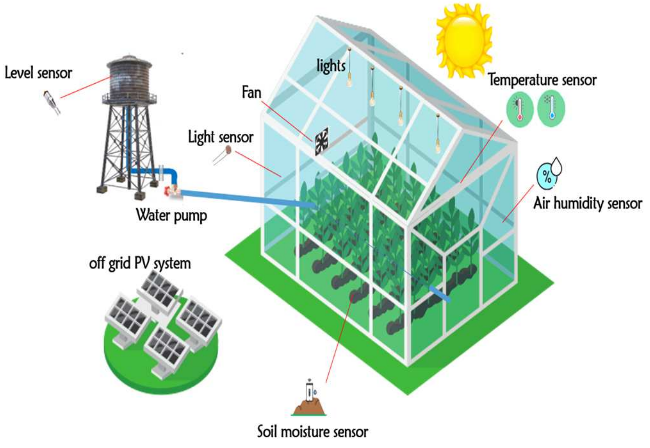


Fig. 3. The proposed greenhouse design.

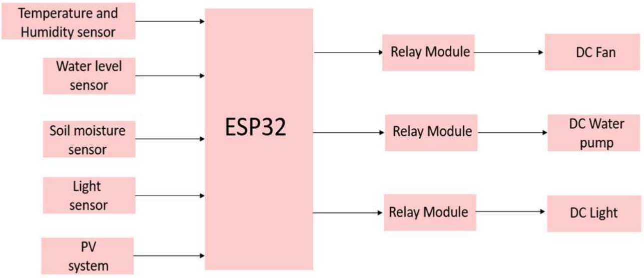


Fig. 4. The proposed greenhouse block diagram.

The ESP32 is connected as depicted in Fig. 5. It incorporates various electronic components, including the DHT11 sensor, which is essential for temperature and humidity readings within the greenhouse. An LDR sensor is employed to measure light intensity in the greenhouse. The YL-69 sensor plays a crucial role in monitoring soil humidity, while a water level sensor is utilized to gauge water levels in the tank. A direct current (DC) fan is in place to ventilate the greenhouse when temperature and humidity exceed the plant's requirements. A water pump is responsible for supplying water to the greenhouse when soil humidity falls below the necessary threshold. Additionally, a DC light source is employed to illuminate the greenhouse in the absence of sunlight, enabling vital plant processes to continue. The ESP32 functions as an Arduino and supports Wi-Fi connectivity, enabling it to receive sensor data and issue commands to control devices, thereby automatically regulating greenhouse conditions. All sensor readings and device statuses within the greenhouse are transmitted to Blynk via Wi-Fi, allowing users to stay informed about the greenhouse's status. A relay module is utilized to isolate both the controlling and controlled devices, and a voltage regulator ensures a steady 5V voltage output.

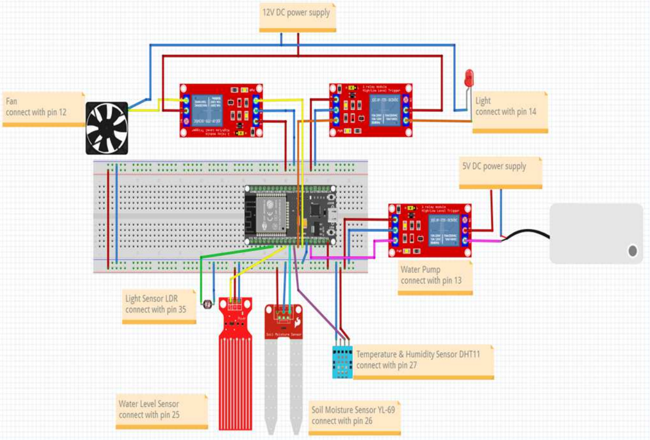


Fig. 5. Sensing and response unit.

The Blynk application was selected to design the user interface due to its versatility, as it can run on various hardware modules such as Raspberry Pi, Arduino, and NodeMCU. Furthermore, it supports a variety of connectivity options, including Wi-Fi, Ethernet, Cellular, USB, serial, and Bluetooth. This allows users to create and use applications to control boards connected to a device with internet access from anywhere in the world using a smartphone [16]–[19]. The Blynk app has a simple and user-friendly graphical user interface (GUI), and users can add widgets to the GUI to control their devices. Fig. 6 shows the user interface of the greenhouse monitoring and control system in the Blynk app.

In order to develop a program to upload to the ESP32 to operate the control greenhouse prototype, the following steps were applied:

- Start: Reset the ESP32, preparing it to execute the instructions.
- Initialize the sensors, Wi-Fi, the Blynk app, and the relays.

The system's operation can be better understood through a flowchart, which illustrates the comparison of the set values with the acquired values, as depicted in Fig. 7.

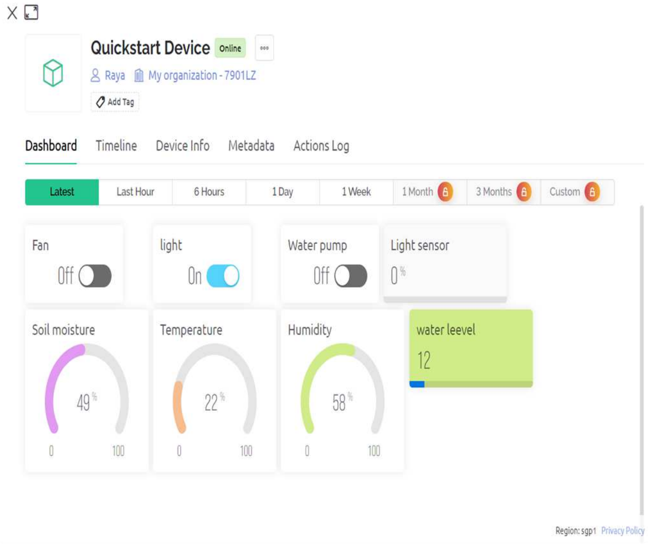


Fig. 6. The user interface of our system in the Blynk app.

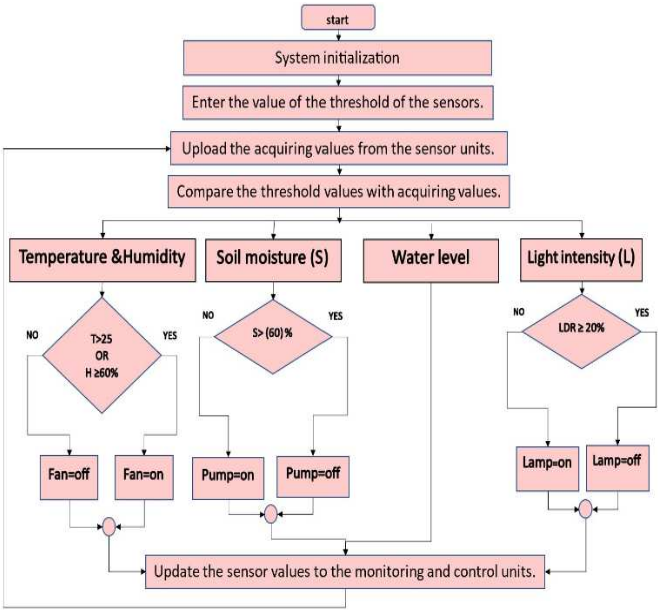
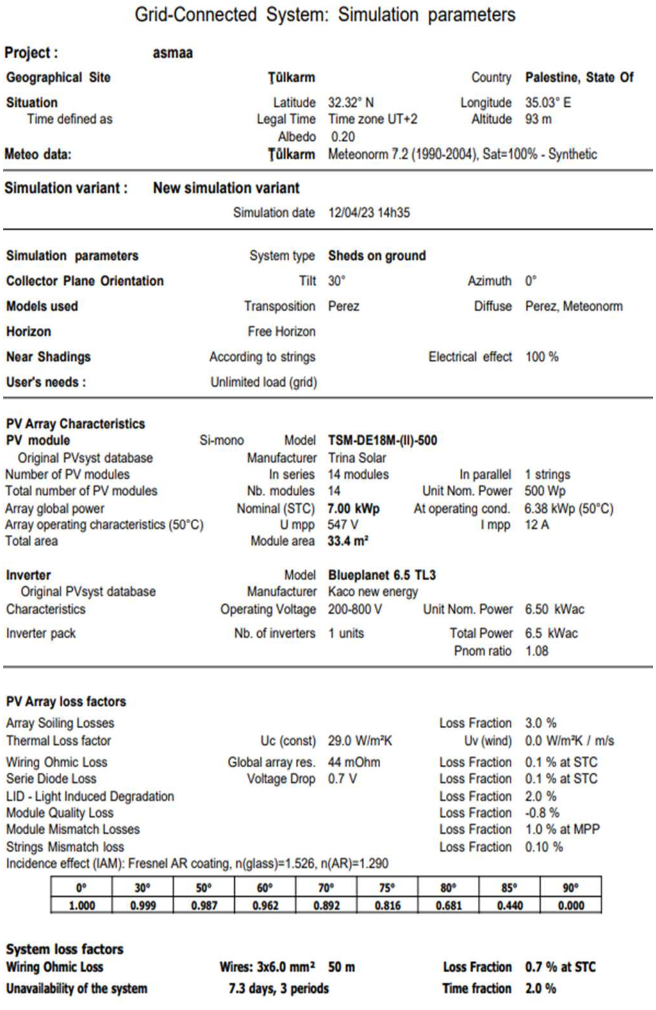


Fig. 7. Flow chart of the system.

A photovoltaic (PV) system can be used in a greenhouse to provide electricity for the ESP32 and other electronic devices used in the greenhouse such as lighting, ventilation, and other equipment necessary for growing plants. This allows the greenhouse to operate without relying on grid electricity or a generator, reducing the greenhouse's carbon footprint and energy costs. Additionally, a PV system can be designed to be grid-tied, allowing any excess electricity generated to be sold back to the grid. This can potentially generate revenue for the greenhouse owner and also increase the overall amount of renewable energy in the local area.

In this study, an agricultural land in Al-Nazla Al-Sharqiya, with an area of 1200 m^{2,} is considered as the case study, as shown in Fig. 8, to study the capacity of the PV system needed for planting the land with tomatoes. Initially, the capacity of the devices used in the greenhouse was calculated. PVsyst, a specialized software tool, was used to determine the necessary capacity of the PV system needed to operate the monitoring and control system in the greenhouse. The results are shown in Fig. 9:

Fig. 8. Agricultural land in Al-Nazla Al-Sharqiya.



Grid-Connected System: Simulation parameters

Project : **asmaa**

Geographical Site		**Ţûlkarm**	Country	**Palestine, State Of**
Situation	Latitude	32.32° N	Longitude	35.03° E
Time defined as	Legal Time	Time zone UT+2	Altitude	93 m
	Albedo	0.20		
Meteo data:	**Ţûlkarm**	Meteonorm 7.2 (1990-2004), Sat=100% - Synthetic		

Simulation variant : **New simulation variant**

	Simulation date	12/04/23 14h35		

Simulation parameters	System type	**Sheds on ground**		
Collector Plane Orientation	Tilt	30°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	According to strings		Electrical effect	100 %
User's needs :	Unlimited load (grid)			

PV Array Characteristics

PV module Si-mono	Model	**TSM-DE18M-(II)-500**		
Original PVsyst database	Manufacturer	Trina Solar		
Number of PV modules	In series	14 modules	In parallel	1 strings
Total number of PV modules	Nb. modules	14	Unit Nom. Power	500 Wp
Array global power	Nominal (STC)	**7.00 kWp**	At operating cond.	6.38 kWp (50°C)
Array operating characteristics (50°C)	U mpp	547 V	I mpp	12 A
Total area	Module area	**33.4 m²**		

Inverter	Model	**Blueplanet 6.5 TL3**		
Original PVsyst database	Manufacturer	Kaco new energy		
Characteristics	Operating Voltage	200-800 V	Unit Nom. Power	6.50 kWac
Inverter pack	Nb. of inverters	1 units	Total Power	6.5 kWac
			Pnom ratio	1.08

PV Array loss factors

Array Soiling Losses			Loss Fraction	3.0 %
Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	44 mOhm	Loss Fraction	0.1 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.1 % at STC
LID - Light Induced Degradation			Loss Fraction	2.0 %
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %

Incidence effect (IAM): Fresnel AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

System loss factors

Wiring Ohmic Loss	**Wires: 3x6.0 mm²**	**50 m**	**Loss Fraction**	**0.7 % at STC**
Unavailability of the system	**7.3 days, 3 periods**		**Time fraction**	**2.0 %**

Fig. 9. Agricultural land in Al-Nazla Al-Sharqiya.

III. RESULTS AND DISCUSSION

This section presents experimental results for a performance test of a prototype greenhouse system. The monitoring, controlling, and sensing unit, along with the response module based on the sensor network, can yield different results. These results are contingent on the effective management of the greenhouse environment. All the individual components, including the LDR sensor, DHT11 sensor, mono soil sensor, water level sensor system, fan, water pump, lamp, 5V relay module, and PV system, were assembled together to evaluate the system. Subsequently, the designed system's performance was tested, and the results obtained and discussed.

The output of the humidity and temperature readings are shown in Fig. 10 and 11.

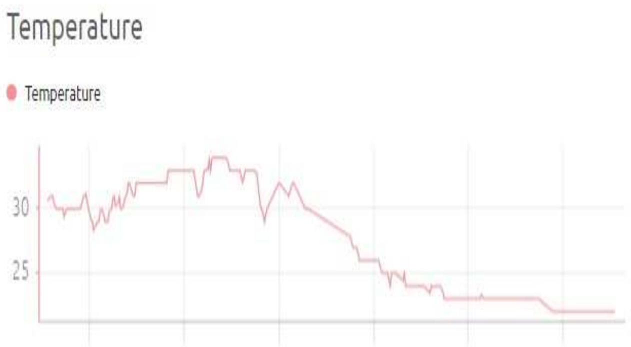


Fig. 10. Temperature inside greenhouse.

Fig. 11. Humidity inside greenhouse.

Based on the change in temperature and humidity values during the day, the fan response in the system changed, as shown in Fig. 12.

Fig. 12. Fan response inside greenhouse.

As noted, when the temperature rises above 25 degrees Celsius or the humidity exceeds 60%, this leads to the operation of the fan inside the greenhouse. If one of the two conditions is not met, the fan will not operate.

The output of the light readings from the light sensor is shown in Fig. 13.

Fig. 13. Light inside greenhouse.

Based on the change in light values during the day, the response of the lights in the system changed, as shown in Fig. 14. As expected, when the light ratio is less than 20%, this causes the lights to turn on inside the greenhouse. In the event that the light ratio exceeds 20%, the lighting will be turned off, and natural lighting will be sufficient until the plants grow healthy.

Fig. 14. Light response inside greenhouse.

The output of the soil moisture readings from the YL-69 sensor is shown in Fig. 15.

Fig. 15. Soil moisture inside greenhouse.

Based on the change in the percentage of water within the soil (soil moisture) throughout the day, the response of the water pump in the system changes, as shown in Fig. 16.

Fig. 16. Water pump response inside greenhouse.

As expected, when the soil moisture exceeds 10%, the water pump will not operate. In the event that it does not exceed 10%, the water pump will operate.

The operation of the water pump leads to a decrease in the water level inside the tank a water level sensor is used to sense the water level, as shown in Fig. 17; thus, the amount of water available is known.

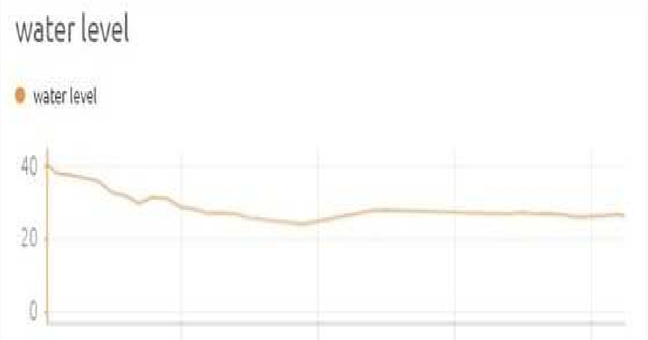


Fig. 17. Water level inside tank.

These results were taken for one day (1st of May); all reference values are real values suitable for tomato plants.

IV. CONCLUSIONS AND RECOMMENDATIONS

This study presents a simple and low-cost control and monitoring design of a greenhouse using an ESP32 microcontroller, highlighting the potential benefits of using this technology in agriculture. Through the use of sensors and actuators, an ESP32-based system offers promising solutions to lowering installations and running costs. It can collect and analyze data about environmental conditions in a greenhouse and make automated adjustments to maintain optimal growing conditions. Additionally, this system can be accessed remotely, allowing growers to monitor their crops from anywhere and make adjustments as needed. The research conducted in this study has demonstrated that an ESP32-based greenhouse control and monitoring system can be reliable, cost-effective, and easy to use. Moreover, it can significantly reduce labor costs while improving crop yield and quality. The use of wireless communication technologies enables real-time monitoring, empowering growers to make informed decisions and take timely actions. Overall, the results of this research demonstrate the feasibility and effectiveness of using an ESP32 microcontroller to control and monitor greenhouses.

With further development and improvement, this technology has the potential to revolutionize agricultural practices, encouraging the investment of all agricultural land and increasing food production to meet the demands of a growing population.

This research has comprehensively examined the design and deployment of an ESP32-based greenhouse management system. However, there remains potential for enhancements in terms of reliability and capabilities. Here are some possible future work recommendations:

- Additional sensors can be incorporated into the sensor module to extend the monitoring of environmental parameters, including soil pH levels, air quality (carbon monoxide and oxygen levels), and passive infrared sensors (PIR) to detect intrusions such as animal movement within the agricultural field, ensuring both security and comprehensive environmental data collection.
- The robustness and reliability of the designed system can be harnessed to establish a network of similar monitoring and control systems for multiple greenhouses.
- The system can be integrated with a camera to monitor the health of plants.
- The shading system can be designed and integrated with the system.

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