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A Prototype System Design for Microgreens Iot-Based Smart Vertical Farm

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Abstract. This study aimed to investigate the impact and potential of integrating IoT technology, specifically the Momo Farm smart vertical farming system, in enhancing microgreens cultivation. The research was motivated by the need for efficient and automated farming solutions to address the challenges of maintaining microgreens on a larger scale, given their daily attention requirements and diverse maintenance needs. The study employed a mixed-methods approach, combining field trials with data analysis from soil humidity sensors and DHT11 temperature and humidity sensors. The results demonstrated that the Momo Farm system effectively automated the cultivation process, optimizing water and lighting supply based on real-time data. The implications of this study are twofold: first, it offers practical value by providing urban farmers with a user-friendly and flexible tool to manage large-scale microgreens cultivation, reducing the need for manual intervention and improving resource efficiency. Second, it contributes to the field of IoT-based smart farming by showcasing how integrating various sensors and cloud-based data storage can lead to sustainable and technologically advanced agricultural practices. Overall, this study highlights the potential of IoT technology in revolutionizing microgreens cultivation practices and supports the broader adoption of smart vertical farming systems in urban agriculture.

Keywords: Microgreens, Smart Farming, Internet of Things, Vertical Farming

1. Introduction

For a healthy lifestyle, the World Health Organization (WHO) suggests that each person should consume 400 grams of fruits and vegetables on a daily basis (EK Amine, 2002). However, the national consumption of fruits and vegetables combined is only 209.89 grams per capita per day, as reported by data from BPS. (Idris, 2020). This amount is still far below the threshold set by WHO and the Ministry of Health (Lokadata, 2020). Despite the pandemic, the consumption of vegetables among the Indonesian population has decreased. In 2020, the average consumption of vegetables by the Indonesian population was only 38.51 kcal, which is significantly lower than the WHO's recommended intake of 62.5 kcal. (Andini Ayu, 2021).

The reason is that the price of vegetables is high, so the community prioritizes carbohydrate needs as an energy source, in this case, rice, while vegetables are essential as a source of dietary fiber, vitamins, and minerals beneficial for digestive health. The high price of vegetables is due to uneven distribution. For vegetable plantation centers, the prices are affordable, but when they reach outside the centers (big cities), the prices sometimes become expensive. Director of Southeast Asian Food & Agricultural Science & Technology SEAFAST Center, LPPM-IPB, Prof Dr. Nuri Andarwulan, explained that land rent prices are high in urban areas. In mapping the city layout, it is also depicted that the allocation of green open space intended for seed gardens is only 5.181% of the total open land available in Jakarta (Supriyatna Iwan, 2018).

Based on data collected by BPS, vegetable production in DKI Jakarta province tends to be unstable and decreased from 2016 to 2021 (Badan Pusat Statistik, 2016). Planting vegetables on limited land can be a solution to meet vegetable needs despite the high price due to uneven distribution. However, extreme weather and pest attacks can have a significant impact on the agricultural sector and affect the quality of vegetables. High rainfall and drought can negatively impact plant growth (Catriana, 2022).
To tackle these challenges, there has been an increasing focus on utilizing technology in agriculture to enhance productivity. Among the technologies being explored, IoT-based smart farming has emerged as a promising solution, offering real-time monitoring of farming processes, plant protection, improved crop quality, fertilization control, and early prediction of plant diseases. In Indonesia, several technological advancements in agriculture have been studied, including the development of mobile application for agrotechnology systems (Fajar et al., 2022) and crop monitoring through the Internet of Things (Buana et al., 2019).

The implementation of IoT technology has had a substantial impact on the digital transformation of the agricultural and industrial sectors. The success of IoT in agriculture has been demonstrated through its application to chili plantations. (Liu et al., 2020). A previous study about cloud-based IoT applications have shown great potential in transforming agricultural practices by providing real-time data collection, analysis, and decision-making capabilities (Yoon & Kim, 2020). Implementing IoT-based smart farming technology at the Serenity Farm farmer group in Cibodas Village has resulted in adequate water and nutrient conservation. By adjusting the watering and fertilization according to the plant's needs, the technology has prevented the wastage of water and fertilizers, resulting in savings of up to 60% of usage (Ministry of Agriculture Republic Indonesia, 2021).

The previous studies proved that IoT has a good impact for agriculture. However, the existing studies efforts have predominantly emphasized improving monitoring and control efficiencies in plant cultivation, without directly tackling the pressing issue of limited open land for urban farming in big cities. Thus, this study aims to shift its focus towards creating a comprehensive solution that can effectively address the challenge of land scarcity in Indonesia, by developing a prototype of an IoT-based indoor vertical farming system that will particularly explore the potential of microgreens. Given their small form factor, as a viable means to optimize space utilization in urban farming practices. Microgreens also contain a wide variety of nutrients and health benefits, including high levels of micronutrients compared to their fully-grown counterparts.

Maintaining microgreens on a small scale is relatively easy due to their compact size and short harvesting period, however scaling up becomes challenging. The daily attention required for optimal water and light supply along with monitoring a large number of microgreens, especially with various types, demands diverse maintenance approaches. The smart vertical farming system offers significant potential in improving microgreens cultivation. An IoT-based indoor vertical farming system provides users with more flexibility by reducing the need for constant microgreens maintenance. The system also enables enhanced monitoring and control of the cultivation environment, critical in preventing issues related to traditional microgreens cultivation such as water intake and excessive humidity, which can lead to mold growth.

2. Literature Review

2.1. Internet of Things

The Internet of Things is a revolutionary trend that is rapidly expanding. It involves adding technology such as sensors and software to physical objects to enable control, communication, and data exchange with other connected devices over the internet. This enables intelligent organization, tracking, positioning, security, real-time online monitoring, upgrades, process control, and individual device control. (Patel et al., 2016). The Internet of Things (IoT) has revolutionized several sectors, including industry, health, agriculture, and education, making them more efficient and convenient (Shafique et al., 2020) To ensure efficient IoT deployments in different scenarios, multiple layers of technology in its architecture demonstrate how the technologies communicate and provide scalability. These include the sensor, gateway, network, management service, and application layers. (Mitra & Dipra Mitra Assistant Professor, 2021).

2.2. Wireless Sensor Network

A wireless sensor network (WSN) is an infrastructure that uses wireless technology to connect multiple sensor nodes spread over a particular area. WSN is a powerful technology that can monitor various environmental conditions, including temperature, humidity, light levels, noise levels, and object movement. This technology bridges the physical and digital worlds, allowing for real-time data collection, analysis, and transmission. (Pratama & Suakanto, 2015). In order to create a wireless sensor network, a protocol is required to manage communication activities among devices. ESP32 and MQTT protocol is widely used for Internet of Things applications such as controlling actuators and reading sensors. Another successful implementation of the wireless sensor network was also done for crop management on a paddy field (Athirah et al., 2020).

2.3. Smart Farming

The agricultural sector has seen significant advancements with the integration of IoT, particularly through the deployment of various sensors to achieve smart farming goals. Cloud-based remote data collection has made it easy to share information and enable intelligent control and decision-making services through IoT services. This has led to increased efficiency in the production process for the smart agriculture industry. A notable application of IoT in the smart farming industry includes the scheduling of various agricultural activities such as irrigation, plant growth, leaf disease detection, and production control (V, 2021).

2.4. Microgreens

Microgreens are edible vegetable seedlings that have gained immense popularity recently and are typically harvested between 10-14 days after sowing. Although they are a fast-growing crop, requiring just 1-3 weeks after sowing in seed, they need sunlight and regular watering to support their growth (Choe et al., 2018). Proper maintenance of soil moisture is in the range between wet and dry conditions, and optimization of environmental factors, such as temperature, which should be maintained between 25°C to 30°C, are also crucial for the healthy growth of microgreens. There is an increasing trend in green vegetable consumption due to their higher concentration of bioactive components compared to ripe vegetables. These bioactive components, such as antioxidants, vitamins, and minerals, are crucial for human health. Microgreens are known to possess numerous benefits, including aiding diabetes control, reducing the risk of heart attacks, lowering cholesterol levels, and boosting the immune system (Agarwal, 2020).

2.5. Five-Layer IoT Architecture

Developing a new architecture for IoT involved combining the technology architecture of the internet and the logical structure of the Telecommunications Management Network with the unique features of IoT. The resulting architecture comprises five layers: the Business Layer, the Application Layer, the Processing Layer, the Transport Layer, and the Perception Layer. The Perception Layer is responsible for perceiving the physical properties of objects using sensors and converting the information to digital signals for network transmission. The Transport Layer uses various networks to transmit data from the Perception Layer to the processing center. The Processing Layer stores, analyzes, and processes the information received from the Transport Layer. The Application Layer develops various applications of IoT based on processed data, such as intelligent transportation, logistics management, identity authentication, location-based services, and safety. The Business Layer manages the IoT applications and the relevant business model (Miao Wu, 2010).

3. Methodology

This research adopts the five-layer IoT architecture, which divides an IoT system into five layers: Business, Application, Middleware, Network and Perception (Wu et al., 2010). In perception layer, there are two sensors, namely the DHT11 temperature & humidity sensor and soil moisture sensor, to monitor the plant in real time. ESP32 microcontroller board supports the tool's data processing and networking activities by receiving inputs from the sensors and sending them to the cloud. The actuators in this layer are 12V LED lights and misting nozzles. After the data is obtained, the collected data will be sent by the network layer via the Internet network, which uses Wi-Fi as the medium and will be sent to the cloud in middleware layer as an intermediary between the device and the user application, and if it has been successfully sent, it will be passed back to the application layer, showing the data of real-time temperature, humidity, and soil moisture of each plot, in the form of the current condition and graph visualization to the IoT-based Smart Vertical Farming application, so that the user as a business layer can immediately monitor the condition of the plants and manually control the actuators if needed.

Fig. 1: IoT-based Smart Vertical Farming Tool Architecture

The block diagram of the IoT-based Smart Vertical Farming Tool can be seen in Figure 3. In this study, the ESP32 microcontroller serves as its brain and is equipped with a Wi-Fi module for connectivity. Two sensors are present in the device, which convert environmental parameters into electrical signals processed by the microcontroller. The DHT11 sensor is placed on the rack to monitor the temperature and humidity of the air surrounding the plants, while the soil moisture sensor is placed in the planting medium and tray to monitor the water level in the planting medium. The sensor captures data, which is then sent to the cloud via the microcontroller's Wi-Fi. The microcontroller is also responsible for controlling the actuators by sending appropriate control signals through the actuator control pins on the microcontroller board. The microcontroller determines when and how the actuators should be activated or deactivated based on user commands and preset timers. A 12V LED light is located at the top of each rack slot, providing UV light to the plants. A water nozzle is located at the top of each rack slot, providing water to the plants. The ESP32 microcontroller communicates with the database and Momo Farm mobile apps using APIs. This study used a cloud-based database called the Firewall Real-time Database. To retrieve data from the cloud, the Momo Farm mobile apps can use APIs to access the cloud database. The app sends a request to the cloud using an API, and the cloud responds with the requested data. Momo Farm mobile apps can display data in a dashboard, graph, and cumulative data. Additionally, Momo Farm mobile app can use APIs to send commands to the cloud, which can then forward those commands to the ESP32 microcontroller to control the actuators.

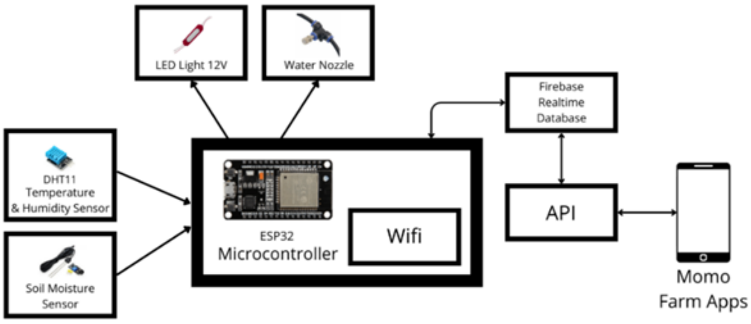

Fig. 2: Block Diagram of IoT-based Smart Vertical Farming Device

A sketch of the IoT-based smart vertical farming device can be seen in Figure 2. After installing the device according to the instructions, the plants will be fully monitored every 15 minutes. This device sends data to the cloud via an Internet connection or Wi-Fi available around the device. Cloud will send the data to Momo Farm mobile apps installed on the user's smartphone as a dashboard containing each plot data's current temperature, humidity, and soil moisture and a graph containing the data in a month. The sketch of Momo Farm device can be seen in Figure 3.

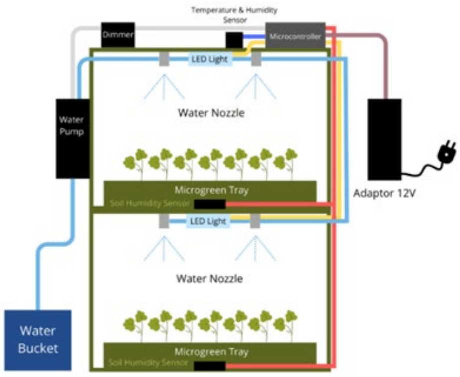

Fig. 3: Sketch of Momo Farm Device

4. Result

4.1. Current Condition

Growing conditions are essential for microgreens as they directly affect plant growth and nutrient levels. Microgreens take 10-14 days to grow and require no fertilizers or pesticides. Factors affecting microgreen growth include exposure to light, temperature and humidity (Weber, 2017). Microgreens need 4-8 hours of direct sunlight each day to grow healthy. It is also important to keep the seeds moist until germination and spray the buds at least once daily (Singer, 2021.). For this experiment, spinach, water spinach, and corn were germinated and maintained manually by putting the trays in a minimum sunlight room and watered manually with a sprayer. Spinach microgreens germinate in drainage trays on top of rockwool as a growing media and to help with the moisture. Water spinach microgreens germinate in drainage trays and are covered with potting soil and stackable trays to distribute pressure. Corn microgreens germinate in drainage trays without any growing media. To maintain the humidity, microgreens are sprayed at least once a day. Microgreens were grown for ten days without any support from the device.

4.2. Proposed System

Smart farming is one of the solutions that can help improve productivity and efficiency in modern agriculture. In this study, a smart agriculture application is implemented to monitor and control farming systems through internet connectivity remotely. The application is developed in Android Studio with a board integrated by Arduino IDE for optimized functionality. Additionally, the application implements the Firebase Real-time Database as a data store to ensure the reliability and availability of real-time data. The application features real-time data monitoring and graphic visualization by using soil moisture, temperature, and humidity sensors. Water nozzles and LED lights provide manual control of irrigation and lighting and automatic settings that can be adjusted using the application's control buttons. The hardware used in this system includes the ESP32 microcontroller with Wi-Fi module, 16x2 I2C LCD, DHT11 temperature and humidity sensor, soil moisture sensor, 12V LED lights, DC 12V High-Pressure pump, water hose (input and output), pump dimmer, and four sets of misting nozzles. This application can be connected to hardware through Wi-Fi connectivity on the ESP32 microcontroller board.

The Momo Farm system requires users to configure Wi-Fi to establish connectivity between the application and the device. After turning on the Momo Farm device, users must enable Wi-Fi on their smartphones and connect to SF-Wifi-Manager. They can then select Wi-Fi configuration and input the SSID and password for the connection. If the entered information is correct, the device will automatically connect to the specified Wi-Fi. If not, users can press the EN and Board ESP32 buttons to troubleshoot the connection. Once connected, users can place germinated microgreens trays into available plots and insert soil humidity sensors into the growing media. The system automatically updates data on graphs and details every 15 minutes. The dashboard displays temperature, air humidity, and soil humidity for each plot. Users can manually control watering and LED lighting through the dashboard and set timers for automatic watering and lighting. The automatic watering feature activates when the soil humidity drops below 10% and stops when it reaches 80%. For more detailed data, users can access the "detail data" page, showing information collected every 15 minutes, including temperature, air humidity, and soil humidity for plots 1 and 2. The "information" page provides details about Momo Farm. When microgreens are ready for harvesting, users can turn off the device, remove humidity sensors, and harvest the microgreens.

Fig. 4: IoT-based Smart Vertical Farming Tool

Fig. 5: Dashboard of Momo Farm App

Fig. 6: Detail Data of Momo Farm App

Actuators can be controlled automatically and manually. Users can turn on and off the actuator manually by pressing the on and off button on the application. If the user wants to control it automatically, then the user can set a timer on the device by turn the actuator on or off at a certain time of day, or users can activate the water nozzle actuator based on a predetermined soil moisture value. Then, the data collected from the sensor will be displayed on the mobile application as a dashboard by displaying the temperature, humidity and soil moisture for each plot. These data are collected every 15 minutes, and the data will be stored in the cloud. Cumulative data can also be accessed on Momo Farm mobile apps.

```
//smart irrigation 1
void smart_irrigation1(){
mPlot1 = analogRead(A0);
Serial.println(percentage);
percentage = map(mPlot1, 490, 1023, 100, 0);
if(percentage < 10)
  {
  Serial.println("pump on");
  digitalWrite(3,LOW);
  }

if(percentage >80)
  {
  Serial.println("pump off");
  digitalWrite(3,HIGH);
  }
}
```

Fig. 7 Preview of Arduino IDE Logic

IoT technology plays a critical role in the Momo Farm system by integrating sensors to collect data on soil humidity and environmental conditions. The collected data is then transmitted and stored in the Firebase Cloud Database, where it undergoes analysis to enable automated control of the watering and lighting processes, leading to an efficient and effective smart vertical farming solution. Soil Humidity sensors are used to measure the moisture content of the growing media in each plot. The soil humidity sensors provide real-time data on the moisture level, which is crucial for determining when and how much to water the microgreens. The DHT11 sensor measures both temperature and air humidity in the growing environment. This data helps maintain optimal conditions for the microgreens' growth and prevents issues such as mold due to excessive humidity.

The soil humidity sensors and DHT11 collect data at regular intervals, every 15 minutes. This data includes soil humidity values for each plot and temperature and humidity readings for the air. To enable communication between the sensors and the central control system, the IoT devices in the Momo Farm system use wireless communication protocols. One common protocol used for this purpose is Wi-Fi, as it allows seamless connectivity between the sensors and the main control hub. The collected data from the sensors is transmitted over the Wi-Fi network to a central control hub or gateway. From there, the data is sent to the cloud server for storage. In the case of Momo Farm, the data is stored in the Firebase Realtime Database, which offers real-time data synchronization and secure storage capabilities.

Once the data is stored in the Firebase Realtime Database, it becomes accessible for analysis. The system can apply various analytical techniques to interpret the data and extract valuable insights. Data analysis algorithms can identify patterns, trends, and anomalies in soil humidity, temperature, and humidity levels. This analysis helps in making informed decisions about when and how much to water the microgreens, adjust lighting conditions, and optimize the growth environment. Based on the analyzed data, the system can be programmed to automatically control the watering and lighting processes. For example, if the soil humidity drops below a certain threshold, the system triggers the watering mechanism to supply the required amount of water. Similarly, the lighting control can be adjusted based on the temperature and humidity levels to create an ideal growth environment for the microgreens.

The system's logic is straightforward: moisture sensors measure the soil's moisture level, and if it detects a low level, a microcontroller triggers the water pump to irrigate the plant. Once the soil has received enough water, it retains moisture, and the pump automatically shuts off.

4.3. Experiment Result

A controlled experiment was conducted to measure the functionality of the device. The tests aimed to determine the accuracy of the sensor, compare the results between manually cultivated microgreens and microgreens grown with the assistance of the Momo Farm device, and to test the functionality of the device for growing microgreens. Corn, spinach, and water spinach were grown using different methods and media in double-layer trays. While the first layer has a small hole for drainage, the second layer collects excess water and protruding roots. The experiments were conducted indoors with minimal sunlight, and the device was connected to Wi-Fi controlled through Momo Farm mobile apps. The testing process was conducted in several stages, including sensor testing, water nozzle testing, and comparing data from the growth of microgreen plants.

- Sensor Testing

  The sensor testing was conducted by comparing the data readings from the sensors with readings from a moisture meter, thermometer, and hygrometer. The testing was performed at different times and under varying environmental conditions. The observed data will be analyzed by calculating the error value of the sensor using the following equation.

$$Error : \left(\frac{A - B}{A}\right) \times 100\%$$

Table 1. Soil Humidity Sensor Test Result

Growing Media	Moisture by Moisture Meter (%) (A)	Moisture by Soil Humidity Sensor (%) (B)	Difference Value (%)	Error (%)
No Media	45.1	0	45.1	100.00
	67.4	0	67.4	100.00
	56.8	0	56.8	100.00
		Average	**56.4**	**100.0**
Cocopeat	20.3	21	0.7	3.45
	45.8	46	0.2	0.44
	49.5	50	0.5	1.01
		Average	**0.5**	**1.6**
Rockwool	80.5	100	19.5	24.22
	68.9	100	31.1	45.14
	75.8	100	24.2	31.93
		Average	**24.9**	**33.8**

Based on Table 1, the average difference in moisture value testing using soil humidity sensor on cocopeat is 0.5%, while the average error value is 1.6%. The use of a soil humidity sensor on rockwool media showed a significant difference in values compared to the moisture meter, with a difference of 24.9% and an error rate of 33.8%. However, when used on a tray without any media, the soil humidity sensor was unable to assess the moisture level, resulting in a 100% error rate. This shows that the value of the difference and the error value is on the soil humidity sensor testing process can still be tolerated for cocopeat and the soil humidity sensor is not effective for detecting tray without media and rockwool.

Table 2. DHT11 Temperature Sensor Test Result

No	Thermometer (°C) (A)	DHT11 (°C) (B)	Value Difference (°C)	Error (%)
1	25.8	26	0.2	0.78
2	25.9	26	0.1	0.39
3	25	25	0	0.00
4	23.9	24	0.1	0.42
5	26.8	27	0.2	0.75
		Average	**0.1**	**0.5**

Based on Table 2, the average difference in air temperature testing using DHT11 is 0.1 ℃, while the average error value is 0.5%. This shows that the value of the difference and the error value in the DHT11 sensor testing process can still be tolerated.

Table 3. DHT11 Humidity Sensor Test Result

No	Hygrometer (%) (A)	DHT11 (%) (B)	Value Difference (%)	Error (%)
1	56	57	1	1.79
2	50	52	2	4.00
3	53	54	1	1.89
4	50	50	0	0.00
5	52	55	3	5.77
		Average	**1.4**	**2.7**

Based on Table II, the average difference in air temperature testing using DHT11 is 1.4 ℃, while the average error value is 2.7%. This shows that the value of the difference and the error value in the DHT11 sensor testing process can still be tolerated.

- Water Nozzle Testing

Data from the water nozzle test results for air humidity readings, can be seen in Table 4 below. The actuator test on this system aims to determine the ability of the water nozzle actuator to change and maintain the environmental parameters needed by plants. This is done by actuating these actuators for some time. Parameter data is measured using the DHT11 sensor. The first test is testing the mist maker actuator. The data obtained is the time required for the mist maker to change the parameters of the artificial environment from 10% to 80% air humidity. Time is measured using a stopwatch. The test was carried out 5 times.

Table 4. Water Nozzle Test Result

No	Soil Moisture		Time
	Start	End	
1	10	80	56
2	10	80	55
3	10	80	55
4	10	80	54
5	10	80	53
		Average	**54.0**

Based on Table 4, it can be seen that the water nozzle actuator can increase the humidity condition from 10% to 80%. The time required varies slightly from one trial to another. This is because the temperature that occurs during the experiment is not the same. The average time needed for a mist maker to increase air humidity from 10% to 80% is around 54 seconds.

- Harvest Comparison

At this stage, the results of microgreen plant growth were tested. In this testing process, the data to be obtained is in the form of a comparison of the weight of the results of microgreen plant growth using the Momo Farm tool and manually. The types of plants used are microgreen plants such as spinach, kale, and corn. 50 samples of each microgreen plant growing in grow box 1 and grow box 2 will be taken randomly. Then the 50 samples were weighed using a digital scale type Digital Scale I-2000. The value recorded on the digital scale will be recorded and then analyzed. The yield weight test for microgreen plant growth was carried out by testing 50 samples from each plant as shown in Table 5 below.

Table 5. DHT11 Temperature Sensor Test Result

Plant	Sample Amount	Micgrogreens Weight (g)	
		Manual	Momo Farm
Water Spinach	50	8.8	9.5
Spinach	50	43.3	47.2
Corn	50	55.4	58.7
	Average	**35.8**	**38.5**

From the data presented above, this study showed a significant difference in the harvest results between using the device and manual methods. The microgreens grown using the device had a stronger leaf, stem color, and condition than those grown manually. This difference can be attributed to the precision and consistency of the device's smart irrigation system, which delivers the right amount of water to the plants at the right time and the amount of UV light the plants are getting. This finding suggests that the tool can be a valuable asset for microgreen cultivation, providing more consistent and efficient results than manual method.

Fig. 8: Experiment with Momo Farm Device

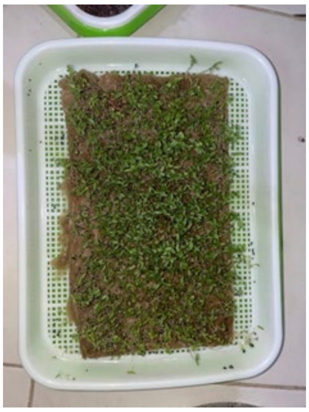

Fig.9: Spinach Grown with IoT Based Equipment

Fig. 10: Spinach Grown Without IoT-based Equipment (Manually)

The study shows the potential for advanced indoor farming practices through the integration of IoT, smart farming systems, and mobile apps. This can lead to more efficient and sustainable farming in limited urban spaces. The focus on real-time plant monitoring and control offers benefits for farmers and urban gardeners, optimizing plant growth and increasing crop yields. Additionally, the prototype's ability to sustainably produce microgreens with minimal human intervention addresses the challenge of limited time and space for gardening in urban settings, promoting local food production and reducing carbon footprints. The data analysis and error calculations can improve sensor technology and data processing techniques, benefiting various industries. This study also validates of IoT integration in agriculture, showcasing its potential for enhancing productivity and resource management. The emphasis on microgreens as a space-saving crop option contributes to theoretical knowledge about suitable plants for indoor farming in limited environments. Furthermore, the study explores the significance of smart farming and sustainable urban gardening, addressing urban challenges with technological solutions. The research underscores the importance of automation in agriculture, supporting low maintenance farming practices and offering valuable insights for further advancements in the field.

4.4. Experiment Limitation

By using this device, valuable data and insights on growth patterns and plant health can be obtained, which can be utilized to optimize the farming system and improve overall crop yields. However, it is important to understand that this device has some limitations that need to be considered.

- This device is effective for monitoring plants that use cocopeat as the growing medium. Cocopeat is a commonly used growing medium in vertical farming due to its good water retention capacity and ability to provide sufficient nutrients for the plants. However, this device may not be suitable for monitoring plant growth when using other types of growing media, such as rockwool or hydroponic systems without any medium.
- Users need to pay attention to the regular watering needs of the trays. If excess water is not removed in a timely manner, for example, after more than a week, water overflow can occur, potentially causing damage to the plants and disrupting their growth. Therefore, it is essential to check and remove excess water periodically to prevent water spillage.
- This device is limited only to microgreens and plant types that are not too tall. This limitation arises from the device's design, which has limited rack height, possibly insufficient to monitor the growth of larger plants such as fruit-bearing trees or vegetables that require more space and greater resources.

5. Conclusion

The integration of IoT concepts with smart farming systems and mobile apps in a closed-space automated agricultural prototype using vertical racking, as demonstrated in the Momo Farm system, proves the feasibility of creating an automated indoor farming prototype. The mobile application designed for this system facilitates user access to control and monitoring, providing data visualization, automation, and data storage capabilities. The experimental results show that the prototype can consistently produce microgreens sustainably. In this experiment, natural sunlight is replaced with LED lights that provide an appropriate light spectrum for microgreens' growth. Water needs are met through a nozzle system that sprays water on each plot. With proper adjustments, microgreens can thrive and maintain their high nutritional content. The main advantage of this prototype is its ability to keep plants alive and healthy even when temporarily unattended. The system's implementation is expected to provide urban dwellers with the benefits of small-scale, sustainable agriculture within their homes, ultimately enhancing their overall quality of life. However, this device has several limitations that need to be taken into consideration. It is only effective for monitoring trays that use cocopeat as the growing media. This means that it may not be suitable for monitoring other types of growing media that may be used in vertical farming. Users also need to pay attention to the watering tray for every few days, as the excess water can cause an overflow if it is not removed for more than a week. This could potentially damage the plants and affect their growth. Therefore, it is important to ensure that the excess water is removed on a regular basis to prevent any overflow. The tool is limited to monitor only microgreens and plant types that are not too tall so it may not be suitable for monitoring the growth of larger plants that require more space and resources.

Based on these findings, there are some suggestions for future research:

- Evaluation of effectiveness of alternative growing media
  Conducting research to evaluate the use of alternative growing media, such as rice husks or composted soil, with this device. The aim of this study is to understand how the device can function and provide relevant data in environments with different growing media.
- Development of smart irrigation system
  Developing a smart irrigation system integrated with the vertical farming device. This system will utilize sensors and intelligent algorithms to regulate irrigation based on the plants' needs and environmental conditions. Through device integration, users can monitor and control the smart irrigation system via a mobile application. The research may also involve the use of additional sensors and plant condition prediction models to enhance irrigation efficiency. By developing this system, users can optimize water usage, reduce water waste, and achieve sustainable plant growth.
- Development of a device for taller plants
  Conducting research to develop a device with higher rack spacing to monitor the growth of taller plants, such as fruit-bearing trees or larger vegetables. In this study, technical aspects like tray height, sensor placement, and monitoring requirements for larger plants need to be considered.

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