

Article

Development of Smart Vertical Farming System for Melon Cultivation by Applying Monitoring System via Internet of Things and Web Application

Somkiat Tangjitsitcharoen^{a,*}, Peeraphat Munsilp, Ratchapon Thanaree, and Veeraprach Vesjaroon

Department of Industrial Engineering, Faculty of Engineering, Chulalongkorn University, Thailand
E-mail: ^{a,*}somkiat.ta@eng.chula.ac.th (Corresponding author)

Abstract. Amid rising global and domestic demand for agricultural products, Thai agricultural industry is facing mounting challenges, including labor shortages, high labor costs, less cultivation area, and the increasing unpredictability of climate conditions. To address these issues and enhance the productivity and resilience of food production, this study proposes the development of an intelligent vertical farming system that applies the principles of the intelligent manufacturing system to agriculture. The vertical farming approach adopted in this study involves training melon vines to grow upward along vertical trellis structures within the greenhouse, thereby optimizing the use of vertical space and increasing planting density per unit of ground area. By integrating Internet of Things (IoT) technologies and a web-based application, the system enables automated environmental monitoring and responsive control for crop cultivation. Unlike previous studies, this research also includes a cost comparison with traditional cultivation methods, providing a clearer economic perspective on the system's feasibility and impact. Melon (*Cucumis melo*) was selected as the target crop for system testing due to its high market value and sensitivity to environmental fluctuations. The system was evaluated in a greenhouse setting with a cultivation area of 1 rai (1,600 square meters or approximately 0.16 hectares), achieving an estimated annual income of 294,600 Baht based on a three-harvest cycle per year. Although the system involves a significant initial investment, it reduces annual variable costs by 10,875 Baht, or 14.5%, with the payback period reached in the early third year. In terms of labor efficiency, the system reduces time consumption by approximately 60.42%, especially in operations related to watering and humidity control. Furthermore, the integration of IoT and web-based technologies facilitates remote monitoring, minimizing the need for frequent on-site supervision. Looking ahead, the environmental and operational data generated by the system can support advanced supply chain optimization, predictive analytics, and data-driven decision-making, marking a significant step toward sustainable and intelligent agriculture in Thailand.

Keywords: Smart Vertical Farming, Melon, Intelligent Manufacturing, Web Application, Internet of Things, Thai Agricultural Industry

ENGINEERING JOURNAL Volume 30 Issue 5

Received 12 September 2025

Accepted 23 April 2026

Published 31 May 2026

Online at <https://engj.org/>

DOI:10.4186/ej.2026.30.5.59

1. Introduction

This study introduces a novel approach that adapts the principles of the Intelligent Manufacturing System (IMS) to the agricultural domain. In recent years, the concept of smart farming such as automated irrigation and nutrient delivery has gained increasing importance due to its ability to address pressing challenges in agriculture [1], particularly labor shortages [2], fluctuating productivity [3], and inconsistent environmental conditions and less cultivation areas [4]. When examined closely, modern farming exhibits strong parallels to manufacturing: the crop can be seen as the product, while the processes of cultivation, monitoring, quality control, and yield optimization resemble those found in industrial production lines.

By viewing agriculture through the lens of manufacturing, the proven methodologies such as Digital Lean Manufacturing (DLM), intelligent in-process monitoring, and data-driven production planning can be applied to farming operations. These methods enable waste reduction, quality improvement, and operational optimization principles that are foundational in advanced manufacturing [5] and can actively promote the realization of Sustainable and Intelligent Manufacturing (SIM) in agriculture.

As illustrated in Fig. 1, this concept of “digital lean agriculture” signifies the next era of farming: one that is intelligent, efficient, and seamlessly integrated with sensor networks and algorithmic control.

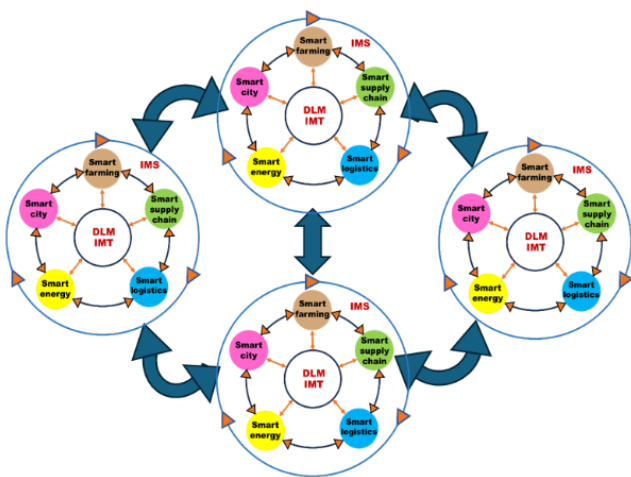


Fig. 1. Conceptual framework of Smart Farming leading to Sustainable and Intelligent Manufacturing (SIM) driven by Digital Lean Manufacturing (DLM) and Intelligent Monitoring Tools (IMT), under the Intelligent Manufacturing System (IMS).

Consequently, the smart agricultural supply chain can be planned and optimized through the use of smart logistics, predictive analytics, and smart energy systems. This integration not only enhances productivity and resource utilization but also contributes to broader sustainability goals [6], including the reduction of

greenhouse gas emissions and the accurate calculation of product-level carbon footprints. Additional advantages include reduced human error, extended growing seasons through microclimate control, scalable modular design for urban farming, and the potential to localize food production minimizing transportation-related emissions and supporting food security [7].

Therefore, this research presents the continued work of the authors in developing an intelligent vertical farming system that leverages Internet of Things (IoT) technologies and rule-based threshold control derived from agronomic references and calibration to achieve automated environmental monitoring and responsive control within a greenhouse setting.

In this study, melon (*Cucumis melo*) has been selected as the target crop due to its high market value, increasing domestic demand, and sensitivity to environmental fluctuation [8]. However, like precision parts in the manufacturing sector, the optimal cultivation of melon depends on controlling multiple interrelated variables such as temperature, humidity, light intensity, and CO₂ concentration which are not effectively manageable through traditional farming practices. To address this, intelligent monitoring systems are required to continuously collect real-time environmental data, determine optimal growth conditions using threshold values derived from agronomic references, and dynamically regulate internal environments to maintain those conditions consistently throughout the crop cycle.

As a result, this research aims to design and implement a smart vertical farming prototype for melon cultivation that enables Thai farmers to transition toward high-efficiency, technology-assisted agricultural practices. By integrating advanced control mechanisms, precision monitoring, and structured process design derived from the IMS framework this initiative contributes to a more sustainable, resilient, and intelligent future for agriculture in Thailand.

2. Research Methodology

2.1. Infrastructure Design

The infrastructure used in this research consists of a pre-built greenhouse that had already been designed and allocated for vertical farming. In this context, vertical farming refers to the practice of training melon vines to grow upward along vertical trellis structures, thereby maximizing the use of vertical space within the greenhouse. The external structure is included with columns, steel frames, walls, floors, air ventilation [9], and curve roof [10]. The vertical trellis cultivation system was proposed for the usable interior space, which was 3.00 by 3.80 meters, and designed the water system to align with the existing structure.

The water system design was based on two main factors. First, the analysis of existing resources showed that there was an external water source with sufficient pressure, removing the need to install an additional pump

and thereby reducing both cost and complexity. Pre-existing irrigation hoses were also utilized as much as possible to maximize resource efficiency. The main pipeline was routed from the exterior into the greenhouse using $\frac{3}{4}$ -inch PVC pipes, laid out in positions optimized for even water distribution and consistent pressure across the growing beds.

Second, the system was designed to support the installation of valve actuators for flexible water flow control. A central valve was strategically positioned to allow easy operation, and the system was divided into two main subsystems. The irrigation system delivers water directly to plant roots in controlled amounts using drip heads and a dedicated valve. The fogging system increases humidity inside the greenhouse to support plant growth, especially during periods of high temperature or dryness.

Each system operates independently to provide greater control. The main materials used were $\frac{3}{4}$ -inch PVC pipes for the main lines and $\frac{1}{2}$ -inch fittings for branches connected to nozzles and other components. The list of fittings included elbows, tees, reducers, connectors, sockets, end caps, and ball or gate valves, totaling over 30 items and five 2-meter PVC pipes.

The installation was carried out in two phases. The first phase involved clearing out unneeded materials, cleaning the area, checking the condition of the floor and walkways, and organizing the space for installation. The second phase included installing the main pipe network, connecting branch pipes and fogging components, setting up control valves for each subsystem, ensuring pressure balance, conducting leak and function tests, and mounting fogging nozzles along the greenhouse beams as shown in Fig. 2.

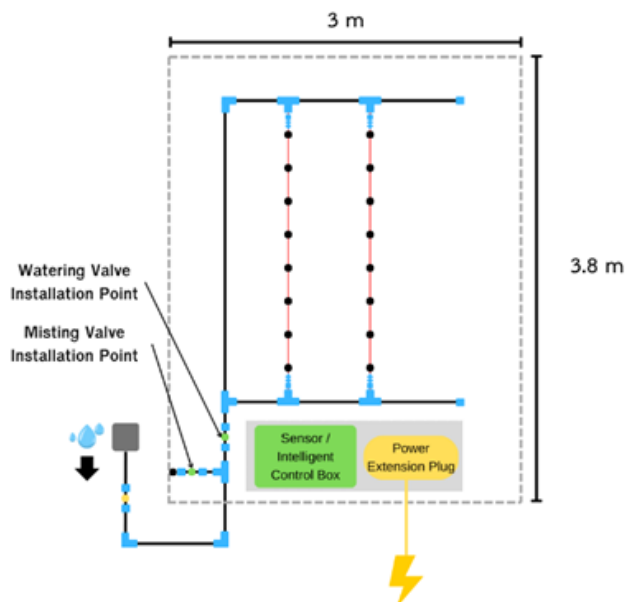


Fig. 2. Schematic layout and real-world implementation of intelligent vertical farming infrastructure.

2.2. System Architecture Design

Smart vertical farming can be divided into six key components as shown in Fig. 3, which are 1. Actuators, 2. Infrastructure, 3. Website, 4. Server, 5. IoT's Sensor and 6. Algorithm. The integration of these six components as shown in Fig. 2 aims to establish a responsive system capable of perceiving, analyzing, and reacting to environment beings accurately.

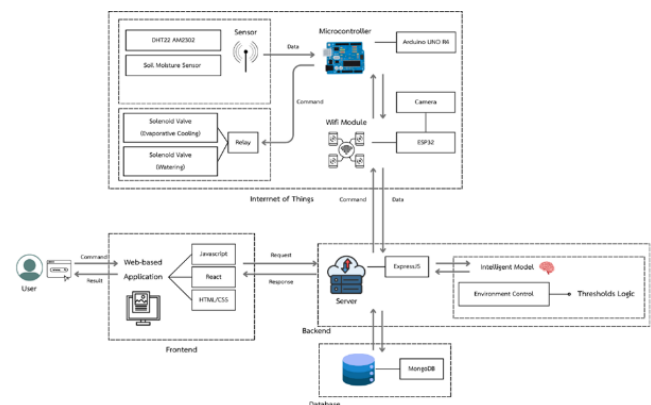


Fig. 3. Smart Vertical Farming Architecture.

2.3. Internet of Things (IoT) Design

The actuators employed in this research are 12V DC solenoid valves [11], with two units utilized for controlling both irrigation and humidity regulation which has a 12V 4-channel relay module utilized to manage current and switch the actuators accordingly. For environmental sensing, the system integrates a DHT22 (AM2302) temperature and humidity sensor [12], along with a soil moisture sensor module to monitor soil water content. The primary controller is an Arduino UNO R4 Wi-Fi, which incorporates ESP32 functionality for wireless communication. In addition, a camera module is installed for real-time visual monitoring of the greenhouse environment as shown in Fig. 4 and 5.

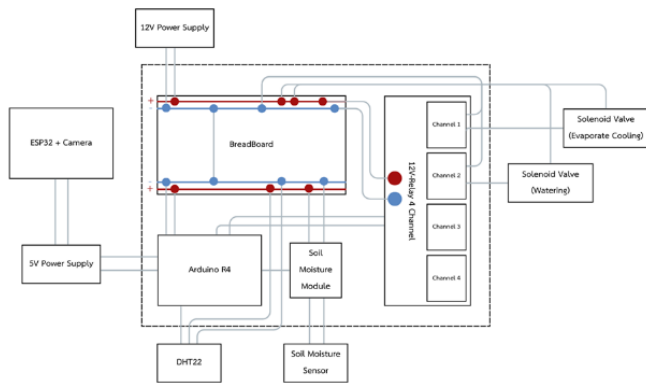


Fig. 4. Circuit Diagram Design

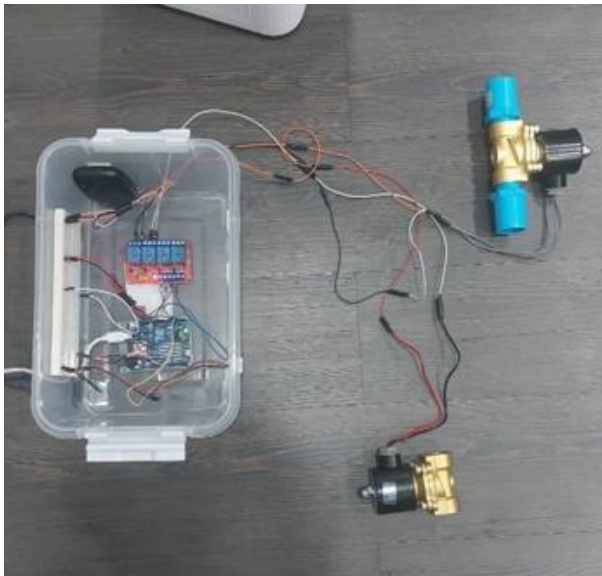


Fig. 5. Real-world Circuit Diagram

2.4. Web-based Application Design

The developed system was designed as a Full Stack Web Application as shown in Fig. 6, consisting of a clearly separated Frontend and Backend to support modular development, testing, and long-term maintainability. The Frontend was implemented using React [13], with a well-structured component hierarchy based on the functional requirements. On the Backend, the system was developed using Node.js with the Express [14] framework to handle client requests and manage communication with the database. The backend architecture follows the Model-View-Controller (MVC) pattern [15], enhancing code clarity and scalability. For data storage, the system utilizes MongoDB hosted on the cloud [16], which reduces the complexity of local configuration and provides greater reliability and ease of maintenance for long-term period of operation as shown in Fig. 7.

The system uses a MERN (MongoDB, Express, React, Node.js) stack to connect the greenhouse hardware to the web application. The Arduino controller uses a method called "polling" to communicate, which means the Arduino acts as a client that regularly asks the server for

new instructions instead of waiting for the server to push them. This polling approach was selected for the prototype because it is much simpler to implement and maintain. Since the Arduino initiates all requests, there is no need to configure complex network settings like port forwarding or static IP addresses at the greenhouse site, which would be required if the backend server tried to send commands directly to the Arduino. Under this setup, the Arduino acts strictly as a client to send requests, and there is no need to configure the hardware to listen for or receive incoming requests initiated by the server, which greatly reduces the technical complexity of the network configuration.

In the technical implementation, this is set to a 7-second interval for checking commands and a 14-second interval for uploading sensor data. The data packets are sent as JSON payloads, which are very small, typically less than 1 kilobyte per transmission. To illustrate the small size, each sensor telemetry packet contains only four primary numeric fields (air temperature, air humidity, soil temperature, and soil humidity). Similarly, the command packets retrieved by the Arduino are highly optimized, containing only three essential fields: the command context (e.g., "foggy" or "water"), the duration of the action in milliseconds, and the current status. This minimal data structure ensures the system stays fast and works reliably even on slow mobile or SIM-based internet connections often found in agricultural areas. For this prototype, the system uses a standard REST API over HTTPS on port 443. By using the WiFiSSLClient library, the connection between the farm and the database is encrypted, providing basic data protection during transmission without the complexity of additional headers. The network latency, which is the time it takes for a request to reach the server and receive a response, is very low, typically ranging from 1 to 3 seconds. To keep the system reliable, the code includes a "self-healing" feature where the Arduino automatically runs a function to reconnect if a connection fails.

To illustrate the system logic and timing, consider a sample scenario for automated irrigation or humidity control (foggy system). First, the sensor reads the environment (soil moisture or air humidity) and sends this data to the server during its 14-second upload cycle. Once the data reaches the backend, the server executes logic to check if the value is below the defined thresholds (75% for soil moisture or 55% for air humidity). If it is, the server creates a command in the database with a "pending" status. To ensure system stability and prevent a "pending stack," the backend logic automatically sets any other existing pending commands for that specific function (watering or foggy) to a "fail" status before creating the new one. This ensures that there is only ever one active pending command in the system at a time for each actuator. The Arduino, which is constantly waiting to poll, then hits the command endpoint. Upon receiving the command with the "pending" status, the Arduino activates the corresponding relay (water or foggy) for 30,000 ms (30 seconds) and immediately updates the status to

"complete" in the database. This specific status-update flow is critical because it ensures the system does not repeat the same command twice, preventing overwatering or excessive humidity.

Based on this architecture, the response time can be calculated for different scenarios starting from the moment a physical change occurs until the actuator is actually turned on. To understand the full system delay, we must consider the two separate timing loops: the 14-second sensor upload cycle and the 7-second command polling cycle. In the best-case scenario, the environment value drops below the threshold exactly at the moment the 14-second sensor cycle triggers an upload. The server immediately processes this data and creates a command with a "pending" status, and by chance, the Arduino 7-second polling cycle happens to trigger just a second later. In this ideal situation, the system reacts in approximately 2 to 4 seconds, which is almost entirely limited by the 1 to 3 seconds of network latency. In the worst-case scenario, the moisture or humidity could drop just after a 14-second sensor upload has already finished, meaning the system must wait the full 14 seconds for the next data transmission. After that data reaches the server and the command with a "pending" status is created, another delay could occur if the Arduino has also just finished its 7-second command poll. This creates a combined hardware wait time of 21 seconds (14 seconds for sensing plus 7 seconds for polling). When adding the 1 to 3 seconds for network latency and server processing, the total maximum response time is approximately 22 to 24 seconds. Even with this maximum delay of less than half a minute, the timing is sufficient for melon cultivation because soil and air conditions do not change rapidly enough to require millisecond precision. This dual-loop architecture ensures that the system reacts to environmental changes effectively while maintaining a low-power, simple network profile that does not require the hardware to be constantly "listening" for incoming server data.

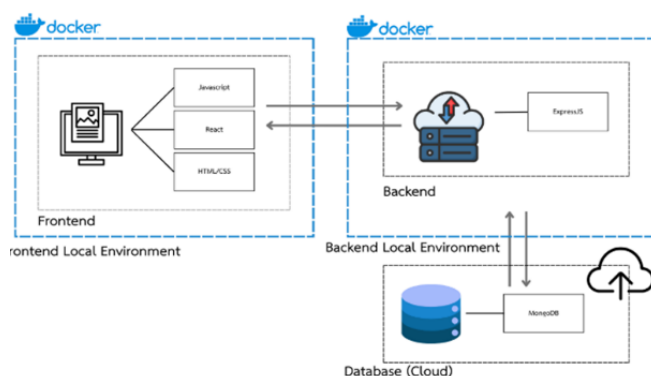


Fig. 6. Full Stack Web Application Architecture.



Fig. 7. Web-Application Page.

2.5. Proposed Algorithm

In this research, the irrigation and misting system is designed to operate automatically based on real-time environmental conditions instead of a fixed schedule, since melon plants have varying water requirements depending on their growth stage. A fixed watering time could lead to overwatering or underwatering, which reduces efficiency and complicated management. To address this, the system relies on actual sensor readings of soil and air humidity. When the humidity falls below the defined thresholds (75% for soil humidity and 55% for air humidity) [17], the system activates either the irrigation valve or the misting device for 30 seconds to restore optimal growing conditions. The threshold values are established through calibration and experimentation. For soil humidity, this involves dividing soil into test trays with different water levels and observing soil texture, density, and moisture characteristics. The most suitable condition is selected, and its corresponding sensor reading is used as the threshold. For air humidity, the value is determined based on academic references and is set at 55 percent to support plant respiration and reduce the risk of disease. This threshold-based control logic ensures that the system provides water and moisture only when needed, thereby minimizing water waste and improving overall maintenance efficiency in the greenhouse environment.

It is important to note that the control algorithm employed in this study is a deterministic rule-based system, not a machine learning or artificial intelligence model. The threshold values were established through a combination of calibration experiments and agronomic references, and this approach was selected for its simplicity and suitability for a proof-of-concept implementation, while providing a foundation upon which future AI-based predictive models can be developed.

3. Experimental Results and Discussions

3.1. Financial Analysis

Based on the financial analysis of implementing the system on a 1-rai area consisting of four greenhouses with three cultivation cycles per year which compared to the traditional method, Journal of Local Management and Development [18], each cycle was found to generate an

average revenue of approximately 98,200 Baht, totaling around 294,600 Baht annually. The traditional approach involves an initial investment of 461,737 Baht and an annual operating cost of 74,811 Baht. In comparison, the smart vertical farming system requires a slightly higher initial investment of 489,321 Baht but significantly reduces the annual operating cost to 63,936 Baht. This reflects a reduction of 10,875 Baht per year, or approximately 14.5% of the total variable cost. An initial investment cost of structure is shown in Table 1.

Table 1. Initial Investment Cost of Structure.

No.	Item	Quantity	Cost per 1,600-meter square (Baht)	Depreciation Rate (%)	Average Depreciation (Baht)
1	Greenhouse	1 unit	70,000.00	5.00	14,000.00
2	Water Pump	2 units	6,000.00	20.00	4,800.00
3	Water Pipe	1 roll	2,500.00	5.00	500.00
4	Drip Heads	500 pieces	0.25	5.00	0.05
5	Weighing Scale	1 unit	1,300.00	5.00	260.00
6	Spray Tube	1 unit	30.00	5.00	6.00
7	Sprayer Tank	1 unit	1,600.00	20.00	1,280.00
8	Solar Panel	2 panels	34,000.00	20.00	27,200.00
9	Main Controller	1 unit	1,400.00	33.33	1,866.48
10	Solenoid Valve	2 units	1,200.00	20.00	960.00
11	Sensor	1 unit	300.00	33.33	399.96
12	Web Server (per farm)	1 unit	3,000.00	33.33	999.90
13	Internet System (per farm)	1 unit	1,000.00	33.33	333.30
Total			122,330.25	-	52,605.69

As a result, the smart system is expected to achieve its breakeven point in the early third year, demonstrating its long-term economic viability, as shown in Table 2.

Table 2. Cash Flow Analysis of Smart Vertical Farming.

Year	Revenue	Investment Cost	Operating Cost	Accumulate Profit
0	0	489,321	0	-489,321
1	294,600	0	63,936	-258,657
2	294,600	0	63,936	-27,993
3	294,600	6,800	63,936	195,871
4	294,600	0	63,936	426,535
5	294,600	187,200	63,936	469,999
6	294,600	6,800	63,936	693,863
7	294,600	0	63,936	924,527
8	294,600	0	63,936	1,155,191
9	294,600	6,800	63,936	1,379,055

The financial analysis indicates that the smart vertical farming system requires higher initial investment due to the IoT and smart system set up, compared to the traditional method, it provides significant long-term economic benefits with maintenance and re-investment calculated. The reduction in annual operating costs by approximately 10,875 THB (14.5%). Based on Cash Flow

Analysis in Table 2., the calculation shows the payback period which could be achieved in the early third year, suggests that this smart vertical farming system is economically feasible for medium-term agricultural investment, for such melon.

3.2. Operational Efficiency

After applying a smart vertical farming system in an experimental agricultural setting, we analyzed the operational data to estimate its potential impact on labor efficiency for farmers. Prior to introducing the system, typical daily routines involved a wide range of manual tasks split between morning and evening shifts. These included greenhouse inspections, hand-watering, environmental control (e.g., temperature and humidity adjustments), soil and microclimate assessments, pruning, and disease monitoring, resulting in over 9.6 hours of labor per day.

Using detailed time allocation data collected during the experiment, we found that several high-effort activities could be either fully automated or significantly streamlined. For instance, manual inspections, accounting for 20.83% of daily time, could be replaced by real-time sensor monitoring. Irrigation, which consumed 13.89%, was automated based on soil moisture levels. The environmental control process (27.78%) was handled

through automatic adjustments of temperature and humidity, and soil monitoring (13.89%) was continuously performed by sensor systems rather than manual checks.

Based on these improvements, the system is estimated to reduce total labor time to approximately 3.8 hours per day, achieving a 60.4% reduction. This would eliminate the need for repetitive evening tasks and significantly lighten the morning workload. More importantly, it allows farmers to redirect their time toward strategic tasks like planning, monitoring trends, or responding to anomalies. These findings suggest that smart vertical farming systems have strong potential to address labor shortages, reduce operational costs, and improve overall productivity when deployed in real-world farming operations as shown in Table 3.

Table 3. Comparison of Daily Labor Time Between Traditional and Intelligent Farming Systems.

Task Type	Traditional System (hours)	Intelligent System (hours)
1. Morning inspection walk	1.00	1.00
2. Evening inspection walk	1.00	0.00
3. Watering	0.80	0.00
4. Environmental control	1.33	0.00
5. Soil and environmental monitoring	2.67	0.00
6. Pruning and disease inspection	1.33	1.33
7. General care	1.47	1.47
Total time	9.60	3.80

3.3. Data Collection

The collected environmental data consists of parameters including temperature, air humidity, and soil humidity. These values are captured by IoT sensors installed on the farm. Once the sensors collect the data, it is transmitted to the backend, then stored in the database. This data is then used to determine whether to trigger automated systems such as misting (fog). Additionally, the stored data can be used for future purposes, such as training predictive models or conducting analysis.

In addition to environmental data, image data is also collected using a camera sensor installed on the farm as shown in Fig. 8. As shown above, the image captures a sequence of plant growth stages within the greenhouse environment. The camera captures images at regular intervals, enabling continuous visual monitoring of plant development over time. This visual data complements the sensor data by providing additional context for evaluating plant health and growth, and it can also be used for further analysis [19].



Fig. 8. Sequential images captured by a camera sensor installed in the greenhouse.

The environmental data collected, such as temperature, humidity, irrigation, and misting records can be monitored via web application on PC and smartphone as shown in Fig. 9 to 11. The recorded data can be used to develop agricultural analytics models or support resource planning efforts.

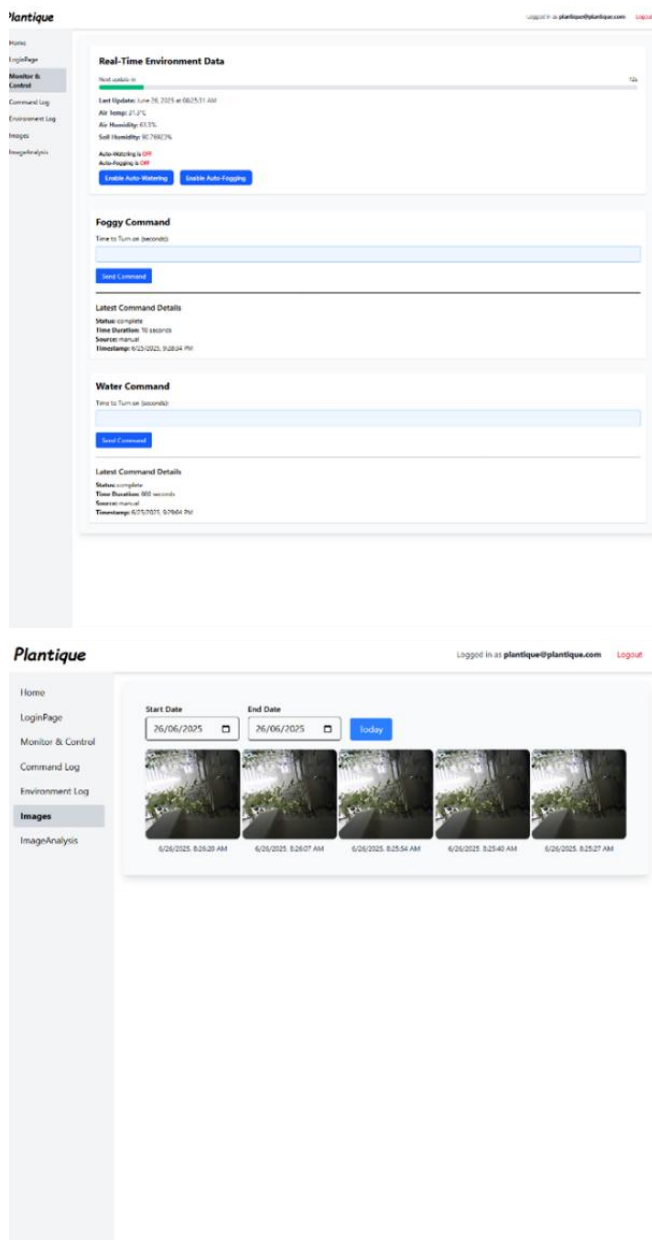


Fig. 9. PC web interface for controlling actuators and monitoring plant images in the greenhouse.

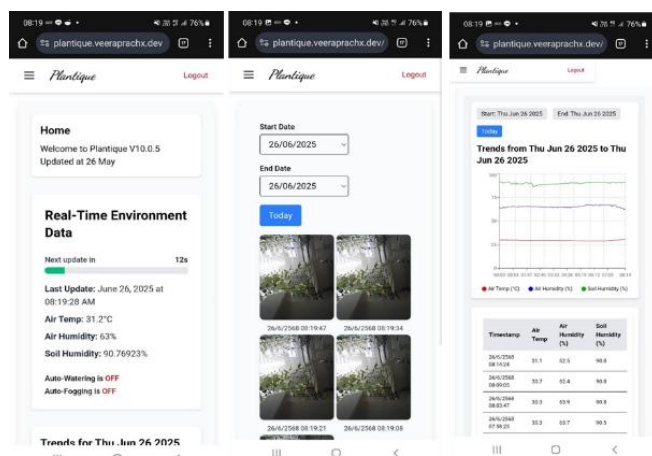


Fig. 10. Mobile web interface for monitoring and controlling the greenhouse environment.

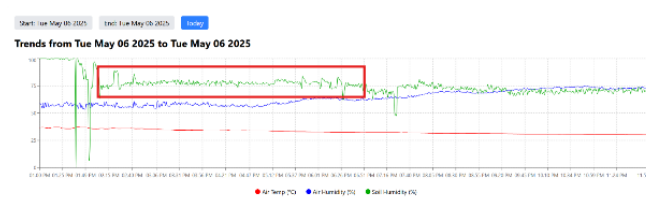


Fig. 11. Monitoring Environment Page of Web-Application.

Figure 12 illustrated the growth rate of melon in smart vertical farming for one cycle which is approximately 4 months.

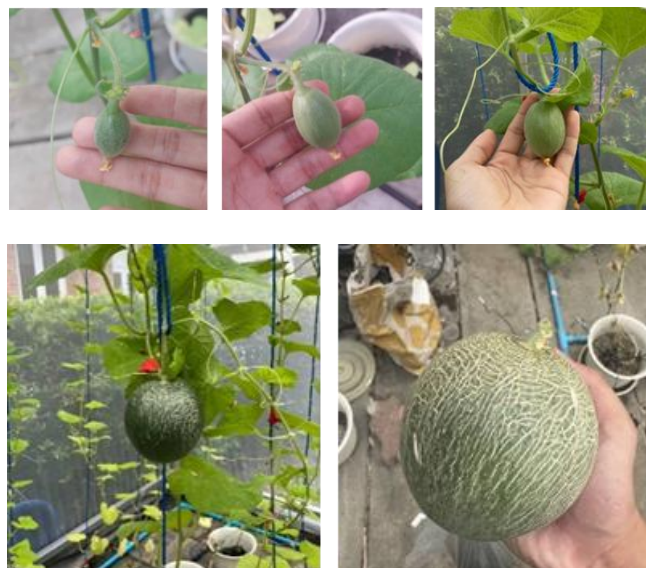


Fig. 12. Sequential images showing melon growth captured in the smart vertical farming.

The DHT22 (AM2302) sensor used in this study provides temperature and relative humidity measurements with a typical accuracy of $\pm 0.5^{\circ}\text{C}$ and $\pm 2\text{--}5\%$ RH. For soil moisture measurement, an Analog soil moisture sensor was employed. The data collection system operates under 14 seconds interval per record. The overall system response time, defined as the duration from the time environmental condition is detected to actuator, appear to be approximately 2–5 seconds under normal network conditions which includes sensor data acquisition, data transmission, and control signal execution.

In terms of control effectiveness, when air humidity dropped below the threshold level, the misting system was able to increase the humidity back to the target range within approximately 1–3 minutes, depending on the initial environmental conditions. Similarly, the irrigation system effectively restored soil moisture levels following activation.

Currently, the proposed and developed system supports only irrigation and misting automation, but it has the potential to be extended to include other processes such as seedling propagation, soil quality analysis, ventilation control, and automated fertilization. Labor analysis indicates that fertilization takes roughly the same amount of time as watering, and the method of application

is similar, simply replacing water with a nutrient solution. Although the current experiment focuses on melon cultivation in a small greenhouse, the core principles of plant care, such as maintaining suitable humidity and adjusting watering according to different growth stages, are broadly applicable to many types of plants. All plants require appropriate environmental conditions for basic growth, so the knowledge gained in this project can be adapted to various cultivation systems.

This research therefore serves as a foundational model for developing flexible automated farming solutions, including future cycles of melon production and beyond. However, the current prototype also exhibited limitations, including the instability of mobile internet connections via SIM-based routers, low image resolution from the onboard camera module, and the use of REST API polling, which introduced latency and scalability issues when compared to more advanced protocols like MQTT [20]. Despite these constraints, the system successfully demonstrated proof of concept and established a strong technological foundation for future developments. Furthermore, the knowledge and methodology from this project are adaptable to other crop types and farming contexts, laying the groundwork for scalable, intelligent agricultural systems.

4. Conclusions

This research presents the design, development, and evaluation of a smart greenhouse system integrated with a web-based application, aimed at improving the efficiency and sustainability of melon cultivation in Thailand. The system was developed using Internet of Things (IoT) technologies and rule-based threshold control logic to enable real-time environmental monitoring and autonomous control of critical variables which are soil moisture and humidity through web-based Application.

According to financial analysis, it was revealed that, despite the system's higher initial investment cost compared to traditional methods, the smart greenhouse reduced annual operational expenses by approximately 10,875 THB or 14.5% of variable costs, and achieved breakeven in the early third year, indicating its long-term economic viability. In terms of labor efficiency, the system proved highly effective, reducing the average daily working time from 9.6 hours to just 3.8 hours, which represents a 60.42% reduction, particularly in repetitive manual tasks such as irrigation and humidity regulation. These gains in efficiency not only minimized human labor requirements but also allowed farmers to reallocate time to more analytical and strategic operations. Additionally, the system's continuous environmental data collection enabled advanced trend analysis, helping to identify patterns such as daily humidity cycles and supporting data-driven planning for future growing cycles.

In conclusion, the developed smart vertical farming system successfully achieved the study's objectives by reducing daily labor time requirements by 60.42% and lowering annual operating costs by 14.5%. The system

proved to be more economically feasible than traditional methods, with a payback period reached in the early third year. Based on its design, the system enables year-round crop production within a greenhouse environment, where air and soil humidity are automatically controlled. By integrating rule-based automation and IoT technologies, the system is capable of collecting real-time environmental data and supporting supply chain planning. This allows Thailand's agricultural sector to align melon production with domestic demand and enhance the country's export potential through the principles of Intelligent Manufacturing Systems. Ultimately, the system successfully demonstrated its ability to grow melons to harvest-ready maturity, validating both its technical functionality and agricultural effectiveness in a vertical farming configuration.

This proof-of-concept demonstrates the potential to not only monitor and automate crop growth, but also to continuously improve, predict, and optimize it enabling smarter planning for logistics and supply chains. As more intelligent agricultural systems adopt this approach, they can interconnect as nodes within the broader IMS (Intelligent Manufacturing System) framework, driving higher yields, energy efficiency, and deeper integration with smart cities, smart energy, and smart logistics systems.

Acknowledgement

Funding from Faculty of Engineering, Chulalongkorn University. The location and infrastructure for melon cultivation, as well as the integration of IoT sensors, were supported by Assoc. Prof. Sanphet Chunitipaisan, Ph.D. Additionally, Asst. Prof. Achariya Suriyawong, Ph.D., provided valuable guidance and advice for data acquisition.

References

- [1] Statista, "Import value of agricultural products Thailand 2013–2023," 2024. [Online]. Available: <https://www.statista.com/statistics/1038272/thailand-import-value-of-agricultural-products>.
- [2] Statista, "Export value of agricultural products Thailand 2013–2023," 2024. [Online]. Available: <https://www.statista.com/statistics/1038144/thailand-export-value-of-agricultural-products>.
- [3] Statista, "Employment by economic sector in Thailand 2022," 2024. [Online]. Available: <https://www.statista.com/statistics/332341/employment-by-economic-sector-in-thailand>.
- [4] Digital Economy Promotion Agency (DEPA), "Investment bulletin," [Online]. Available: <https://www.depa.or.th/storage/app/media/file/investment-bulletin.pdf>.
- [5] B. He and K.-J. Bai, "Digital twin-based sustainable intelligent manufacturing: A review," *Advances in Manufacturing*, vol. 9, pp. 1–21, 2021.
- [6] M. Usman, and A. A. Yusuf, "Optimising transportation systems for sustainable agricultural supply chains: Integration of smart logistics and

- precision farming techniques,” *International Journal of Sustainable Engineering and Emerging Technologies (IJSEET)*, vol. 5, no. 1, 2024. [Online]. Available: <https://airjournal.org/article/optimising-transportation-systems-for-sustainable-agricultural-supply-chains-integration-of-smart-logistics-and-precision-farming-techniques>.
- [7] M. Kunwar, “IoT in vertical farming: Role of sensors & automation in urban agriculture,” *HashStudioz*, 2025. [Online]. Available: <https://www.hashstudioz.com/blog/iot-in-vertical-farming-the-role-of-sensors-and-automation-in-urban-agriculture/>.
- [8] P. Srinil, T. Puangsuwan, U. Buatoom, and S. Kunjet, “Automatic Control System Application for Melon Growth in Greenhouse Using IoT and Fuzzy Control,” *Journal of Science Ladkrabang*, vol. 30, no. 2, pp. 74–89, 2021.
- [9] S. Hemming, E. van Henten, B. van ’t Ooster, B. Vanthoor, and S. Bakker, “Systematic design of greenhouse crop production systems,” *INCOSE*, 2008. [Online]. Available: <https://edepot.wur.nl/31376>.
- [10] Rajamangala University of Technology Lanna (RMUTL), “KBS No.41 Technology for Growing Melon in Greenhouse,” 2023. [Online]. Available: <https://www.rmutl.ac.th/news/23568-2023-11-28>.
- [11] M. Al-Kofahi, C. Chapman, B. Edison, E. Johnson, M. Harman, N. Zayyad, J. Seybert, C. Watters, R. Emme, and T. Sliva, “Using a microcontroller to automate a green house for experiments,” *Journal of Agriculture and Life Sciences*, vol. 3, no. 2, 2016. [Online]. Available: https://www.jalsnet.com/journals/Vol_3_No_2_December_2016/1.pdf.
- [12] S. Silvola, *Environmental Monitoring System for Greenhouses*, Vaasan Ammattikorkeakoulu University of Applied Sciences, 2024. [Online]. Available: https://www.theseus.fi/bitstream/handle/10024/863719/Silvola_Samuel.pdf?sequence=2.
- [13] React, “React – A JavaScript library for building user interfaces,” 2023. [Online]. Available: <https://reactjs.org/>.
- [14] MDN Web Docs, “Express web framework (Node.js/JavaScript),” 2025. [Online]. Available: https://developer.mozilla.org/en-US/docs/Learn_web_development/Extensions/Server-side/Express_Nodejs.
- [15] GeeksforGeeks, “MVC Design Pattern,” 2025. [Online]. Available: <https://www.geeksforgeeks.org/system-design/mvc-design-pattern/>.
- [16] MongoDB, “MongoDB Documentation,” 2025. [Online]. Available: <https://www.mongodb.com/docs/>.
- [17] Orgánico Derivados, “Melon Horticultural Products,” [Online]. Available: <https://www.organicoderivados.com/en/horticolas/melon>.
- [18] N. Weakrathok and K. Jurach, “Cost and Return Analysis of Melon Cultivation by Members of the Mae Sot Agricultural Cooperative, Mae Sot District, Tak Province,” *Journal of Management and Local Development*, vol. 4, no. 2, 2021. [Online]. Available: <https://so11.tci-thaijo.org/index.php/jMLD/article/view/924/38>.
- [19] Reintech, “MongoDB and IoT: Storing Sensor Data,” 2024. [Online]. Available: <https://reintech.io/blog/mongodb-and-iot-storing-sensor-data>.
- [20] Svix Resources, “MQTT vs REST,” [Online]. Available: <https://www.svix.com/resources/faq/mqtt-vs-rest/>.



Somkiat Tangjitsitharoen completed D.E. degree in Mechanical Engineering from Kobe University, Japan, in 2004. He is currently the head of Advanced Manufacturing and Precision Engineering Research Center at the Industrial Engineering, Chulalongkorn University, Thailand. His research interests include in-process monitoring and optimization of manufacturing processes, micro-machining and micro-assembly, high precision cutting, and intelligent manufacturing systems and machine tools.

Peeraphat Munsilp, photograph and biography not available at the time of publication.

Ratchapon Thanaree, photograph and biography not available at the time of publication.

Veeraprach Vesjaroon, photograph and biography not available at the time of publication.