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Design and implementation of outdoor home smart farming based on raspberry pi for home assistant management

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Abstract Outdoor home smart farming, also known as urban farming, is the practice of cultivating fruits, herbs, or vegetables for personal consumption on a small scale within a residential area. It is more sustainable compared to conventional agriculture in all aspects. However, there were various challenges in implementing outdoor home smart farming, including limitation or lack of skills, resources, or infrastructure to produce good and high-quality crops. This study addresses these challenges by integrating Python scripting and Linux OS with hardware components like the Raspberry Pi 4 Model B, ESP32, soil moisture sensors, and UV lights. Home Assistant, an open-source software, was utilized to run the script programming for outdoor home smart farming. The integrated smart devices into Home Assistant were used to monitor and analyze the farming parameters outcomes to assist decision-making and provide further user action. As a result, the system was efficient due to only consuming 0.16% for water usage and 0.64% for energy consumption compared to daily household use, as well as reducing water usage by up to 82.45% for the watering process. These results highlight the system's capability to optimize resource usage and enhance crop productivity while minimizing environmental impact. By leveraging smart devices and IoT frameworks, the study showcases how modern technology can revolutionize traditional farming practices. The automated system not only reduces manual labor but also provides real-time data to assist in decision-making and further user actions. In conclusion, the implementation of Home Assistant management based on Raspberry Pi in outdoor home smart farming effectively addresses the challenges of urban agriculture.

Keywords: outdoor home smart farming, home assistant, water usage, energy consumption, plant growth

1. Introduction

Nowadays with the advancement in farming, farmers use smart farming practices to increase crop health and production by implementing effective irrigation systems and providing appropriate ultraviolet light according to farming requirements based on environmental change to achieve sustainable agriculture instead of conventional agriculture practices. However, it is identified that the limitation or lack of skills, resources, or infrastructure poses a challenge to operate smart farming systems due to the complex architecture of using smart farming technologies, such as IoT devices, data analytics, and automation (Gómez et al., 2019; Quy et al., 2022; Verschae, 2023). This highlights the need for practical, user-friendly solutions that address these barriers.

Existing IoT-based agricultural solutions have demonstrated success in optimizing resource use and productivity, particularly in urban environments where resources are constrained. Vallejo-Gómez et al. (2023) emphasize that compact and cost-effective IoT systems are highly adaptable to urban farming, enabling precise resource management. However, many of these systems lack integration into a unified platform that supports real-time monitoring and automation. By leveraging the Raspberry Pi's affordability and versatility and combining it with the Home Assistant's robust automation capabilities, this study offers a novel solution to enhance accessibility and operational efficiency in outdoor home smart farming.

This study aims to address the challenge of performing farming tasks, especially watering plant process, to prevent overwatering or water wastage and improve energy-efficiency use. The study focuses on developing and implementing outdoor home smart farming by integrating the proper YAML script to enable the automation features to assist farmer tasks and monitor crop development, as well as evaluate the effectiveness of Home Assistant management based on Raspberry Pi. The scope of the study was to utilize the Home Assistant management to monitor and control the crop development properties by optimizing the Raspberry Pi and connecting with smart devices to fulfill the tasks and objectives. By systematic assessment regarding water usage and energy consumption using Home Assistant management based on Raspberry Pi, outdoor home smart farming was able to enhance crop yield in terms of plant growth rate while reducing environmental effects to enable sustainable agriculture and improve energy-efficient use by integrating with a variety of technologies, including smart devices and IoT framework (Dev et al., 2023; Gebresenbet et al., 2023).

2. Materials and Methods

2.1. Hardware and software implementation

The hardware implementation involved installing and configuring smart devices and components to connect to Raspberry Pi under a similar framework protocol, Wi-Fi, to develop and implement the outdoor home smart farming on site. In contrast, the software implementation consisted of the Home Assistant operating system installation and configuring the smart devices to integrate into Home Assistant management and develop the Home Smart Farming automation hub. For the hardware implementation, the IoT smart devices used to develop outdoor home smart farming included Raspberry Pi 4 Model B, Sonoff THR320D, Sonoff MS01 Soil Moisture sensor, ESP32 Microcontroller, YF-S201 Water Flow Rate Sensor, Ultraviolet Light, Sonoff S60TPG Smart Plugs, etc. These smart devices and components were connected to Raspberry Pi under a similar network and integrated into Home Assistant management.

Figure 1 illustrates the proposed architecture connection and operation of outdoor home smart farming based on Raspberry Pi for Home Assistant management.

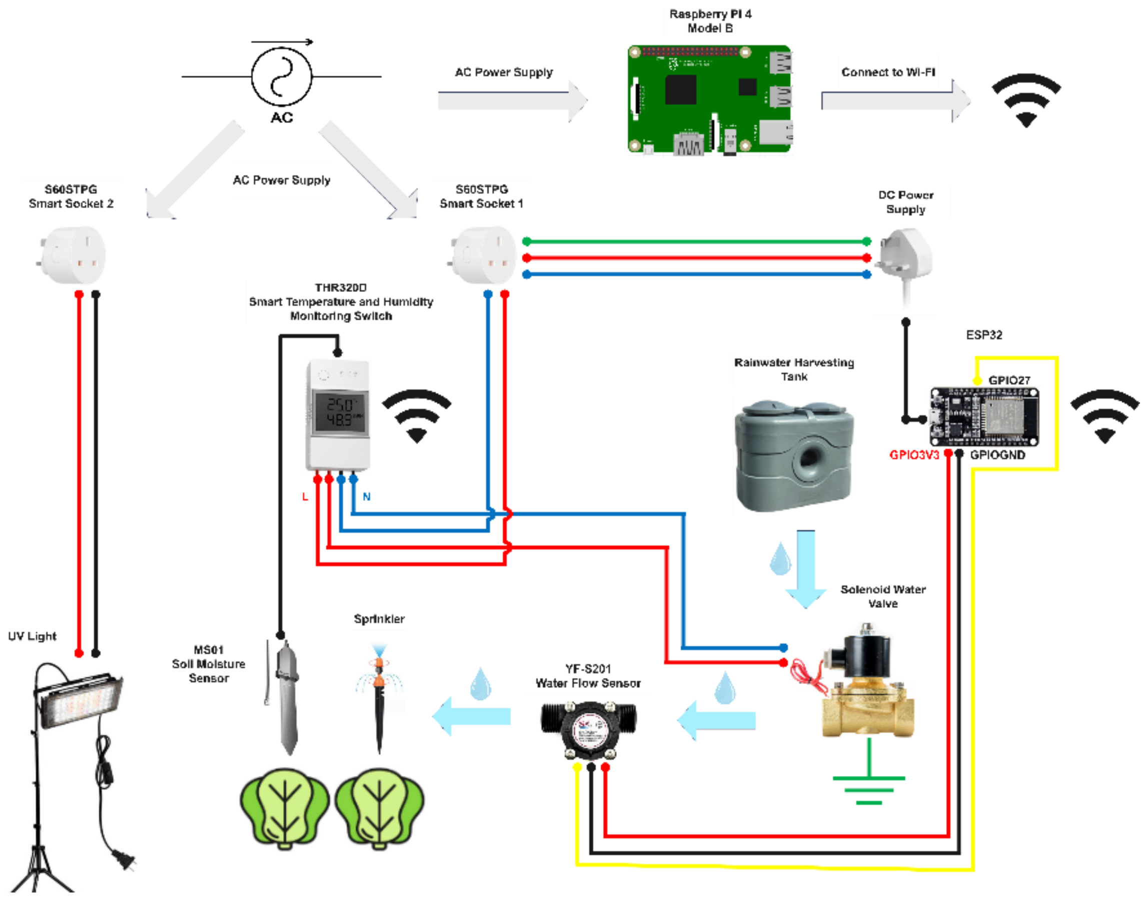

Figure 1 Proposed architecture connection and operation of outdoor home smart farming based on Raspberry Pi for Home Assistant management.

The utilization of Sonoff THR320D working with Sonoff MS01 was used to monitor and update the soil profile status in terms of the relative percentage of soil humidity concerning environmental changes and to act as a switch to regulate the solenoid water valve. On the other hand, ESP32 and the YF-S201 were used to monitor and regulate total volume water usage and water flow rate for watering plants. The optimization of ultraviolet light was to provide a proper ultraviolet source on plants at night to promote crop productivity and enhance plant development. The smart devices of Sonoff S60TPG were used to monitor energy consumption to operate the systems. In addition, Raspberry Pi, Sonoff THR320D, and ultraviolet light were supplied with alternating current, while ESP32 was supplied with direct current as the primary source. From another perspective, the system met the sustainable principle by using rainwater as the main source for watering the plants.

In addition, the software implementation consisted of the installation of the Home Assistant operating system as the software to run the script and integrate the smart devices into Home Assistant management. YAML scripts, including "configuration.yaml," "automations.yaml," "scripts.yaml," and "esphome.yaml," were developed using File Editor features under Home Assistant to configure the smart devices with specific entity devices and enable automation features for outdoor home smart farming. Then, the script was integrated into Home Assistant along with connection to smart devices, and the information was stored in the "HASS" folder. The sensor or smart devices would trigger and call the variable services under the YAML script according to the environmental condition changes and instruct the system to act automatically based on the agricultural properties required. The Home Smart Farming dashboard was developed in Home Assistant management as a Farming Automation hub to monitor and analyse the farming parameters to cultivate the plant, especially for Pak Choi vegetables, as well as track the plant development. The card features were implemented under the Home Smart Farming dashboard to monitor and gain insight into outdoor home smart farming sites and control the status and activities of the smart devices from the dashboard.

Figure 2 shows the Home Smart Farming dashboard for outdoor home smart farming systems.

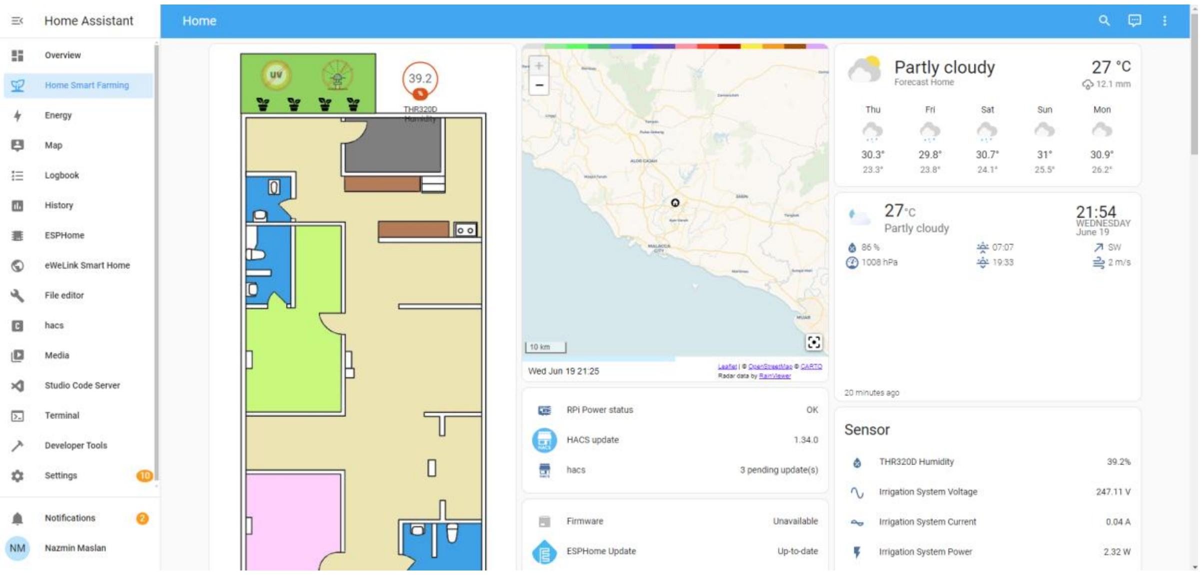

Figure 2 Home smart farming dashboard.

2.2. RH% soil humidity analysis

The quantity of moisture in the soil relative to its maximum capacity at a given temperature is known as soil humidity, commonly expressed as relative humidity (RH%) (Sahin et al., 2023). Maintaining soil humidity levels between 20% and 30% is essential for Pak Choi vegetable cultivation to achieve maximum crop development and productivity (Sadewa, 2016). Thus, the relative percentage of soil humidity needed to cultivate Pak Choi vegetables ranged between 20% and 30%. The water irrigation system was set to operate when the soil humidity was below 20% to prevent dehydration of the plants. On the other perspective, the system was idle when the soil humidity was above 30% to avoid overwatering and damage to the roots of Pak Choi vegetables. Thus, the relative percentage of soil humidity was recorded and analysed by the optimal daily soil moisture content for cultivating the Pak Choi vegetables within 14 days of system applications.

2.3. Water Usage Analysis

Water is vital to plants because it fulfilled various essential functions in their development and growth. Water plays a critical role in many metabolic processes and helps with photosynthesis by supplying the required medium for enzyme activities (Edwards et al., 2019). For this study, water usage was monitored in terms of the total water volume used. The water usage analysis was conducted using two methods, manual and automated approach. The manual approach involved cultivating Pak Choi vegetables using a conventional technique, which meant watering the plants manually using a water jug. Nederhoff and Stanghellini (2010) studied on tomato farming and showed that watering volumes could vary from 1.28 to 4.4 liters per plant, notably affecting plant growth. Therefore, a total of 3 liters of water was used to perform the watering process twice a day for the manual approach. On the other hand, the automated approach cultivated Pak Choi vegetables using a water irrigation system implemented in the outdoor home smart farming system, which operated automatically to water the plants. Keneti et al. (2022) reported that the water sprinkler was efficient because it provided rotational motion and improved water distribution via impacting water, reducing stress on plant roots and making it efficient for Pak Choi vegetables. Thus, water sprinklers were used due to their high water use efficiency and promotion of high crop yield for cultivating Pak Choi vegetables.

2.4. Energy Consumption Analysis

Energy consumption is the power supplied to the outdoor home smart farming system, which operates both water irrigation and ultraviolet light systems. Energy consumption is the amount of energy utilised by the system or devices following the operation time and is often measured in kilowatt-hour (kWh) (Katunský, 2011; Sendari et al., 2022). For this study, the S60TPG Smart Plug was used by integrated into Home Assistant management to monitor and control the power management to supply energy and operate the water irrigation and ultraviolet light systems to improve the crop yield for the Pak Choi vegetables.

2.5. Plant Growth Analysis

The effectiveness of outdoor home smart farming has been analysed based on notable difference in the plant growth rate for manual and automated approaches in cultivating the Pak Choi vegetables. The farming process was conducted with two methods, the manual approach by conducting the agriculture task with the conventional method. In contrast, the automated approach utilised advanced smart farming techniques by integrating smart devices to assist the farming task, especially water irrigation and ultraviolet light systems, to improve plant growth. The plant growth rate was observed and analysed using the visual inspection method and measured the plant characteristics, the stem height growth and the number of leaves germination at intervals of Day 1, Day 7, and Day 14 for both manual and automated approaches.

3. Results and Discussion

The outcomes show that the implementation of outdoor home smart farming based on Raspberry Pi for Home Assistant management was effective in assisting the farming tasks and enabling energy-efficient use regarding water usage and energy consumption to operate the systems. It also promoted high crop productivity and enhanced plant development for the Pak Choi vegetables. The relative percentage of soil humidity was maintained at around 30% over 14 days of system applications, as shown in Figure 3. More precisely, the average relative percentage of soil humidity was sustained at 35.42%, which is optimal for soil moisture content for cultivating Pak Choi vegetables to improve crop development and achieve high yields.

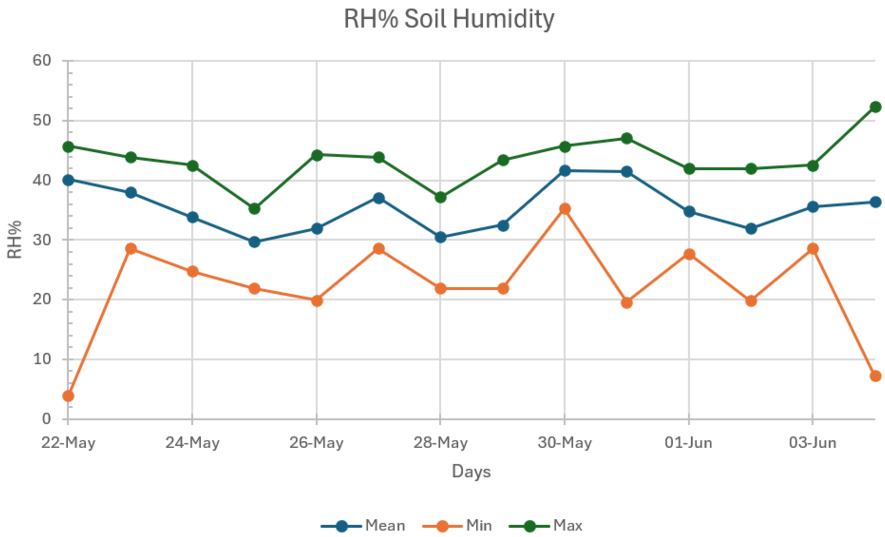

Figure 3 Daily relative percentage of soil humidity to cultivate the Pak Choi vegetables.

The use of water for the manual approach was maintained at 3 liters per day, whereas watering the Pak Choi vegetables twice per day. At the same time, the highest water usage for the automated approach was 1.20 liters on 26 May 2024, while the lowest water usage was 0.26 liters on 22 May 2024, as shown in Figure 4. Furthermore, the total amount of water usage for the automated approach was 42 liters or 3 liters per day, while the automated approach only consumed 8.94 liters or 0.64 liters per day. Thus, there was a notable difference in water usage between manual and automated approaches. Therefore, outdoor home smart farming is effective due to low water consumption, which only consumes 0.64 liters per day, compared to a manual approach, which was 3 liters per day.

The highest total energy consumption for both water irrigation and ultraviolet light systems was on June 1, 2024, which was 0.0558 kWh. In contrast, the lowest total energy consumption for both systems was on May 25, 2024, which was 0.0430 kWh, as shown in Figure 5. Furthermore, the total daily energy consumption for both water irrigation and ultraviolet light systems was 0.694 kWh, while the total average daily energy consumption was 0.050 kWh. Thus, the implementation of outdoor home smart farming is effective in terms of saving energy due to only consuming a small amount of energy, which was less than 1 kWh per day.

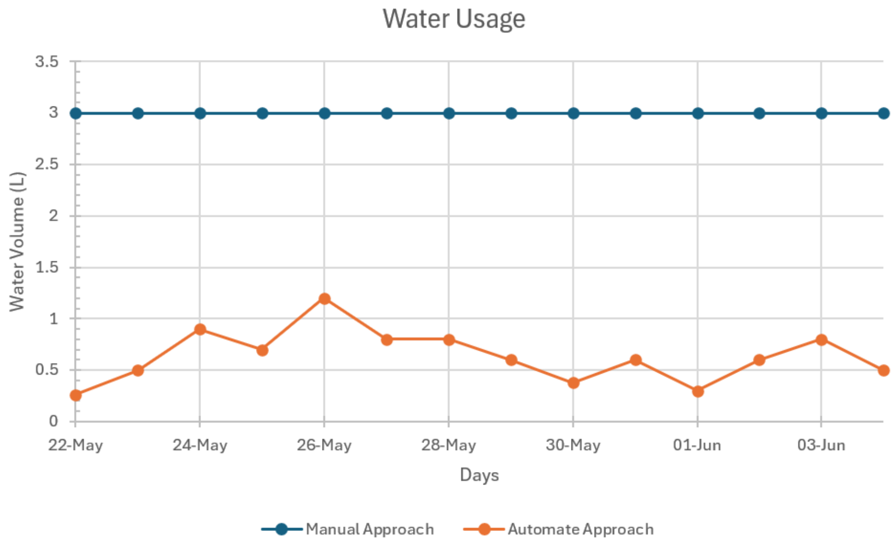

Figure 4 Daily water usage for both manual and automated approach to cultivate the Pak Choi vegetables.

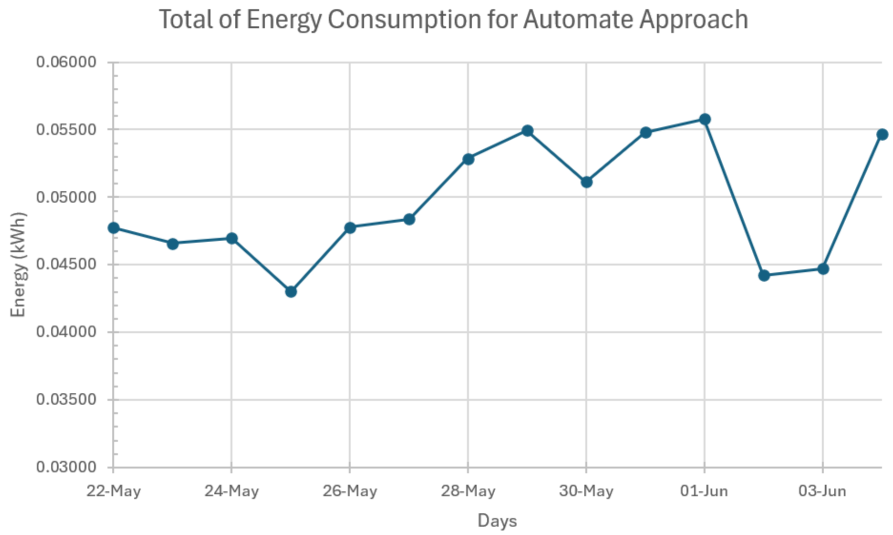

Figure 5 Daily total energy consumption for both water irrigation and ultraviolet light systems to cultivate the Pak Choi vegetables.

The percentage of water usage for both manual and automated approaches was 0.73% and 0.16%, respectively, compared to the overall water usage of household use, as shown in Table 1. Although the water irrigation system implemented in outdoor home smart farming used sustainable energy, which was rainwater, the use of water for the automated approach is more water-saving compared to the manual approach. Thus, implementing an automated approach using smart devices and optimizing IoT methods for performing farming tasks in outdoor home smart farming saved water usage by up to 82.45% instead of the conventional method. This finding is supported by a recent study by Touil et al. (2022) who states that the smart irrigation system saved water from 20% to 92% by integrating precision methods and advanced sensors to improve water use efficiency and enhance crop productivity compared to conventional methods. In a recent discovery, Chauhdary et al. (2024) reported that precision irrigation with IoT-based controls enhances crop yields by 20% to 27% while saving 20% to 30% of irrigation water, highlighting the benefits of automation for saving resources. Therefore, implementing an automated approach in outdoor home smart farming saved water and reduced water usage by up to 82.45% by supplying water based on real-time data on soil profiles, compared to traditional methods for performing farming tasks, especially cultivating Pak Choi vegetables.

The percentage of energy consumption for the automated approach was 0.64% of the overall energy consumption of households, as shown in Table 1. Hence, the use of outdoor home smart farming is effective in terms of saving energy due to its small energy consumption, which was less than 1% of the overall energy consumption compared to household use. This is consistent with the data by a recent study by Khaleefah et al. (2023) that stated using sensors and devices for smart agriculture could reduce energy consumption by optimising IoT data transmission, leading to enhanced network efficiency and reduced energy usage. As a result, implementing an automated approach in outdoor home smart farming saved energy due to its small energy consumption compared to overall household use, as well as improved crop productivity.

Table 1 The effectiveness level of an outdoor home smart farming system that was monitored and controlled by Home Assistant management.

Items	Daily household consumption	Manual Approach	Automate Approach
	Water Usage		
Water Usage (per Day)	410.96 L	3 L	0.64 L
Water Usage Percentage (Compared to Households)	99.27 % (Manual) & 99.84 % (Automate)	0.73 %	0.16 %
Water Usage Reduction Percentage	-	82.45 %	
	Energy Consumption		
Energy Consumption (per Day)	7.72 kWh	-	0.0496 kWh
Energy Consumption Percentage (Compared to Households)	99.36 %	-	0.64 %

The plant growth rate was observed and analysed using the visual inspection method and measured the plant development regarding stem height growth and the number of leaves germinating at intervals of Day 1, Day 7, and Day 14 for both manual and automated approaches. There was a higher plant growth rate for the automated approach than for the manual approach. The initial stem height for manual and automated approaches were quite similar, at around 1 cm, as shown in Figure 6. Thus, the plant growth progress for the automated approach was higher, with the final stem height around 5 cm, while the stem height for the manual approach was only around 3 cm.

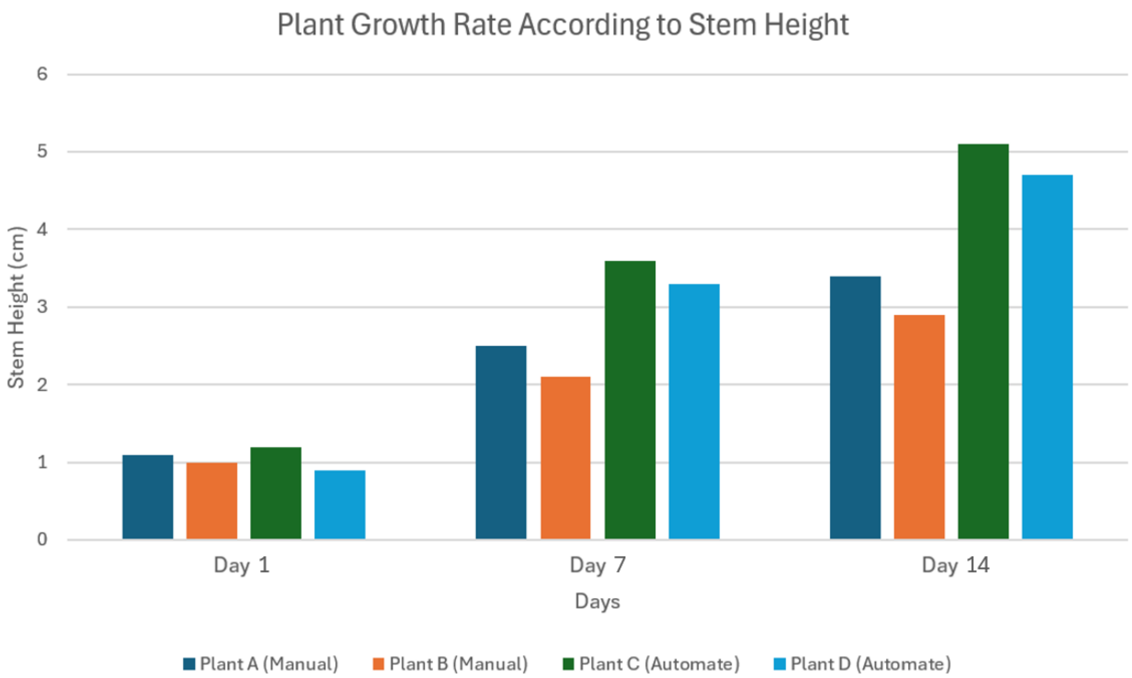

Figure 6 Plant growth rate according to stem height.

On the other hand, there was higher plant growth development for the automated approach compared to the manual approach. The initial number of leaves germinated for manual and automated approaches were quite similar, with around six units of leaf number, as shown in Figure 7. Thus, the plant growth rate for the automated approach was higher, with the final number of leaves germinating around a total of 14 leaf units, while the number of leaves germinating for the manual approach was only around 12 leaf units.

As a result, the implementation of outdoor home smart farming by integrating water irrigation and an ultraviolet light system improved plant growth development in terms of stem height and the total number of leaves germinating for Pak Choi vegetables. This view is also supported by a related recent study by Sahoo et al. (2022), which stated that the utilisation of IoT devices to monitor and control parameters including humidity, temperature, air quality, and proper violet lights promoted optimal growing conditions to improve leaf growth on mint plants and enhance mint plant development over a ten-day period. Similarly, Maraveas (2023) noted that optimized ultraviolet lighting in smart greenhouses simulates natural growth conditions, which helps crop yields to be better. Thus, the integration of outdoor home smart farming, which consisted of water irrigation and an ultraviolet light system, is effective in monitoring and controlling Pak Choi vegetables because the system allowed real-time adjustments to promote optimal growing conditions and fulfil the required agricultural properties, as well as to improve crop yield.

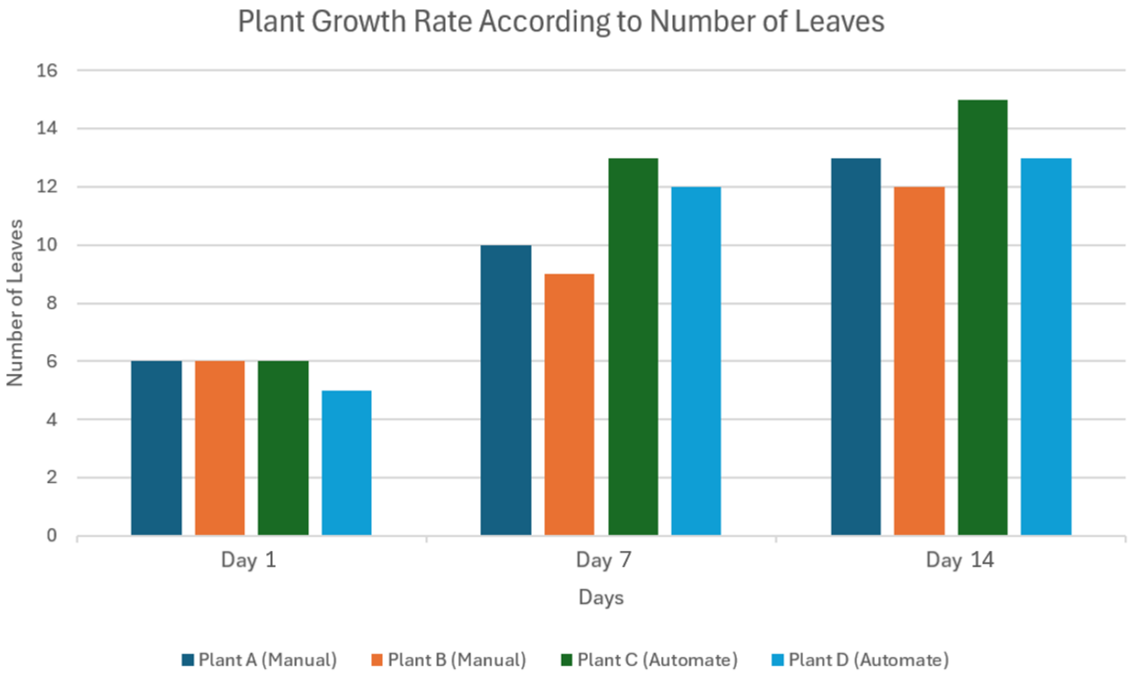

Figure 7 Plant growth rate according to number of leaves.

4. Conclusions

In conclusion, the implementation of outdoor home smart farming to cultivate the Pak Choi vegetables is effective due to the water usage for the automated approach being relatively lower than the manual approach, which was 0.16% and 0.73% respectively, compared to the water usage of household use. Furthermore, the energy consumption for the automated approach was relatively low, consuming only 0.64% of energy consumption from overall household use. In addition, the automated approach reduced water usage by up to 82.45% for watering purposes compared to the manual approach. Furthermore, implementing outdoor home smart farming improved plant growth development for Pak Choi vegetables in terms of stem height growth and the number of leaves germinating over a 14-day period. Therefore, outdoor home smart farming using Home Assistant management based on Raspberry Pi is effective compared to conventional agriculture practices due to consuming only a small amount of energy and reducing the use of water for the watering process, which led to preventing water wastage and improving farming productivity.

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Ethical considerations

Conflict of Interest

The authors declare no conflicts of interest.

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