Improving marigold agriculture with an IoT-driven greenhouse irrigation management control system

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ABSTRACT

In recent years, the internet of things (IoT) has been used to support the automated farming functions of greenhouses, preventing insects and pests, and stabilizing unsuitable weather and light conditions. Concerning an innovative IoT in agriculture, there are still a number of obstacles to enhancing greenhouses' effectiveness. This study presents the architecture, algorithms, and implementation of an IoT-based automated irrigation control system with temperature and humidity sensors. The system monitors relative humidity parameters using an internet-connected relay that controls irrigation. The relative humidity level is controlled by a 50% threshold. The effectiveness of marigold cultivation can be evaluated by means of marigold stem height, size, number of marigold flowers, and weight of the marigold harvest. The stimulating growth of marigolds is affected in every way by the differences between the proposed IoT system in a greenhouse and the conventional growing method outdoors. This contribution research validates the experimental findings to ensure that the air environment monitoring and irrigation control system consistently increases marigold yield.

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1. INTRODUCTION

Plant growth depends on the proper environmental conditions, including different soil types, pH, relative humidity, light, and temperature [1]. The growth environment of plants can affect the growth, quality, and number of agricultural produces. The challenge of controlling environmental conditions for growing plants should be under control according to each plant's individual needs. Several technologies for growing crops in greenhouses have been utilized to support improving plant growth and cultivation. Plant growth in greenhouses can be monitored and adjusted to a better suitable environment to meet the conditional needs of growing well, planting many types of seeds, and can produce crops out of season [2], [3]. The experiment design, development, and improvement of greenhouses have been continuously studied using modern technology to integrate increasing the effectiveness and efficiency of greenhouses for suitable plant growth. Greenhouse systems provide closed conditional areas for plant protection from unfavorable environmental conditions, pests, and diseases. Additionally, greenhouses offer the advantage of significantly expanding off-season products [4], [5], satisfying the year-round demand for fresh and high-quality produce by substantial retail chains. Greenhouse agriculture focuses on varieties of vegetables, crops, flowers, and fruits, such as tomato, lemon, eggplant, zucchini, cucumber, melon, squash, lettuce, oak, strawberry [6], grapes, sunflower, nigella, daisies, and marigold.

The feasible implementation of the close-environmental system can grow seeds and plants accurately for growing plant environments, especially for weather and insect conditions. One of the most promising technologies with inexpensive, portability, ease of implementation, and lower power consumption is the internet of things (IoT). Previous research on IoT solutions for water controlling and precise water management has been demonstrated and accomplished [7]–[9]. Network communications enable the smart networking of physical IoT devices, such as microcontrollers, sensors, actuators, and the internet to communicate and exchange data. The benefits of network links enable collaborative communication between machines and humans anytime and anywhere [10]. The IoT discovers its primary application in the agricultural sector for irrigation management, real-time monitoring, and remote sensing control, as stated by the capabilities in the previous study [11]. Consequently, IoT has the potential to improve agriculture, thereby increasing crop output and enhancing production quality through managing and handling several agricultural processes [7].

This study examined the optimal soil humidity, temperature, and light intensity conditions. According to the findings, the IoT automated environmental information system enhanced the plant's height and width. The optimal growing conditions for marigold seeds were relative humidity (50 to 70%), air temperature (20 to 35 ℃), soil moisture (45 to 59%), soil temperature (19 to 32 ℃), and light intensity (1,000 to 1,200 lx) [12]. However, this study only examined the marigold's growth rate, not investigating the final product. The insufficient result of marigold flower cultivation should be studied and reported for the practical result of IoT technology use. Heo *et al.* [13] studied and compared the growth and photomorphogenesis of marigold and salvia bedding plants grown from seeds to produce flowers in differences under conditions using fluorescent light and under monochromatic blue or red light and mixture radiation of fluorescent lamps with light emitting diodes (LEDs). Jomsri *et al.* [14] developed an automatic leaf disease diagnosis system for marigold plants. The system is able to detect marigold leaves and identify leaf spot disease. The system can detect leaf spots and notify gardeners in confined and expansive areas. The limitation of the research did not pertain to leaf and spot size.

However, despite these advantages of IoT application and studies for marigold growth, the research finding is only partially successful, which entails a challenge in improving the air-conditioning system in a special plant [15], such as a closed greenhouse [16], [17]. Currently, marigold flowers are the most important flowers in many economic and social sectors in Asia [18], such as Thailand, India, and Indonesia. Gardeners encounter problems with leaf diseases that affect causing the trees to deteriorate and die negatively in open areas affecting the agricultural sector [14]. For optimal marigold growth, it is necessary to control air-conditioning factors. Therefore, precise relative humidity and temperature control are required for the purposes of this study. This article focuses on designing, developing, and evaluating a greenhouse integrated with an automated relative humidity control system using the IoT. In this article, the authors present the design of an IoT-based irrigation scheduling system for micro sprinkler irrigated crop fields in a greenhouse to improve the cultivation of marigold flowers. The research contributions of this study are summarized as: i) design IoT-based hardware and software architecture for marigold growth in a greenhouse, ii) develop an automated real-time irrigation scheduling system using a micro sprinkler approach, and iii) assess the efficacy of the automated system based on plant production and growth.

2. METHOD

2.1. Proposed research method

As depicted in Figure 1, the proposed system design and development of an automated relative humidity control system utilizing the IoT involved several processes. A greenhouse preparation was assembled, as depicted in Figure 2. The authors reused a greenhouse from previous marigold growth in this experimental study. Figure 3 shows the marigold plantings in plots planned to plant inside the greenhouse. The next step was the information system and technology development, including a web server configuration process. A web server configuration begins with the installation of a web server, the creation of a database system, and the development of a relational database. Then, the proposed system design and prototype development processes were established, as shown in Figure 4. The architecture layout and IoT devices for improving the greenhouse of marigold culture using automated irrigation with relative humidity controlling system were designed. The actual system application process was implemented by Algorithm 1, used to get data from SHT11 sensors and store the humidity and temperature data in the database system. Moreover, Algorithm 2 was used to retrieve data from the database system and display the results thru the graphical dashboard. The final process was the evaluation results of plant cultivation compared the proposed IoT-based system and the conventional method (CM) based on the means of marigold stem height, size, number of marigold flowers, and weight of the marigold harvest.

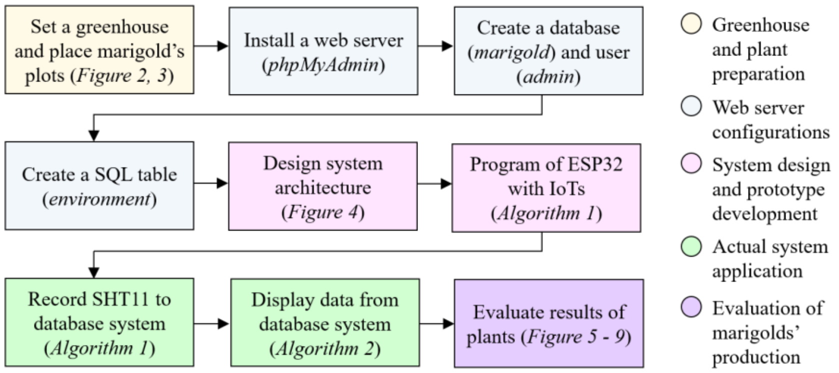

Figure 1. Research methods of IoT-based automated irrigation controlling system

Figure 2. Greenhouse setting and materials

Figure 3. Marigold plants in actual greenhouse

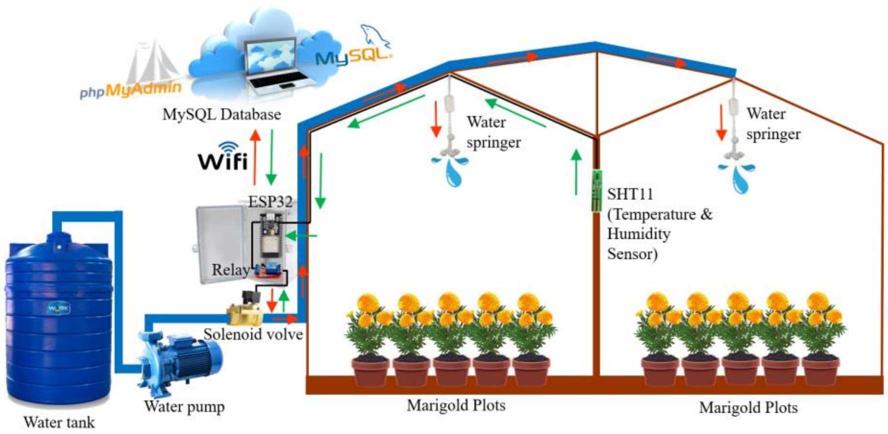

Figure 4. System model of IoT-based automated irrigation control system in a greenhouse

Algorithm 1 for read, insert, and control relative humidity from SHT11 sensor

```
Input: wifi_ssid, wifi_pwd, server_name, dbname, username, dbpwd, api_key_value, SHT_sens
Output: wifi_status, db_status, SHT_status, SHT_humidity, SHT_temp
Procedure:
Valid wifi_ssid, wifi_pwd
Valid servername, dbname, username, dbpwd
Valid api_key_value of ESP32
Include SHT11 library
Define SHT11pin
Define relay pin
Define value = 50
while do
      Read SHT_humidity
      Read SHT_temp
      Calibrate values of SHT_humidity and SHT_temp
      if SHT_humidity < value
            set relay high
```

```
    else
        set relay low
    Insert SHThumidity, SHTtemp, datetimestamp into database
    delay 60UL*60UL*1000UL
    if SHT status < 1
        start ESP32
        alert to users through httpResponseCode
      Close dbname
```

Algorithm 2 for display data of SHT11 sensor from database system

```
Input: server_name, dbname, username, dbpwd, SHThumidity, SHTtemperature
Procedure:
Valid servername, dbname, username, dbpwd
Include javascript
Get results from Select SHThumidity, SHTtemp, datetimestamp from database
json_encode(results)
if result > 0
    while
        call drawpiechart function
            drawchart(results), add column, add rows, getvales, getelementById
else
    print result 0 record
      Close dbname
```

2.2. Controlled conditional growth of closed system greenhouse

The top of the greenhouse was built using a plastic sheet. In addition, the plastic sheet replaced on the top of the greenhouse can protect the greenhouse from rain. The sides were covered with black shading nets without UV protection filtering 70% of light additionally for use in controlling the relative humidity and preventing insects, as shown in Figure 2. In this setting environment experiment, the estimated light intensity was uncontrolled because Thailand is a tropical country that affects enough light for the growth of tropical plants.

A marigold plant is grown simply from seeds and it normally takes 25 days for an average plant reaching height of 3 cm [13]. Marigolds germinate rapidly, sprouting in a few days and blooming for approximately 4 weeks. During the experimental study, the authors used a total of 200 plots of marigold plants, which had been grown for 30 days, approximately height 24-30 cm. In the actual greenhouse, the plots of marigolds are divided into two experimental groups of 100 plots each, as depicted in Figure 3.

The controlled conditional growth sets the relative humidity in the greenhouse not to be lower than the specified percentage (not less than 50%). When the relative humidity is lower than the threshold, the water pump will be initiated by a relay switch, and micro-sprinklers on the ceiling will spray water to increase the relative humidity and reduce the temperature in the greenhouse. IoT sensors inside the greenhouse collect environmental data on humidity and temperature and send data to the database system every hour.

2.3. Automated irrigation control system

An effective irrigation control system for greenhouse cultivation meets certain requirements to ensure optimal plant growth and water usage. The proposed approach includes sensors that precisely measure air temperature and humidity, essential for determining the greenhouse plant's water requirements. An automatic floating valve has been installed in the reserve water tank so that the water consistently monitors the threshold level required by the gardener. The system's simple interface enables the grower to set the desired moisture level and irrigation schedule easily. Unless a gardener is notified, a relay tests the solenoid valve's functionality and maintains a constant water flow proportional to the relative humidity level. The system installed a 300 watt electric water pump. For remote monitoring and control, the system has established a reliable and stable Wi-Fi internet connection. A Wi-Fi router operating at 2.4 GHz is installed within 10 meters of the irrigation control system. Finally, the system is designed with energy efficiency, reducing energy consumption, and operating expenses. By adhering to these requirements, an irrigation control system can increase greenhouse crop yield and quality while decreasing water waste and labor expenses.

Figure 4 displays the architecture workflow and environmental design of a greenhouse's IoT-based air-conditioning automation system's major components. The suggested monitoring of humidity, temperature, and remote control of marigold plant pots were shown. The overview of the IoT-based automated relative humidity control system's system model depicted the system's regulating input, process, and output. The input layer included the SHT11 sensor receiving environmental humidity and temperature data. A microcontroller (ESP32) was employed as a portable integrated circuit at the process layer. The ESP32 can perform various tasks, including receiving sensor data, determining the necessary relative humidity levels, managing the on/off status of a relay, and establishing the web server. The output layer included setting and retrieving a relay to control an irrigation system with a solenoid valve, connecting to the web server, server name, database name, username and password, inserting an environmental parameter into the database system, and retrieving environmental data via the web application. The next stage was connecting the ESP32, a relay, and a solenoid valve to a circuit. Two sprinklers were utilized to support the solenoid valve. An automatic water pump with a floating switch was put in the water tank to monitor and control the water level. Arduino integrated development environment (IDE) is open-source software for writing and uploading code to a variety of microcontrollers, including Arduino boards, ESP8266, and ESP32 [19]. This study configured the ESP32 for usage with the Arduino IDE, which requires modifying the API key value of the ESP32.

In addition, a microcontroller, a set of environmental sensors, and an irrigation system (including a relay, a solenoid valve, a pump, and a watering sprinkler system) were used to control and monitor the selected parameters. As follows is the communication between the various entities:

- A SHT11 sensor gathered real-time environmental data on humidity and temperature [20] from various greenhouse regions. The SHT11 sensor measures humidity and temperature accurately over a wide measurement range and features industry-proven quality and dependability. The authors calibrated the SHT11 sensor for a fixed 5 volt regulator using (1) to convert digital readout (SO_T) to celsius temperature value [21], with coefficients for sensor precision given (1):

$$T_{°C} = d1 + d2 \cdot SOT \tag{1}$$

  Where $T_{°C}$ is the true temperature, d_1 is the constant value depends on electronic input value of SHT11's VDD pin (-40.1), d_2 is the constant value depends on temperature accuracy required from SHT11 (0.04), and SO_T is the temperature value from SHT11 (12 bits). For the sensor's full accuracy, the humidity sensor must be compensated for non-linearity. The accuracy of the humidity display is indicated by the coefficients in (2) and (3):

$$RH_{linear} = C_1 + C_2 \cdot SO_{RH} + C_3 \cdot SO_{RH^2}\ (\%RH) \tag{2}$$

$$RH_{true} = (T_{°C} - 25) \cdot (t_1 + t_2 \cdot SO_{RH}) + RH_{linear} \tag{3}$$

  Where $T_{°C}$ is the true temperature, t_1, t_2, C_1, C_2, C_3 are the constant value of accuracy relative humidity from SHT11 (0.01, 0.00008, -4, 0.0405, -2.8×10^{-6}), and SO_{RH} is the relative humidity value from SHT11 (12 bits).
- Every hour, an ESP32 microcontroller uploaded collected data via Wi-Fi to a local host web server running phpMyAdmin for controlling, monitoring, and notification reasons. Using MySQL for create, read, update, and delete (CRUD) operations is an abbreviation for the four core database systems (CRUD). A mobile device can access a marigold greenhouse's web-based environment monitoring system.
- The automated irrigation system was designed to irrigate automatically at the designated time. Using a relay module, the ESP32 can control solenoid valves. The marigold greenhouse's environmental sensors were relayed in real-time to the specified ESP32 microcontroller, which compared the relative humidity and temperature.

In Algorithm 1, the authors define the home Wi-Fi configuration and variables (*Wi-Fi ssid*, *Wi-Fi password*, *server name*) for the IoT-based automated relative humidity system utilizing ESP32 programmed to read humidity and temperature data (*SHThumidity*, *SHTtemp*) from the SHT11 sensor over the Wi-Fi connection. In addition, the static irrigation condition is specified to regulate relative humidity. Suppose the value of relative humidity is lower than 50%. In that case, the relay will set a high status (*SHThumidity<50*), and the solenoid valve will turn on to water through two watering sprinklers automatically. Using phpMyAdmin to configure the database name, username, and password (*dbname*, *username*, *dbpwd*) and the MySQL programming language to manage data, data can be recorded into the database system. The authors have set the hourly recording delay time to *delay 60UL*60UL*1000UL*. However, if the SHT11 sensor fails to send the response signal to the ESP32, the system can automatically reset the ESP32. The greenhouse dimensions were 4 meters in length, 4 meters in width, and 3 meters in height. During the experimental study, a user monitoring information dashboard was developed. In Algorithms 2, the authors connected a home Wi-Fi network using configuration and variables (*wifi_ssid*, *wifi_password*, *server_name*). Then the IoT-based automated relative humidity system retrieved humidity and temperature data (*SHThumidity*, *SHTtemp*) from the MySQL database system over the Wi-Fi. The web application imported Google charts to generate graphical charts using the JavaScript-embedded platform (*json_encode*, *drawpiechart function*).

2.4. Measurements factors affecting growth

Flowers of the marigold have a single layer of yellow and orange petals. It is a dicotyledonous plant ranging in height from 25 cm to 60 cm. Typically, a cluster of marigold plants produce a cluster of five to ten yellow flowers. A marigold flower diameter is range among 2 cm to 8 cm and the yielding period is approximately 60 days to 70 days [22]. The growth of marigold plants is affected by temperature, pH, and light [23]. Suitable relative humidity and temperatures of marigold plants are range between 50% and 60% [12] and range between 19 °C and 32 °C [13], respectively. Especially at night growth of marigold plants can have a significant impact on flower size. In addition, photoperiods exceeding 12 hours have an effect on flower size. The optimal pH range for marigolds is between 6.8 and 7.0, similar to that of other flowers. Marigold plants require direct sunlight. Therefore, marigold plants should be planted in soil that receives at least six hours of direct sunlight per day outdoors as the same as in a greenhouse [24].

In this study, the marigold seedlings used as a starting culture were 30 days old. Using the same marigold seedlings, soil, and natural light for 30 days, a comparison was conducted between an IoT-based automated relative humidity system and a conventional growing technique. All marigold plots were fertilized with the 12-24-12 formula at the rate of 1 teaspoon per plant between 35 and 45 days old. The IoT-enabled automated relative humidity system in the greenhouse was monitored to prevent relative humidity from falling below 50%. In contrast, the conventional growing method required twice daily irrigation (only at 8 am and 4 pm). The results of a comparison of marigold plants were determined by measuring their sizes, stems, number of marigold flowers, height, weight, and flower cultivation over 20 days. Every other day, the flowers were harvested ten times.

3. RESULTS AND DISCUSSION

The stimulating growth of marigolds is affected by the different growing methods of the proposed IoT system in a greenhouse and the conventional growing method. Figure 5 illustrates the four-week differences between the proposed IoT system and the conventional growing method. With an average stem height of 44.00 cm for the proposed IoT system and 35.25 cm for the conventional growing method, the proposed IoT system produced taller marigold stems. Figure 6 illustrates the significant differences between harvest seasons. The average size of marigold flowers cultivated using the IoT system approach was 7.55 cm, compared to 5.25 cm using the conventional growing method.

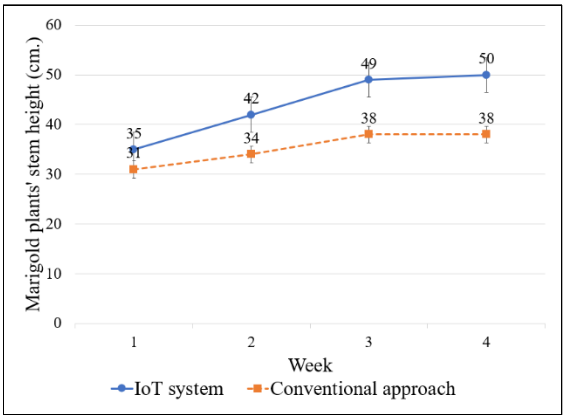

Figure 5. Effect of different growing methods on marigold plants' stem height

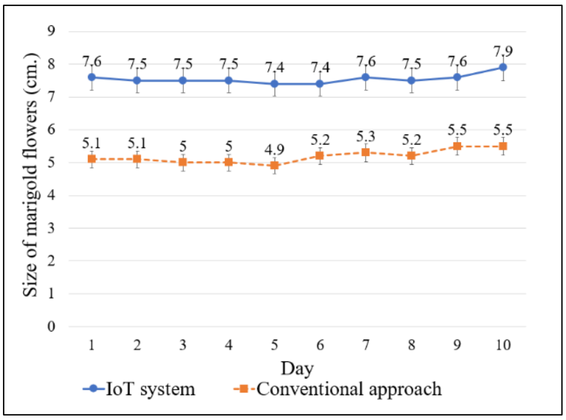

Figure 6. Effect of different growing methods on flower sizes of harvested marigold plants

Figure 7 illustrates the statistically significant variations in the number of harvested marigold flowers. The proposed IoT system approach produced an average of 260.50 more marigold flowers than the CM, which produced an average of 226.70 marigold flowers. Figure 8 depicts the significant correlation between the total weight of harvested marigold flowers and the number of marigold flowers produced. Approximately 2-4 marigold flowers are ready to be harvested per day. With an average weight of 2,363.39 g and 1,471.09 g, respectively, the weight values of the proposed IoT system approach were greater than those of the conventional growing method. In Table 1, ten harvested times illustrate the effect of the IoT system and the conventional growing method on the growth of marigolds in terms of average diameter, numeric values, and the total weight of harvested flowers. Figures 9(a)-(d) compares the physical characteristics and diameters of marigold flowers grown using the proposed IoT-based irrigation systems and CM. Figures 9(a) and (c) depict the outcomes of IoT-based irrigation systems on a marigold flower. In contrast, Figures 9(b) and (d) depict the outcomes of a conventionally grown marigold flower.

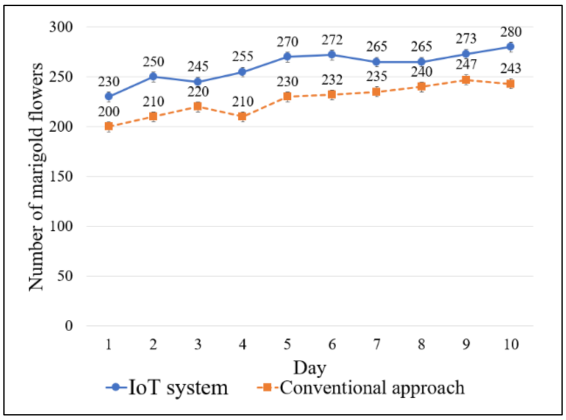

Figure 7. Effect of different growing methods on cultivations of marigold flowers

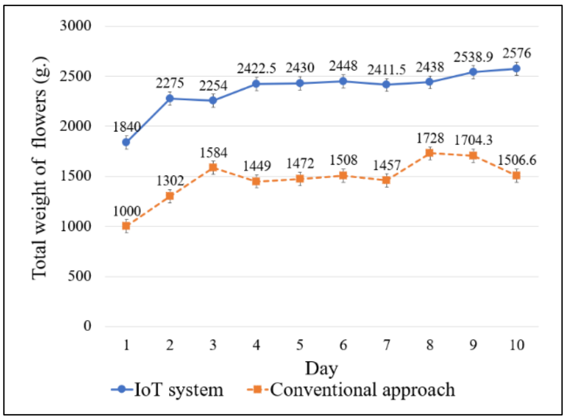

Figure 8. Effect of different growing methods on the total of weight marigold flowers

Table 1. Different results of marigold growth based on the IoT system and the conventional growing method for cultivation on average sizes, total number of flowers, and total weight

Day	Sizes (cm)		Numbers		Weights (g)		Day	Sizes (cm)		Numbers		Weights (g)	
	IoT	CM	IoT	CM	IoT	CM		IoT	CM	IoT	CM	IoT	CM
1st	7.60	5.10	230	200	1840.00	1000.00	6th	7.40	5.20	272	232	2448.00	1508.00
2nd	7.50	5.10	250	210	2275.00	1302.00	7th	7.60	5.30	265	235	2411.50	1457.00
3rd	7.50	5.00	245	220	2254.00	1584.00	8th	7.50	5.20	265	240	2438.00	1728.00
4th	7.50	5.00	255	210	2422.50	1449.00	9th	7.60	5.50	273	247	2538.90	1704.30
5th	7.40	4.90	270	230	2430.00	1472.00	10th	7.90	5.50	280	243	2576.00	1506.60

(a) (b) (c) (d)

Figure 9. Physical characteristics on integrity: (a) IoT system, (b) conventional growing method a flower diameter, (c) IoT system growing approach, and (d) conventional growing approach

This study focuses on automating relative humidity control parameters so that marigold plants can be cultivated more efficiently in a practical greenhouse, particularly with the support of an IoT-based automated irrigation system. Similar recommendations are provided in [12], [13], [24] for marigold plants grown with an optimal relative humidity of 50% throughout the duration of the study. Likewise, the IoT-based control system of a factor in success can operate and monitor environmental data sustainably. The negative effects of climate change and global warming on agriculture can be mitigated by optimizing critical parameters, including environmental information (temperature, humidity, CO_2, soil moisture, pH, and light intensity), data acquisition, plant production and growth, and removing barriers to the commercial and industrial adoption of smart design and development systems [13], [14], [24]–[26]. In addition, IoT technology can be used to improve the production and growth of marigold plants, as the stem height values and diameter range have reached the standard presented in [22]. Surprisingly, the number of marigold flowers harvested [22] was below the norm for both methods. The average yielding period is between 60 and 70 days, whereas the duration of this study was only 30 days.

4. CONCLUSION

The conclusion of the research article highlights several significant contributions and implications of the proposed IoT-based automated air-conditioning control system for marigold plants in a greenhouse. This article proposes an IoT-based automated air-conditioning control system for marigold plants in a greenhouse using the SHT11 temperature and humidity sensor. The sensor is essentially calibrated and connected to an ESP32 microcontroller. The ESP32 enables data storage in the database system using PHPMyAdmin through a Wi-Fi connection. Using a relay to control the on-off solenoid valve, the system maintains dynamic irrigation treatments based on the requirements of particular relative humidity conditions. The experimental results demonstrate and confirm that the proposed approach is advantageous for the efficient water management of plot-grown marigold plants. The stem height, yield productivity, number of harvested marigold flowers, and weight of harvested marigolds can be increased by 24.82%, 45.75%, 14.91%, and 66.78%, respectively, compared to the manual irrigation method.

The theoretical contributions of the study include the development of a practical approach to automate relative humidity control parameters for marigold plants in a greenhouse. The study integrates an IoT-based control system to monitor and optimize critical environmental parameters, including temperature and humidity, based on natural light intensity. The research findings demonstrate the potential of IoT technology to improve the production and growth of marigold plants, leading to increased stem height, yield productivity, number of harvested marigold flowers, and weight of harvested marigolds.

The practical applications of the research are significant, as the study offers an innovative and culture-effective approach to optimize growing management for marigold plants. The proposed IoT-based system enables the efficient control of irrigation treatments, leading to the increased growth and yield of marigold plants. The system offers potential benefits for greenhouse growers, enabling the additional automation and monitoring of critical environmental parameters, leading to improved crop yields, reduced water usage, and improved ecosystem management. Despite the significant contributions and implications of the proposed system, the study also has some limitations. One of the main limitations of the study is the relatively short duration of the experiments, which were only conducted for 30 days. Future research could focus on investigating the long-term effects of the proposed system on marigold plants and the consistency of the data obtained from the system compared to the traditional growing method. Additionally, future studies could investigate the integration of more sensors and machine learning algorithms to analyze the data obtained from the proposed system to optimize the control of environmental parameters and improve crop yields further.

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