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Adoption of the internet of things in smart vertical farming systems

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ABSTRACT

The vegetable industry is a fundamental part of Malaysia's agricultural and economic landscape, providing essential food supplies, creating employment opportunities, and contributing to economic growth. However, recent challenges, such as labor shortages in the agricultural sector, have limited the capacity of Malaysian vegetable businesses to meet increasing market demand. This study proposes the Smart Vertical Farming System (SVFS), utilizing the Internet of Things (IoT) as part of a broader 'green revolution' focused on applying advanced Information and Communication Technologies (ICT) in agriculture. Using a waterfall development framework and a qualitative research methodology, the SVFS was designed to monitor critical agricultural parameters such as soil moisture, light exposure, and ambient temperature. Initial implementation involved cultivating two different vegetable varieties alongside traditional farming methods. Remarkably, after 19 days, the results showed that vegetables grown using the SVFS experienced faster growth rates and increased leaf production compared to those cultivated conventionally. These findings suggest that integrating innovative farming technologies can significantly improve vegetable quality and yield, while also stabilizing market supply to meet consumer needs at competitive prices. This research demonstrates the potential for technological advancements to address pressing issues within the agricultural sector and enhance overall food security in Malaysia.

Contribution/Originality: This study introduces the Smart Vertical Farming System (SVFS) as a solution to the labor shortage challenges faced by the Malaysian vegetable industry. Employing IoT technology and a waterfall development framework, the SVFS effectively monitored key agricultural parameters and enhanced vegetable growth rates compared to traditional methods. The results highlight the potential of innovative farming technologies to improve vegetable quality and yield, ensuring market stability and meeting consumer demands. This research underscores the transformative impact of technological advancements in addressing agricultural sector issues and enhancing food security in Malaysia.

1. INTRODUCTION

Farming is one of the oldest occupations in human history. The importance of agriculture over time cannot be overstated because it provides the third most important thing for humans to survive after air and water: food. The total population is expected to grow to around 8.3 billion by 2030 [1]. Because of the tremendous growth in the human population, there is an urgent need for agricultural development to meet future food demands. According to the United Nations (UN) 2030 Agenda for Sustainable Development [2], 17 objectives are being set (Figure 1), with objective number 2 being explicitly for agriculture. The production of food through agriculture is critical to achieving the goal of "zero hunger".

Figure 1. Sustainable development goals.

Source: William [2].

The success of agriculture in Malaysia is reflected in the self-sufficiency ratio (SSR) reported by the Department of Statistics Malaysia (DOSM) in 2021 [3], with 16 of 33 selected agriculture commodities (including livestock and fisheries) recording SSRs of more than 100 percent, as illustrated in Figure 2.

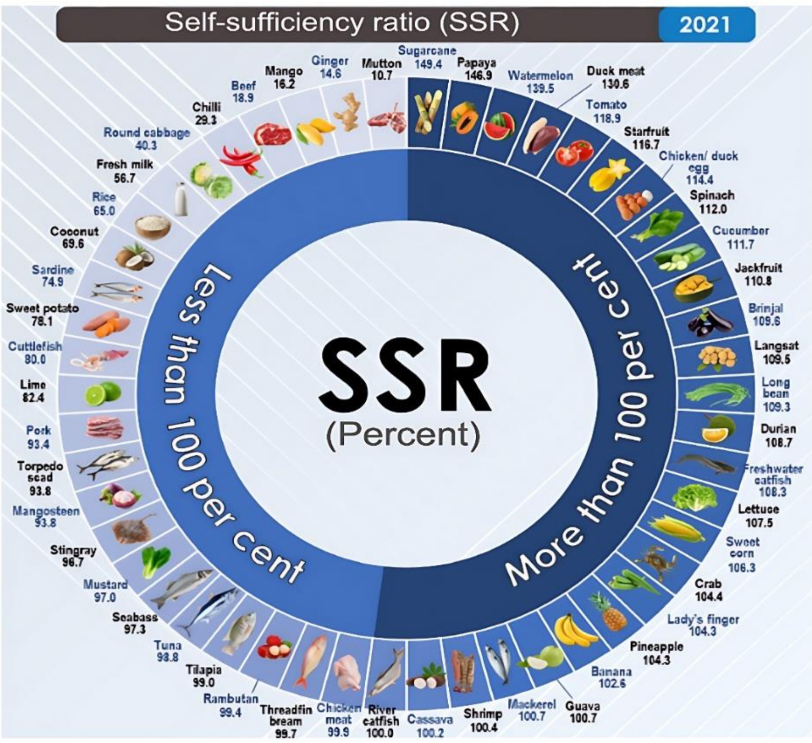

Figure 2. Self-sufficiency ratios of Malaysian agricultural commodities.

Source: Department of Statistics Malaysia [3].

However, Malaysian vegetable production could not meet the existing market demand [4]. The main reason is a labor shortage in the agricultural sector [5]. This is due to two factors: 1) The young people in the area did not want to work in agriculture [6]; 2) the majority of current farmers are part of the "aging population" [7]. The World Health Organization (WHO) classifies people aged 65 and older as "aging." They are unable to work due to their age and workplace conditions.

The Malaysian government chose to import veggies from other nations, namely Thailand and China, to address this issue [8]. However, reliance on imported products has been linked to another issue, which is food security. Sulaiman, et al. [9]. Kuek et al. [10] have stated that relying on imports exposes the country to vulnerabilities during a financial downturn. One solution to this problem is to hire foreign laborers. The charge for hiring a foreign worker in the agricultural sector [8] may be a hardship for most small- to medium-sized farmers; therefore, this is not yet a viable solution.

Researchers have created smart farming (SF) and vertical farming (VF) to allay these worries. The use of information and communication in equipment, machinery, and sensors for agricultural production systems is known as SF [11]. VF, on the other hand, mentions growing vegetables inside a building [12]. This idea has gained widespread acceptance in many developed nations due to its inexpensive implementation costs, availability of healthier food, enhanced food security, and reduced water consumption [13]. To overcome the aforementioned challenges, the authors of this study designed and created a smart vertical farming system (SVFS), a combination of SF and VF.

2. RELATED WORKS

2.1. Intelligent Farming

Farming has been a traditional industry throughout human history. Farming includes growing crops and keeping animals; it produces food and raw materials for humans.

Many contemporary nations, such as Singapore and the United Kingdom, are presently considering and implementing SF. According to Pivoto et al. [11], one of the characteristics of SF is the incorporation of technologies into a farm. SF is a farm management technique that makes use of contemporary technologies to improve crop quality and yield [14]. The system will have embedded sensors that will gather information about the weather, air quality, soil conditions, and light levels [15].

Artificial intelligence (AI), Internet of Things (IoT), smart machinery, and other new technologies have been integrated into SF.

For example, an IoT-based remote control vehicle can perform agricultural tasks such as spraying, cutting, and weeding in both automatic and manual modes. The controller continuously monitors the temperature, humidity, and soil conditions and supplies water to the field as needed [16]. SF is still in its early stages, with opportunities for researchers and businesses to participate. Continuous advancements and innovations in these technologies promise to revolutionize sustainable farming practices.

2.2. Review of Existing Farming Method

2.2.1. Vertical Farming (VF)

VF is an example of contemporary farming technology. It reduces transportation costs by growing crops inside a structure, typically in a city or other urban region (Figure 3). VF has been shown to save 5% of irrigation water when compared to traditional farming [17].

Figure 3. Sample of VF.

The location close to an urban area, the innovative use of land or buildings, the use of soil-free growing techniques, the application of advanced technology to regulate the growing environment, and the output often favoring local markets are features of VF. VF generally uses a mix of artificial and natural illumination. Artificial lighting is typically based on light-emitting diode (LED) technology and can be powered by renewable energy sources such as solar or wind energy. Increased production per unit area, the provision of nutritious food, enhanced food security, and reduced water use are all benefits of VF [13]. Fully automated production is possible with VF; the owner can use a robotic arm to plant and cultivate plants. This will lessen the impact of future labor shortages. However, VF necessitates sufficient space for vegetable planting, advanced technologies, and a complex process, and the initial setup cost is high.

2.2.2. Rooftop Plant Production

Rooftop Plant Production (RPP) is the practice of growing plants on the roofs of residential, commercial, and industrial structures, as shown in Figure 4. An example of outdoor farming is RPP. Increased local food production and security, reduced transportation costs, and a stronger local economy are all advantages of RPP. Due to their greater exposure to sunlight than the ground, rooftops are excellent environments for urban plant growth [18]. RPP aids in insulating heat from solar exposure, which lowers the energy needed to cool the building. Tomatoes, cucumbers, and peppers are among the crops suitable for rooftop cultivation.

Figure 4. Sample rooftop plant.

The disadvantage of a rooftop plantation is that it requires a rooftop environment, which may be hazardous to the employee working there. However, the weather significantly impacts the quality and growth time of the plants.

2.2.3. Aquaponics

Aquaponics is a hybrid of aquaculture (the cultivation of fish and other aquatic animals) and hydroponics (the cultivation of plants), as illustrated in Figure 5. In an interdependent arrangement known as aquaponics, plants are fed by the waste products of aquatic creatures. In return, the vegetables clean the water before it is returned to the fish. Microbes, fish, and their waste all contribute significantly to the nutrition of plants. These helpful microorganisms gather in the gaps between the plants' roots, where they break down sediments and waste from fish into nutrients that the plants can utilize for growth.

A perfect fusion of aquaculture and agriculture is the eventual outcome. This approach has the advantages of organic fertilization, efficient water and nutrient utilization, and environmental friendliness [19]. In a small aquaponics garden, vegetables that do not require many nutrients can be cultivated. We can choose from lettuce, kale, watercress, arugula, ornamental flowers, mint, herbs, okra, leeks, radishes, spinach, and other small vegetables. Beans, broccoli, cauliflower, tomatoes, and cucumbers can all benefit from improved nutrition and aquaponics technology.

With aquaponics, there are no environmental restrictions; thus, it can be used both indoors and outdoors. It is scalable, and there are no hazardous petrochemicals, pesticides, or herbicides to be used. Additionally, it is sustainable.

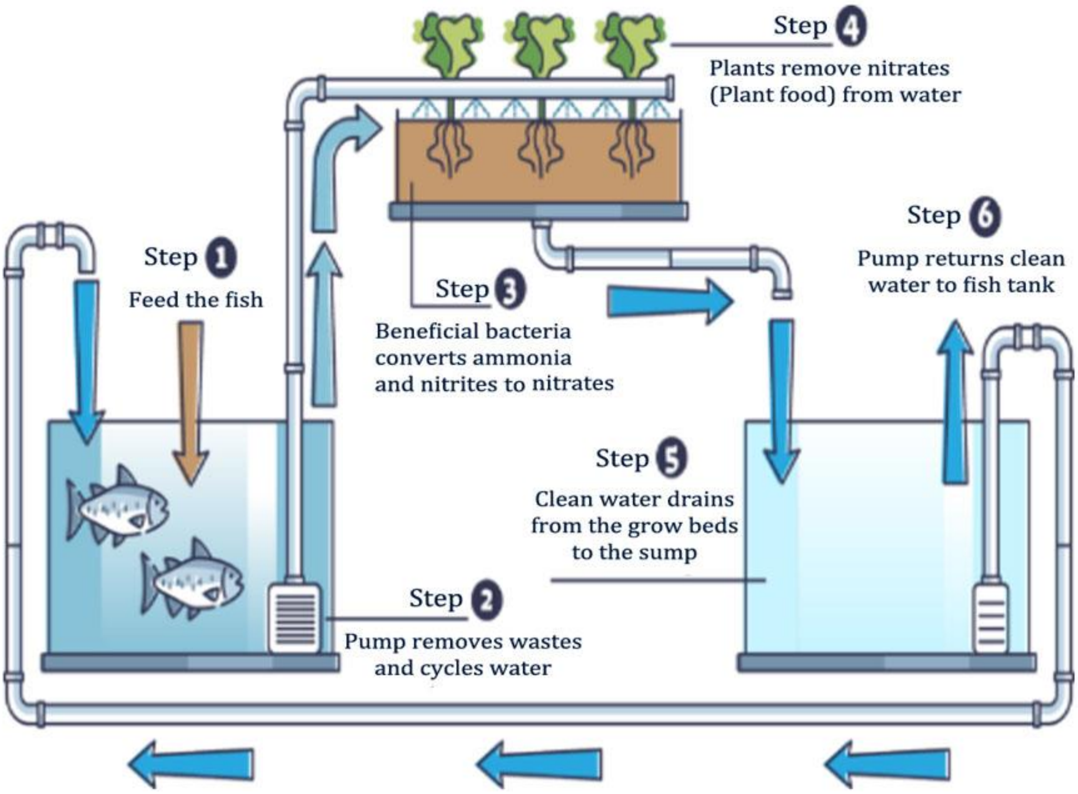

Figure 5. Sample of aquaponics.

2.2.4. Summary of Existing Farming Methods

Table 1 depicts a summary of current farming methods based on the literature. It is possible to conclude that VF has more advantages than rooftop and aquaponics.

Table 1. Summary of existing farming methods.

Criteria	Vertical farming	Rooftop plant production	Aquaponics
Indoor	Yes	No	Yes
Cost for initial setup	High	Medium	High
Automated control	Yes	No	No
Mobile application supported	Yes	No	No
Log record	Yes	No	No
Growing time	Shorter	Depending on the weather	Depending on the weather
Quality	Good	Depending on weather	Depending on the weather & fertilizer from the water
Soil required	Minimum	Yes	Yes
Suitability of plants	Vegetables, ornamental plant	Vegetables, ornamental plant	Mainly for vegetables

2.2.5. Internet of Things (IoT)

"A vast network of "Things" talking with one another will be created by the IoT" [20]. IoT is a new communication mechanism that utilizes existing technologies, not new technology. The IoT can perform the following tasks, according to Chen et al. [21], including location sensing and information sharing, fleet management, environmental sensing, remote medical monitoring, secure communication, and others. The IoT enables humans to improve their work efficiency, monitor business processes, save time and money, and generate more revenue.

Broadband Internet has become a basic requirement, and the cost of connecting has decreased. As a result, it has accelerated the development of IoT devices. Appliance manufacturers have begun to build network-capable devices. IoT is essentially the connection of any device to the Internet [22]. IoT smart device producer Xiaomi is well-known for manufacturing smart ceiling lights, air purifiers, dishwashers, induction cookers, and other products. Other companies have begun to focus on integrating IoT to stay current with the trend, including Apple Inc., Samsung, and LG.

Convenience, improved productivity, connectivity, wellness, interaction, and personalization are some of the benefits of IoT. Efficiency refers to improvements in connectivity that reduce the amount of time typically spent completing the same tasks. Connectivity is the capacity to operate many devices from a single device.

3. METHODOLOGY

This study utilized the waterfall model as the system development methodology. The model was chosen primarily because the proposed system was on a small scale. The model consists of requirements gathering and analysis, system design, implementation, and testing phases. Each phase is completed before moving on to the next, ensuring a structured and sequential approach. This linear progression allows for thorough documentation and clarity at every stage of development [23]. Below is a summary of the phases.

3.1. Phase 1: Requirement Gathering and Analysis

In this phase, a qualitative approach was adopted to assess and examine the advantages and disadvantages of industrial and indoor farming methods through interviews and observations. The interview was divided into two parts: one with a seasoned farmer (Madam Ng Cui Yi) and the other with a housewife who also farms vegetables (Madam Wong). The outcomes are as follows: 1) The soil's humidity must be considered by the authors; otherwise, the roots of the vegetables will rot. It is crucial to monitor soil moisture since the roots depend on it as a key signal. Additionally, the authors focus on the irrigation system to prevent the soil from becoming overly saturated.

The three movies listed by the writers for observation are Growing Roots - Farmers growing vegetables on rooftops [24], TechKnow - Farmers growing vegetables with LED lighting [25], and Singapore urban farming offers sustainable solutions [26]. The scientists found that indoor farming requires a lot of water and light, and that growing vegetables vertically can enhance yield in a small space.

3.2. Phase 2: System Design

Use case diagrams are used to illustrate the functions and services that the system offers to the user, as well as the system's needs. Use cases for the Monitoring System and the Controlling System are shown in Figure 6 and Figure 7, respectively.

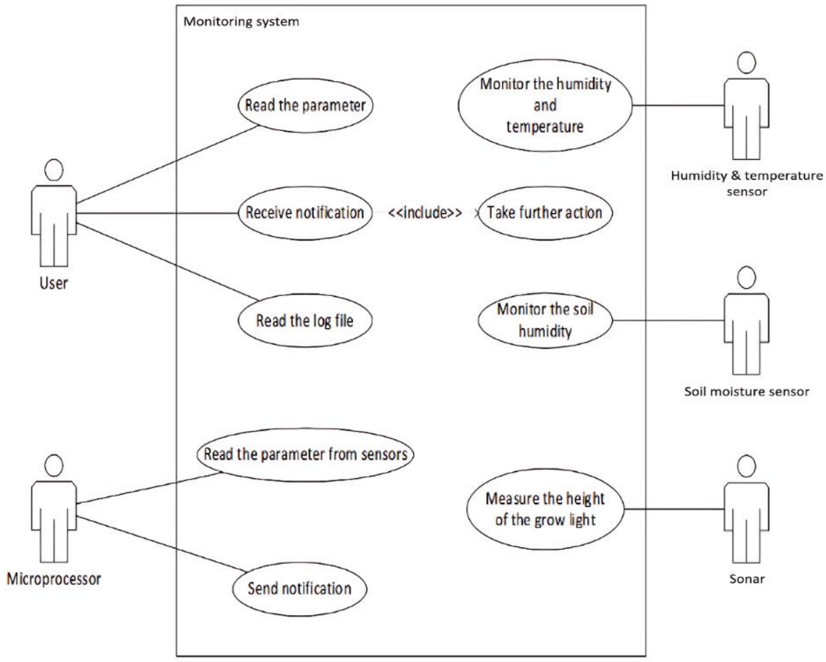

Figure 6. Use case diagram of a monitoring system.

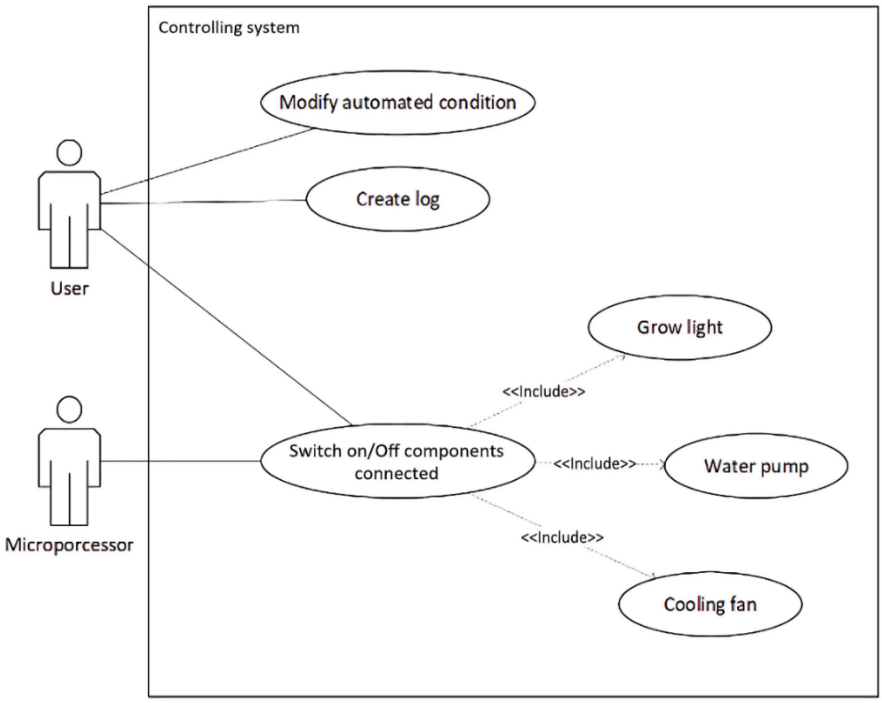

Figure 7. Use case diagram of controlling system.

3.3. Phase 3: Implementation

The Android Studio IDE was used to create the suggested system on Windows. The authors were able to connect all of the sensors and I/O devices, thanks to the IDE, which helps combine hardware and software [27]. The Arduino circuit board was selected to create the microcontroller prototype as illustrated in Figure 8. A microcontroller is an integrated device that can process logic and detect signals [28].

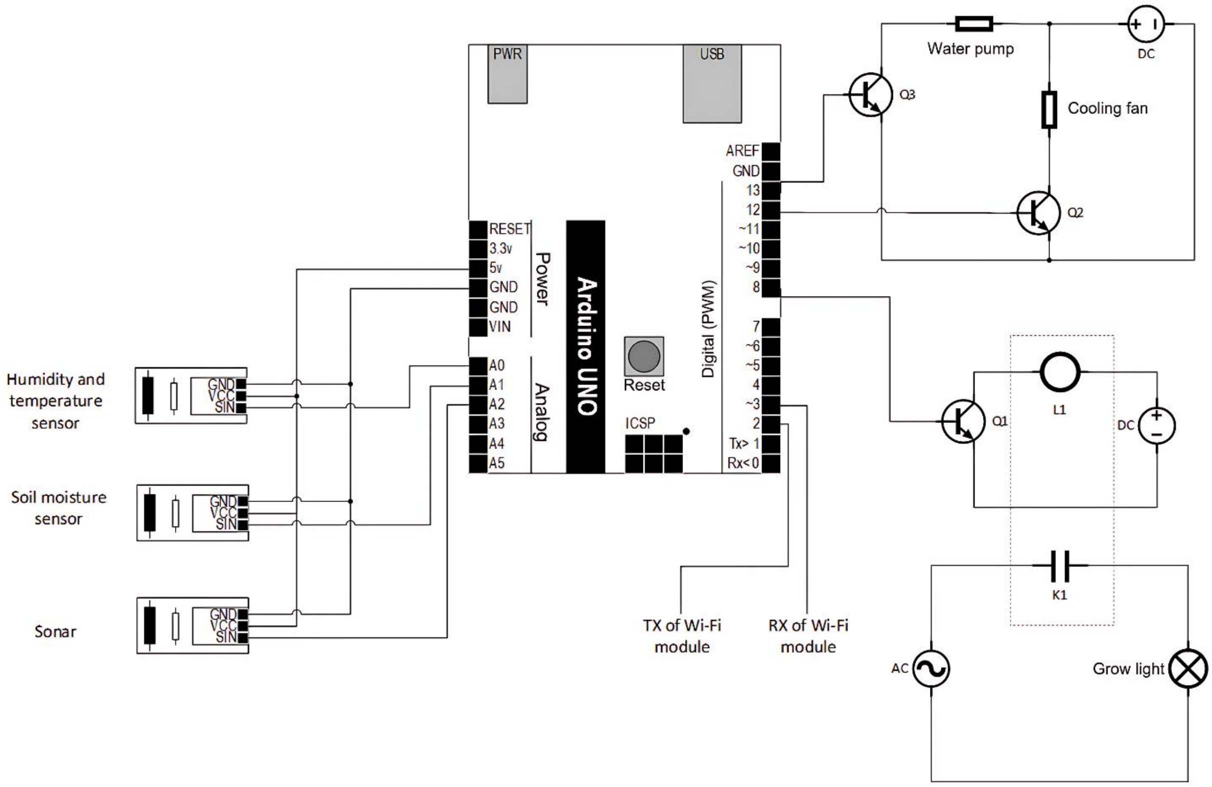

Figure 8. Circuit diagram of IoT device.

Firebase is a platform for developing mobile and web applications that include database functionality, messaging, and reporting. Because of this, the authors use Firebase to store data about the type of vegetable planted, the date of planting, and the length of the growing season. Firebase also enables Arduino to connect to it to deliver notifications to smartphones. The planting environment's temperature and humidity are measured using a DHT11 sensor. The thermistor and the capacitive humidity sensor comprise this sensor. Any microcontroller can easily read the DHT11 sensor. A soil moisture sensor called the YL-69 is used to measure soil humidity. The sensor's two components are an electronic board and two pads. The pads' function is to detect the presence of water. The sensor's output is voltage, and the authors chose a full-spectrum grow light for this study. The light's temperature is 6300K, and its appearance is white. Plants cultivated under white light have more leaves than those grown under blue light, according to Haris et al. [29]. The grow light should be installed 12 to 24 inches above the crops, as indicated in Figure 9. It was also advised not to leave the lights on all day because the plants require at least 6 hours of haziness for "resting." The network connection was established using the ESP8266 Wi-Fi module. With minimal programming and runtime loading, this module can be combined with sensors and other applications using the Arduino microcontroller.

The system was created in Java, but to connect with the Arduino microcontroller, code must be generated in the Arduino IDE and loaded into the Arduino module.

Figure 9. Grow light setting.

3.4. Phase 4: Testing

The implemented solution was tested for hardware compatibility with the developed Android application functionalities. The authors evaluated the following hardware: temperature and humidity sensors, soil moisture sensors, ultrasonic sensors, a water valve, a cooling fan, and artificial lights, which are some of the sensors used. The following module for the Android app has undergone testing: obtaining information about temperature, humidity, soil moisture content, and auto control. Vegetable types can be saved, edited, and removed from the database; a summary of production for the previous month; planting a new vegetable; updating auto control information; sending notifications; and controlling components. The user can observe if the mobile application can manage the associated devices. The authors identified certain issues during the testing phase and were able to fix them. The created SVFS was tested by planting Chinese and white stem choy sum alongside conventional agricultural practices. Vegetable height and leaf count will be measured during the growing season. A farmer (Madam Ng Cui Yi) and a housewife were also interviewed by the authors to assess the usability and acceptance of SVFS (Madam Wong). The following sections discuss the outcomes of the testing.

4. RESULTS AND DISCUSSION

Figures 10 and 11 depict a 25-day white stem choy sum growth comparison between traditional farming and SVFS. According to the observations (Figure 10), from day fourteen onwards, more leaves grew than in conventional agriculture. The height analysis (Figure 11) shows that choy sum grown under artificial light grows much faster than those grown traditionally. It is clear from day 7 that the height of the vegetables in traditional and SVFS methods is 3.5 cm and 4 cm, respectively. After 25 days, the height is 12 cm and 14 cm in traditional and SVFS methods, respectively.

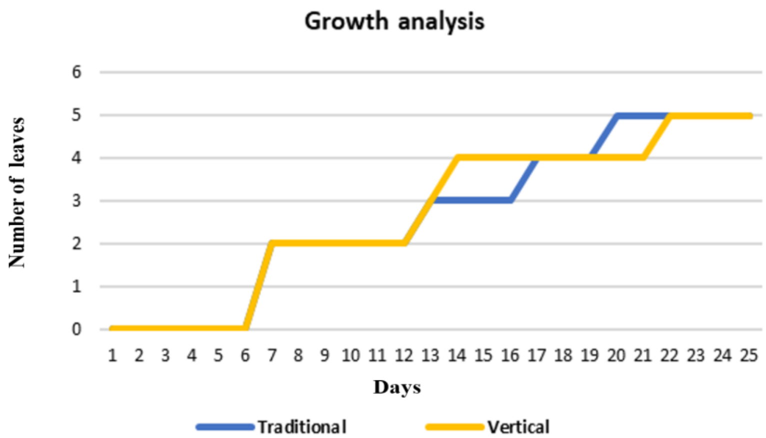

Figure 10. White steam choy sums growth analysis - number of leaves.

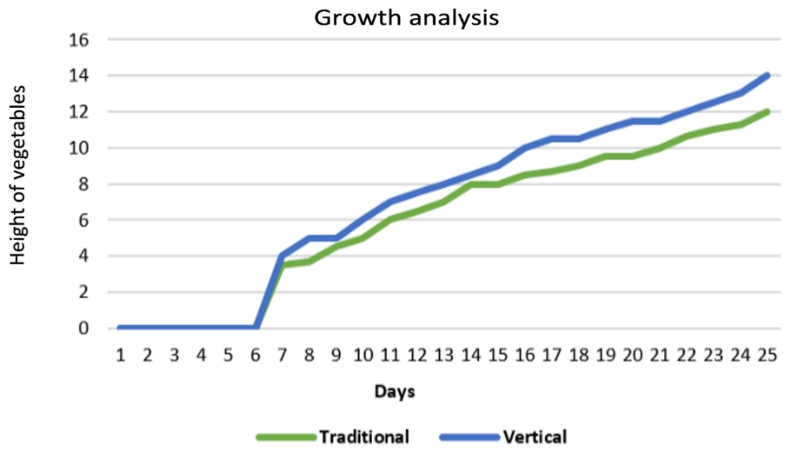

Figure 11. White steam choy sums growth analysis - growth height (in cm).

Figures 12 and 13 depict a 19-day comparison of Chinese choy sum growth using traditional farming and SVFS methods. According to the author's observations (Figure 12), from day eleven onwards, more leaves grew than in traditional farming. The height analysis (Figure 13) shows that Chinese choy sums grown under artificial light grow much faster than those grown traditionally. It is clear from day 5 that the height of the choy sums in traditional and SVFS methods is 0.5cm and 0.9cm, respectively. In both traditional and SVFS methods, the height after 19 days is 8.5cm and 11cm, respectively.

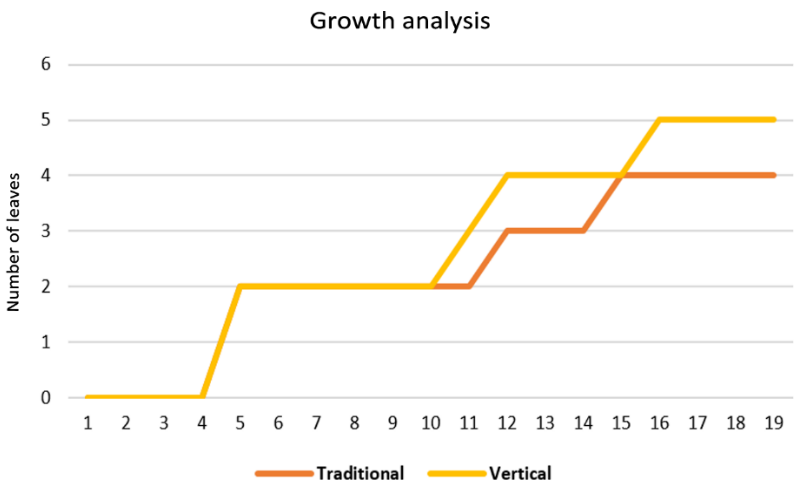

Figure 12. Chinese choy sums growth analysis - number of leaves.

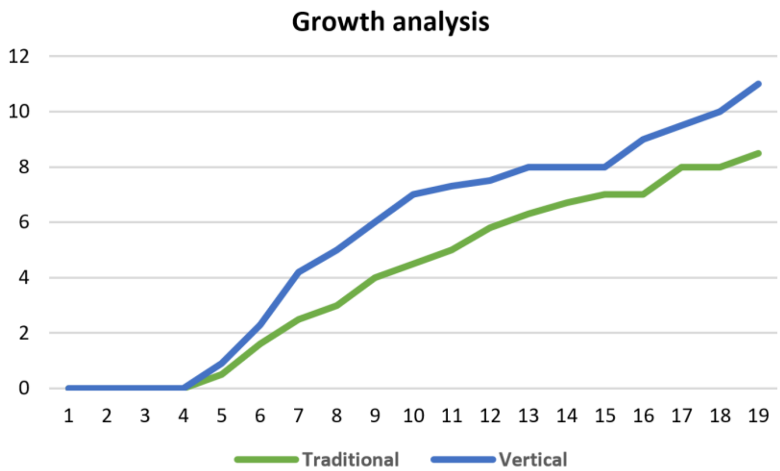

Figure 13. Chinese choy sum growth analysis - growth height (in cm).

Overall, the findings indicate that vegetables grown under SVFS can grow faster and produce more. The findings of this study are also consistent with those of Haris et al. [29].

The overall system user interfaces are accepted for usability evaluation by two farmers. However, it would be better if a user manual supported in several languages was available. There were other hardware recommendations, such as modifying the timing, reducing water pressure, and adding a camera to monitor the vegetables. On the other hand, the respondents enthusiastically expressed interest in implementing the SVFS on their farms in the future after it was accepted. SVFS is far superior to conventional farming in every respect.

5. CONCLUSION

Finally, the proposed SVFS was considered to fulfill the study objectives. In this project, the authors developed an IoT-based prototype and an Android application. Users can control the connected components of the prototype using the mobile application. They can monitor temperature, humidity, and soil moisture content through the app. Additionally, users can automatically manage the farm based on user-defined conditions in auto-control mode.

The authors proposed SVFS as a solution to increase the quantity and quality of vegetable production in Malaysia. The proposed system will assist farmers in reducing their workload and monitoring the condition of their farms. In the future, this project could be improved with AI technologies, such as robots capable of planting and harvesting.

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Institutional Review Board Statement: The Ethical Committee of INTI International University, Malaysia has granted approval for this study.
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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