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IOT BASED SMART AND ECONOMIC GREENHOUSE MONITORING AND AUTO-TUNED CONTROL SYSTEM FOR RURAL FARMING

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ABSTRACT

Greenhouse cultivation plays a significant role in the agricultural sector, particularly in Asia, where it supports a substantial population. However, the challenges of water scarcity, food shortages, and the need for precise environmental parameter control necessitate innovative solutions. In this study, an IoT-based Smart Greenhouse Monitoring System is proposed to optimize greenhouse conditions and improve agricultural practices. This system utilizes sensors to monitor key environmental parameters within the greenhouse such as temperature, light intensity, and soil moisture. These sensors continuously collect data, which is then transmitted to a microcontroller board. The board performs data analysis and sends the information to an online web server through a Wi-Fi connection, allowing real-time monitoring and control. By leveraging the Internet of Things (IoT) technology with an auto tuned PID Control algorithm. The developed system also enables efficient water usage during crop irrigation by providing accurate information on soil moisture levels. Also, the IoT-based Smart Greenhouse Monitoring System leads to labour savings and enhanced time management. Through automated monitoring and control, farmers can optimize their workflow and reduce manual interventions, resulting in increased efficiency and productivity. Overall, this study aims to integrate IoT technology into greenhouse operations, contributing to the sustainability, productivity, and economic viability of greenhouse agriculture. A comparative analysis is also carried out between ATmega-based microcontroller Vs PID algorithm implemented Arduino microcontroller. By providing real-time monitoring capabilities, the IoT-based Smart Greenhouse Monitoring System offers a promising solution to optimize resource usage, enhance crop yield, and foster economic growth in the agricultural sector.

Keywords: *Soil moisture, PID controller, IoT Technology, Agriculture, Greenhouse*

1. INTRODUCTION

Greenhouse cultivation has become an integral part of the agricultural sector, playing a crucial role in ensuring food security and promoting sustainable farming practices, particularly in densely populated regions like Asia. However, the agricultural industry faces numerous challenges such as water scarcity, food shortages, and the need for precise environmental control within greenhouses. To address these challenges, the integration of Internet of Things (IoT) technology offers a promising solution Hikma et al., [1]. By harnessing IoT-based Smart Greenhouse Monitoring Systems, farmers can achieve real-time monitoring and control of essential environmental parameters, leading to efficient resource utilization, increased productivity, and improved environmental sustainability (as shown in Fig. 1). In this research, we present an IoT-based Smart Greenhouse Monitoring System that aims to optimize greenhouse conditions, enhance agricultural practices, and unlock economic benefits for rural communities. The system incorporates advanced sensors, data analysis techniques, and seamless connectivity to revolutionize greenhouse agriculture and contribute to the overall advancement of the agricultural sector. Despite the immense potential of greenhouse automation, the adoption of fully automated greenhouse systems has been relatively limited [2]. Various factors contribute to the slow uptake, including technical complexity, high costs, and maintenance requirements. The agricultural industry, being one of the oldest human endeavours, still heavily relies on manual labour, hindering the widespread implementation of automated greenhouse monitoring and management systems. However, the importance of a greenhouse monitoring and control system cannot be understated. It not only provides a controlled climate for optimal plant growth, protecting crops from adverse weather conditions but also extends the growing season, enabling earlier planting and later harvesting M. Mekki et al., [3] (as shown in Fig. 2). To address these challenges, an automatic greenhouse system capable of careful management and monitoring in predefined climatic conditions is essential Gaikwad et al., [4]. Throughout history, various techniques have been employed in agriculture, with early farmers relying on traditional methods for crop cultivation Ullah, M.W et al., [5]. However, the emergence of smart greenhouses brings several benefits to the forefront Soheli et al., [6].

By leveraging advanced technologies and automation, a smart greenhouse enhances crop yield, optimizes resource usage, reduces labour-intensive tasks, and ensures the production of high-quality agricultural products. These benefits make the implementation of smart greenhouse systems an attractive prospect for modern agriculture. A smart greenhouse has a variety of benefits, including. Increased yields are a result of greenhouse automation and intelligent optimization, which offer the plant the ideal circumstances for growth [7].

Monitoring the plants and adjusting fertigation rates, lighting, water, temperature, and air are all made feasible by greenhouse automation systems. Prevent wilting of crops in greenhouses by protecting plants from excessive temperatures: Temperature control is essential for maintaining yield quality and avoiding wilting of crops in greenhouses Maraveas et al., [8]. The automatic control of atmospheric conditions increases crop quality: Automated greenhouses control humidity changes, security breaches, heaters, fans, equipment, and power outages to provide a financially advantageous outcome for the Quy, Vu Khanh et al., [9]. If we have a lot of big greenhouses to handle, a smart greenhouse can help us save time and money. In addition, sophisticated computer technology regulates the environment for the plants using a variety of sensors to maximize each development stage, obviating the need for manual labour and boosting output. One of the main advantages of automation is its capacity to lower total production costs.

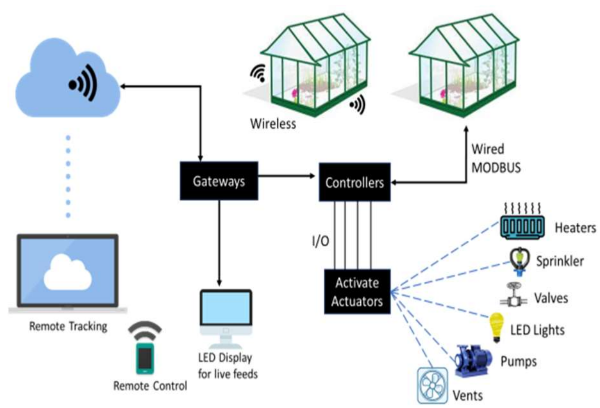

Figure 1: Schematic representation of IoT-empowered smart greenhouse

Although an integrated automated system has upfront expenses, the long-term benefits make it worthwhile. Growers now have access to automation systems of any price thanks to better technology and a wide range of alternatives Kumar et al., [10]. An automated greenhouse will make sure your systems are functioning as a cohesive unit, saving you money on total production expenses. Regrettably, too many growers are losing money owing to wasteful energy consumption.

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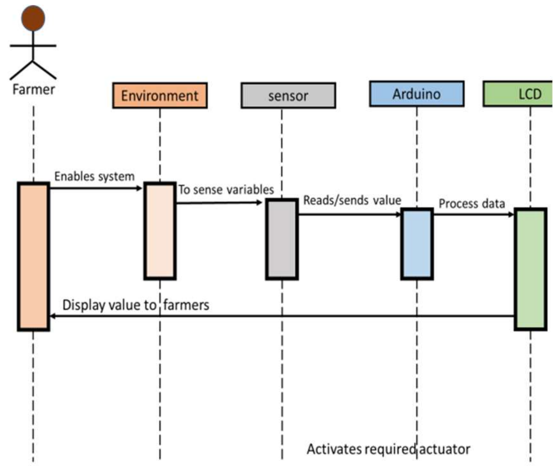

Figure 2: Sequence Diagram for the greenhouse system

Based on literature reports some of the significant crops cultivated through greenhouses in Asia, specifically India along with their significance are explained in Table 1. The following are some literature reports on this study that are discussed: Food security looks to be a growing concern for all nations in the world due to the planet's population growth, resource depletion, loss of agricultural land, and unfavourable environmental circumstances.

Table 1 Significantly cultivated crops in greenhouses in Asia

Crop Cultivated by Greenhouse	Significance
Tomatoes	Greenhouse cultivation of tomatoes is widespread in India. Controlled environments provided by greenhouses allow for optimal growth, leading to higher yields and superior-quality tomatoes.
Cucumbers	Greenhouse cultivation enables the year-round production of cucumbers, ensuring a steady supply in the market. The controlled climate within greenhouses provides favourable conditions for cucumber growth and protects the crop from adverse weather.
Capsicums (Bell Peppers)	Bell peppers are commonly grown in greenhouses in India. The controlled environment of greenhouses helps in achieving the desired colour, shape, and size of the peppers, making them more marketable.
Leafy Greens	Various leafy greens, such as lettuce, spinach, and kale, are cultivated in greenhouses in Asia. Greenhouse cultivation ensures a consistent supply of fresh, nutritious greens throughout the year, regardless of seasonal variations.
Strawberries	Greenhouse cultivation has revolutionized strawberry production in India. By creating an optimal environment, including controlled temperature and humidity, greenhouses enable year-round cultivation of strawberries, extending the availability of this popular fruit.
Flowers	Greenhouses are extensively used for cultivating flowers, including roses, carnations, and gerberas. Greenhouse cultivation ensures consistent flower quality, prolongs the flowering period, and enables export opportunities.
Herbs and Spices	Greenhouses provide an ideal environment for cultivating various herbs and spices such as basil, mint, coriander, and ginger. Controlled conditions help in maintaining the flavour, aroma, and quality of these crops.
Exotic Fruits	Greenhouse cultivation allows to production of exotic fruits like passion fruit, dragon fruit, and guava, which might be challenging to grow in open fields due to specific climatic requirements.

To optimize the advantages for farmers, studies show how IoT and Blockchain systems may relate to agriculture's intelligent components. Security is crucial for agricultural goods that must be safeguarded as well as for resources. As a result, methods for monitoring and securing the infrastructure for smart agriculture based on IoT and blockchain have been developed [11]. Most regions effectively use greenhouse systems (GHS) to offer ideal climatic conditions for the development and proliferation of plants. The crop is exposed to internal climatic conditions in the

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GHS, including interior temperature, interior humidity, and interior CO2 concentration. The temperature of the canopy, the outside air's humidity, the wind's speed, and solar radiation are the primary external disturbances. These disruptions are by their very nature dynamic and unpredictable. These controllable factors do, however, interact strongly with one another. As a result, the GHS is a collection of closely connected MIMO systems Mahfuz, N et al., [12]. Recent decades have seen an increase in the demand for technology in agriculture because of climate change and resource scarcity. To increase production effectiveness and crop resilience, farmers are obliged to embrace information and innovative communication techniques. The finest plant development may be accomplished in greenhouses since they are protected habitats. IoT for smart greenhouses refers to sensors, devices, and information and communication infrastructure for efficient indoor parameter control, including light exposure, ventilation, humidity, temperature, and carbon dioxide level. This article outlines the benefits and future potential of this technology in the agriculture sector and exhibits cutting-edge IoT-based solutions for smart greenhouses Bersani et al., [13]. Smart agriculture, smart cities, and smart farms are just a few of the intelligent applications that have widely adopted the Internet of Things (IoT). The agricultural world has recently given the greenhouse business a lot of thought because of its potential to generate fresh agricultural products at an incredible rate of expansion. To improve food production, the greenhouse needs ideal parameter settings and a regulated atmosphere. Consequently, even a little change might result in a significant increase in production at a lower total cost. We submitted an optimization method for greenhouse systems that are supported by blockchain to this study, Faisal Jamil et al., [14].

This work intends to create a remotely maintainable and programmable greenhouse system prototype for a nursery. Solar power is used in the design and control, and the ESP-32 serves as a data processor for messages sent via the Telegram app. This study compares temperature, growth, and plant weight which are all controlled and monitored manually in non-greenhouse conditions automatically in a smart greenhouse, Anuar et al [15]. Creating optimal soil and climatic conditions for the cultivation of agricultural goods in greenhouses run by intelligent systems, as well as making it easier for consumers to acquire these products, have been significant research and application topics. The subjects of "Smart Agriculture" and "Smart Greenhouse" were explored in this study. As a result, a smart greenhouse prototype was built. It was then configured to match the selected climate conditions. As such, the main objective of this study was to improve the project by utilizing the collected sensor data. We wanted to explore the viability of cultivating several plants in the same greenhouse, which was one of our main goals Kirci et al.,[16]. Automated greenhouses and smart farming techniques have been shown to aid in the growth of the world's population by supplying food that is fresh and extremely nutritious. The intelligent greenhouse house monitoring system helps increase output and raise the Caliber of the final product. The goal of this work was to create a sophisticated automation system to control the microclimate of the greenhouse. Two tomato varieties (Roma and cherry tomato) were used in both smart greenhouse systems and conventional greenhouse systems to evaluate the agronomic and quality parameters, Ahmad et al., [17]. With the spread of new technologies like the Internet of Things, enhancing yields and cost-effectiveness in agriculture and farming operations is crucial. Using IoT to automate operations that formerly required human contact, farming and agricultural processes can become more successful. The fast growth of the Internet of Things (IoT)-based tools has altered almost every sector of life, including commerce, agriculture, surveillance, etc. The Internet of Things (IoT) may be used to gather information on horticulture, soil fertility, irrigation, insect and pest detection, bug location disturbance of organisms to the sphere, and climate change.

2. MATERIALS AND METHODS

The main purpose of the IoT integration technology is to create an efficient greenhouse climate that will drastically reduce labour expenses and allow small-scale farmers to grow food all year round. The system is composed of sensors, microcontrollers, and actuators (as shown in Fig. 3). The system is designed to detect changes in the environmental parameters when they rise over a certain threshold. The microcontroller then receives the data from its input ports and takes the appropriate action to return the parameter to the desired level. The instructions given to the microcontroller cause the actuators (fan, lamp, and pump) to turn on. To display the situation within the greenhouse, an LCD is used. Finally, the complete equipment becomes portable, user-

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friendly, and simple to assemble. This study is first simulated and then implemented in hardware for the Spinach crop that is commonly cultivated in India. Detailed information on the parameters' set values is provided in this subsection.

Temperature: Spinach grows best in cool to mild temperatures. The ideal temperature range for spinach cultivation in a greenhouse is around 15 to 25 degrees Celsius (59 to 77 degrees Fahrenheit). It is important to maintain consistent temperatures within this range to promote optimal growth and prevent heat stress or bolting (premature flowering and seed production).

Soil Moisture: Spinach prefers well-drained soil with consistent moisture. The soil moisture level should be kept relatively consistent, avoiding both waterlogging and excessive drying out. It is generally recommended to keep the soil moisture at around 60% to 80% of the field capacity. Regular irrigation and monitoring of soil moisture levels using appropriate sensors or manual methods are essential for successful spinach cultivation.

Light Intensity: Spinach is considered a shade-tolerant crop and can grow in varying light conditions. In a greenhouse setting, spinach typically requires moderate to high light intensity for optimal growth. Aim for light levels of around 12,000 to 18,000 lux, which can be achieved through a combination of natural sunlight and supplemental artificial lighting if necessary. Providing sufficient light ensures proper leaf development and helps prevent stretching or elongation of plants. The set values mentioned above also help with greenhouse control. As an illustration, the following are considered; the relay will activate the fan to decrease the temperature when it is too high (40°C) when the temperature reaches the appropriate threshold value specified for temperature, soil moisture, and light intensity. Similarly, to, the pump activates when the predetermined value for soil moisture drops below 55%. Moreover, the bulb is turned on when the light intensity drops to 11,500 lux. This illustration is implemented in a real-time prototype in two different configurations; using only the Atmel ATmega328P microcontroller without any control scheme and the same is implemented using an Arduino-based PID control scheme to improve the accuracy and faster response of the system. The hardware components used in the monitoring system are described shortly.

2.1 Process Variables Monitoring System using Atmega239P Controller

The Atmel ATmega328P is a 32K 8-bit microcontroller based on the AVR architecture, processing many instructions per clock cycle at about 20 MIPS used in this study. It performs specific duties like controlling the fan based on temperature thresholds. The moisture sensor measures soil moisture content and provides analog output, reminding users to water the spinach regularly. The sensor operates under specific conditions with a maximum voltage of 5V and a current less than 20mA at temperatures between 10 and 30 degrees Celsius. The moisture sensor consists of two buried probes with stiff copper wires to measure soil moisture by electrical conductivity. High moisture content lowers resistance, while dry soil presents more resistance due to less efficient conductivity. The relay is an electrically powered switch used in circuits requiring low-power signal operation. It has two major circuits, primary and secondary, with the primary circuit controlling the switch. The ESP8266 WiFi Module enables easy Wi-Fi connection for microcontrollers and allows connection to sensors and devices with minimal upfront programming. A 12V AC motor pumps water to the agricultural field when moisture content falls below the defined level. The photoresistor, sensitive to incoming light, triggers resistance changes in light-sensitive circuits. The system utilizes IotGecko, an IoT-based program, to monitor relevant metrics. Users log in or create an account, choose the IoT application, and customize data display layouts through the dashboard. The electronic system integrates controllers to internet servers seamlessly using IotGecko, bringing the IoT system online

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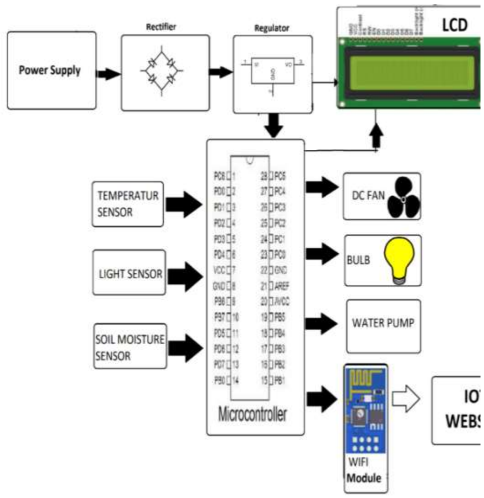

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Figure 3: Monitoring System Block Diagram

2.2 Auto-tuned PID Controller using Arduino

The Arduino PID control algorithm utilizes installed sensors to monitor soil conditions as shown in Figure 4. The microcontroller processes the sensor data and sends instructions to the automated pump for irrigation. The PID algorithm ensures optimized water usage by continuously measuring soil moisture levels using a soil moisture sensor with faster performance and accuracy. It employs a threshold-based approach, comparing the moisture level with a predefined threshold. When the moisture level falls below the threshold, the irrigation system is activated to water the plants. This simple and beginner-friendly algorithm guarantees that the right amount of water is provided to the plants at the appropriate time, thus promoting crop health. Additionally, the system can collect data and perform regression and condition monitoring in the cloud, giving farmers valuable insights into soil conditions without requiring manual irrigation. Furthermore, a user-controlled robot can spray pesticides on the crops through a mobile app, maintaining optimal crop conditions. The combination of these developed systems enables farmers to receive real-time notifications for each process in the field.

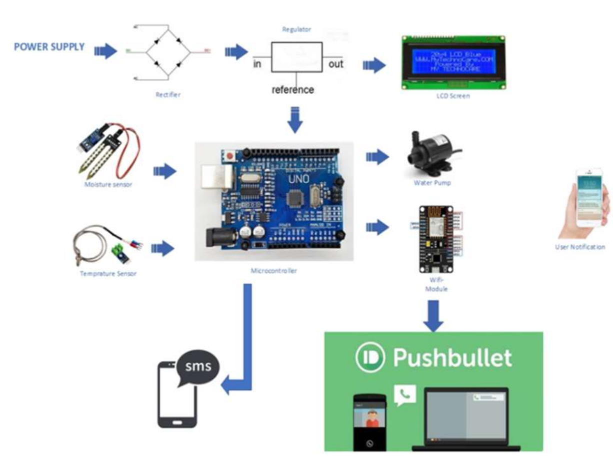

Figure 4: Schematic diagram of Arduino-based auto-tuned PID Controller

3. RESULTS

The major goals of this study are to boost output, lower labour costs, and minimize crop damage. The simulation is initially carried out by using IotGecko software (as shown in Fig. 4). The greenhouse setup and the PCB integration are shown in (Fig. 5 & 6). This process made use of a soil moisture sensor that is put into the soil. It determines if there is moisture in the soil below.

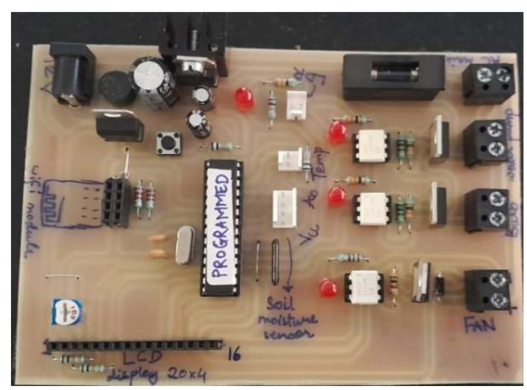

Figure 5: Integrated PCB of the developed system

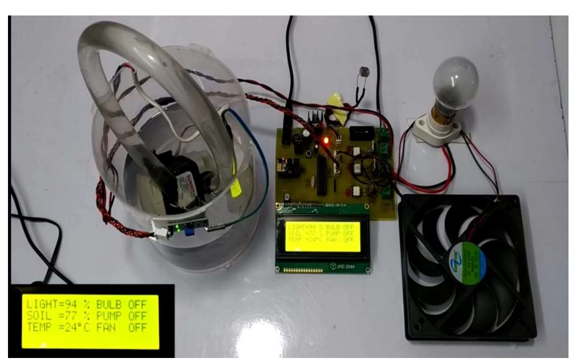

Figure 6: Hardware prototype

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3.1 Working of the Developed System

The study is initially carried out by using IotGecko software and an Atmel ATmega328P controller without the implementation of any control scheme which is shown in Figure 7. When the liquid presence is high in the ground soil. The soil permits current flow as the current is high the resistance is low, so the output is low (0). When the water content is low, the soil restricts current flow since the resistance is high and the output is high (1). As the soil moisture sensor senses the liquid content the output is forwarded to the controller of the system. The rain sensor is installed to detect the rain to stop the motor turn off. The controller accepts the input from the sensor. It determines if the input moisture content in the field is below or above the predetermined level. If the moisture content in the field from the moisture sensor input to the controller is greater than the pre-defined level. The microcontroller retains the motor in an OFF state. Else whenever the Input is high (1) when the liquid content is below the pre-defined level the controller commands, the motor driver to start the motor pumping for providing water to the spinach till the liquid content in the ground soil reaches the pre-defined level again when the soil reaches the moisture level the pump is turned OFF. Similarly, if the temperature and the light intensity do not match the predefined value, the respective actuators perform their function. This cycle keeps continuing until the user intervenes in the system's operation.

3.2 System output without implementation of Control Scheme

The soil moisture sensor detects liquid presence in the ground. When moisture is high, the output is low (0) due to low resistance, and when moisture is low, the output is high (1) due to high resistance. The sensor sends this output to the microcontroller. A rain sensor stops the motor in case of rain. The microcontroller checks if moisture is above or below the set level. If above, the motor remains off; if below, the motor pumps water until the moisture level reaches the set point, then turns off. Similarly, actuators respond to temperature and light intensity variations. This cycle continues until manual intervention. The model has been experimented with without the implementation of a control scheme. It is observed that the fan stops when the temperature reaches 18°C, the bulb status turns on when intensity is 24% and the motor turns off when moisture in the soil reaches 65%. But it was observed that these actuators take 10 seconds of delay to turn on after the predefined value has been reached. The response to the parameter variation is not instant which can be addressed by the implementation of a PID control algorithm.

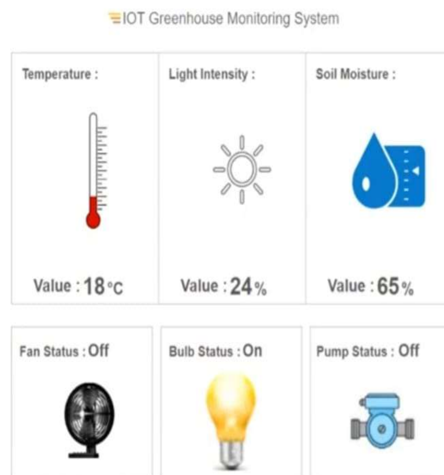

Figure 7: IotGecko software output without implementation of Control Scheme

3.3 Implementation of auto-tuned PID Controller using Arduino

The PID controller, known as a Proportional-Integral-Derivative controller, is a feedback control mechanism utilized in control systems to regulate and maintain a desired setpoint. This widely used algorithm in industrial plants continuously calculates an error signal by comparing the measured process variable such as temperature, moisture etc., with the desired setpoint. Based on this error signal, it adjusts the control output to minimize the error and bring the process variable to the setpoint. In this study, Arduino is used which serves as an automatic PID controller to efficiently control the temperature and moisture content of the spinach crop. The controller tries to minimize the error and maintains the process variable within desired limits. The ideal equation of PID controller in the time domain is given by equation (1),

$$u(t) = k_p\, e(t) + k_i \int_0^t e(t)dt + k_d \frac{de}{dt} \quad (1)$$

Where,
u(t) -control signal
e(t) - control error (e = ref – y)
ref – setpoint

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y – measured process variable

k_p, k_i, k_d are the proportional gain, integral gain and derivative gain respectively.

$$G_{PID}(s) = k_p\left(1 + \frac{k_i}{s} + k_d s\right) \qquad (2)$$

To design a control system, it is ideal to use the transfer function of the controller in the s-domain which is given by equation (2),

i. The PID control algorithm implemented in this study is demonstrated as follows.
ii. Step 1: Include the required libraries - LiquidCrystal.h for LCD control and PID_v1.h for PID algorithm implementation.
iii. Step 2: Declare variables to store gain, reference voltage, pin numbers for LEDs, temperature sensor input, potentiometer input, and oven output.
iv. Step 3: Declare variables for the PID controller tuning parameters (Kp, Ki, Kd), setpoint, controller input (y), and controller output (u).
v. Step 4: In the setup() function:
vi. Initialize serial communication at 9600 bps.
vii. Set up the LCD.
viii. Configure LED pins as outputs.
ix. Set the PID mode to AUTOMATIC.
x. Assign the sample rate for the PID control.
xi. Step 5: In the loop() function:
xii. Read the setpoint value from the potentiometer, scale it to the range of 0-255, and store it in the Setpoint variable.
xiii. Read the thermocouple input, convert it to Celsius using the gain and reference voltage values, and store it in the y variable.
xiv. Execute the PID algorithm using the myPID.Compute() function to calculate the PID output (u) based on the setpoint, input (y), and tuning parameters (Kp, Ki, Kd) set earlier.
xv. Write the PID output to the oven output pin using the analogWrite() function.
xvi. Step 6: Control LEDs:
xvii. Check if the temperature is within the desired range (between 15°C and 25°C).
xviii. Turn on the GreenLED if it is within the range, or the RedLED if it is not, using the digitalWrite() function.
xix. Step 5: Serial Communication:
xx. Display the temperature, setpoint, and PID output values on the Serial Monitor using the Serial.print() and Serial.println() functions.
xxi. Listen for incoming data on the Serial Monitor to update the tuning parameters of the PID controller.
xxii. If new tuning parameters are received, parse them using the Serial.parseFloat() function, and update the PID tuning using the myPID.SetTunings() function.
xxiii. Step 6: Update LCD Display:
xxiv. Update the LCD display with the current setpoint and temperature values using the lcd.print() function.
xxv. Write the degree symbol (°) to the display using the lcd.write() function.
xxvi. Step 7: Add a delay of 500 milliseconds using the delay() function to avoid rapid updates of the PID control loop.

The code for Arduino PID temperature control includes two libraries - LiquidCrystal.h for LCD control and PID_v1.h for PID algorithm implementation. It declares variables for gain, reference voltage, pin numbers for LEDs, thermocouple input, potentiometer input, and oven output. The setup() function initializes serial communication, sets up the LCD, configures LED pins, and assigns PID control parameters. The loop() function implements the PID controller's main logic. It reads the potentiometer-set setpoint, and thermocouple input, and computes the PID output based on tuning parameters. The output controls the oven through analogWrite(). The code also controls LEDs based on the temperature range. Serial communication displays temperature, setpoint, and PID output, allowing PID tuning via the Serial Monitor. The LCD is updated with current values, and a 500 ms delay avoids rapid PID updates.

3.4 Tuning of the developed PID Controller

To obtain the desired performance characteristics for a system the controller gains is to be tuned to an appropriate value. The controller tuning aims to achieve closed-loop stability (the output of the system output will remain bounded for bounded input), performance improvisation (the system tracks the reference changes and rapidly suppresses) and robustness (the systems acquire enough gain and phase margins to allow variations in system dynamics and modelling errors). Controller tuning refers to the process of

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finding the best set of controller gains for a specific system or process. Proper controller tuning is crucial for stable and accurate set-point tracking. This study compares two tuning methods: the conventional Zeigler Nichol's tuning and the auto-tuning approach, to determine their effectiveness in the developed control scheme. The Ziegler-Nichols (ZN) rule is a heuristic method for tuning PID controllers, aiming to find suitable values for the PID gains. The tuning process involves setting the integral and derivative gains to zero and gradually increasing the proportional gain until it reaches the ultimate gain. At this point, the control loop's output shows consistent and stable oscillations. The ultimate gain and the oscillation period (time between successive oscillation peaks) are then used to determine the appropriate values for the controller gains. Owing to this, in this system, an auto-tuned PID controller is implemented. These steps of auto-tuning shown in Figure 8 enable the user to achieve faster setpoint tracking or disturbance rejection. Thus, the auto-tune feature makes tuning simpler in short duration. The values of auto-tuned controller gains are given in Table 2.

Table 2:Values of auto-tuned controller gains

Controller Gains	Value of Controller Gains
Kp	34.68
Ki	134.83
Kd	2.23

3.5 Stability Analysis of the developed controller

The stability analysis is performed by applying an impulse signal to the model. The impulse responses are shown in Figure 9. It is observed from the above impulse response that, for both the system blocks the impulse response is exponentially decreasing which supports the stability of the system. The corresponding poles and zeroes of the controller shown in Figure 10 are real and negative roots and hence they lie on the left-hand side of the s-plant. Hence the system is stable.

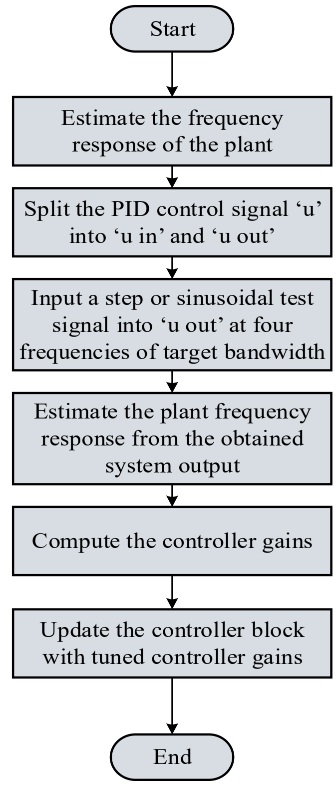

Figure 8: Steps in auto-tuning of PID Controller

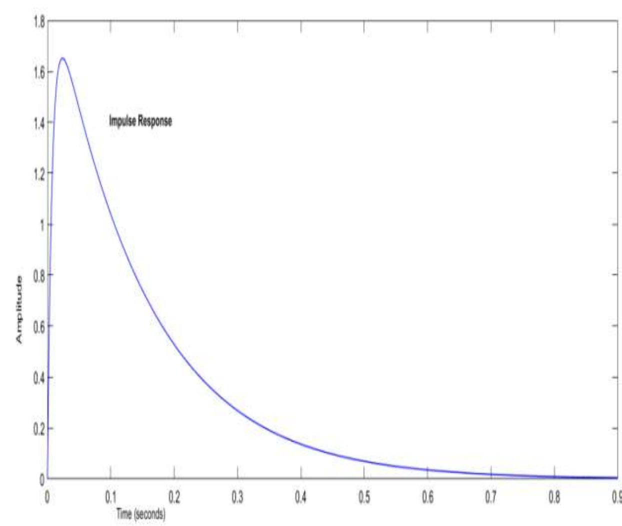

Figure 9: The impulse response of the auto-tuned PID Controller

The system response is analyzed using Matlab software. After turning the performance and robustness of the system are estimated and the values are observed to be those shown in Table 3. Based on the provided values, the control system exhibits good performance with relatively fast response characteristics. The rise time of 0.35

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seconds indicates how quickly the system reaches its final value after a step change in the reference or input. The settling time of 1.23 seconds represents the time it takes for the system's output to stabilize within a defined tolerance range after reaching the final value. The small overshoot of 13% indicates that the system approaches the desired setpoint smoothly without excessive oscillations. The peak value of 1.13 shows the maximum deviation from the desired setpoint during the system's response. The high gain margin of Inf dB indicates a robust control system with a significant safety margin before instability occurs. The phase margin of 60 degrees indicates good stability margins, ensuring the system remains stable even if phase shifts occur. Overall, the closed-loop stability of the control system is confirmed as "Stable," meaning it can effectively regulate the process with desired accuracy and without significant instability issues. The developed system is implemented on the crop that is cultivated and its performance is studied as shown in Figure 10. These results suggest that the control system is well-tuned and capable of maintaining the desired setpoint efficiently. However, additional performance improvements could be explored to reduce settling time and overshoot further, depending on specific application requirements.

Table 3: Performance and robustness of auto-tuned controller gains

Parameters	Values
Rise time	0.35 s
Settling time	1.23 s
Overshoot	13%
Peak	1.13
Gain margin	Inf dB
Phase margin	60 degrees
Closed loop stability	Stable

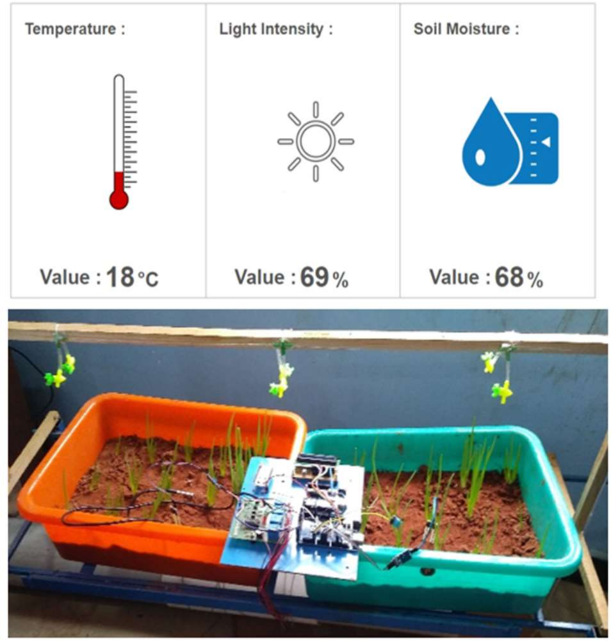

Figure 10: Demonstration of Arduino based auto tuned PID controller in Spinach crops

4. DISCUSSIONS

The paper presents a successful implementation of a Smart greenhouse monitoring and control system that effectively manages the greenhouse environment by monitoring temperature, light intensity, and soil moisture. The system's model operated as expected and demonstrated efficient functionality, utilizing easily available components. The integration of various sensors and actuators allowed for real-time adjustments based on environmental changes, ensuring optimal conditions for plant growth was initially carried out usingATmega328P controller. Notably, the automated pump control, triggered by soil moisture levels, showcased the economic benefits of this technology but it was observed a slower response. The same setup was then implemented using an Arduino-based auto-tuned PID controller which resulted in optimal performance with a faster response. The study highlights the comparative results, emphasizing how the motor pump reacts when the moisture levels fall below a specific threshold and the maintenance of moisture and light intensity. The LCD panel provided a comprehensive display of critical parameters, enabling easy monitoring for the greenhouse manager. Looking forward, the paper asl demonstrates IoT integration, which connects the farmer to the system's data through the internet, facilitating remote access and data evaluation via the IotGecko website and Push

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bullet. The goal of this project is to promote small-scale farmers' access to advanced cultivation techniques, enabling them to grow healthy crops year-round with minimal supervision. This discussion acknowledges the successful outcomes of the system while outlining potential areas for further development and broader implications for sustainable agriculture practices. The control system achieves a rise time of 0.35 seconds and a settling time of 1.23 seconds, with an overshoot of 13% and a peak value of 1.13. The gain margin is infinite (Inf dB), and the phase margin is 60 degrees, confirming its stable and robust nature for greenhouse environment regulation.

5. CONCLUSIONS

This research study presents a successful implementation of a Smart greenhouse monitoring and control system using IoT technology. The system effectively manages the greenhouse environment by monitoring temperature, light intensity, and soil moisture in real-time. It is observed that in the system the fan stops when the temperature reaches 18°C, the bulb status turns on when intensity is 24% and the motor turns off when moisture in the soil reaches 65%. The integration of various sensors and actuators allows for prompt adjustments based on environmental changes, ensuring optimal conditions for plant growth. Initially, the system operated with an ATmega328P controller, demonstrating efficient functionality with easily available components. Notably, the automated pump control based on soil moisture levels showcased economic benefits, but with a slower response. Subsequently, an Arduino-based auto-tuned PID controller was implemented, resulting in optimal performance with faster response times. It is observed that in the system the fan stops when the temperature reaches 18°C, the bulb status turns on when intensity is 69% and the motor turns off when moisture in the soil reaches 68%. Comparative results emphasized the motor pump's reaction when moisture levels fell below a specific threshold and the maintenance of moisture and light intensity. The LCD panel provided a comprehensive display of critical parameters, facilitating easy monitoring for the greenhouse manager. The study also demonstrated IoT integration, connecting farmers to the system's data through the internet via IotGecko and Pushbullet, allowing remote access and data evaluation. Hence, this study aims to promote advanced cultivation techniques for small-scale farmers, enabling year-round cultivation with minimal supervision.

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