Innovative smart showcase design for indoors and eco-friendly hydroponics

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Article Info

Article history:

Received Feb 18, 2024
Revised Mar 31, 2025
Accepted May 27, 2025

Keywords:

Hydroponics
Indoors farming
Internet of things
Microcontroller
Smart showcase

ABSTRACT

Hydroponics is a unique and fascinating farming technique for producing plants and vegetables. Without having to use a large area of land, people can easily apply the technique to produce fresh and hygienic vegetables. However, the technique cannot be used in apartment environment due to the limited sunlight. Thus, this study introduces an innovative hydroponic system, called as hydroponics smart showcase system that can be implemented indoors, even in the presence of minimal sunlight, and can be monitored online by users. The proposed system consists of a net pot of 4-5 hydroponics cups with a diameter of 50 mm, air temperature and humidity sensors, water level sensors, ultraviolet (UV) lights, indicator displays, and DC fans. Experimental results show that the development of innovative hydroponics using smart showcase has succeeded in stabilizing the air in the showcase according to the specified references. Moreover, UV light intensity settings for photosynthesis can be applied remotely with duration of 24 hours.

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1. INTRODUCTION

The threat of global climate change endangers water quality and quantity, and will impact conventional agriculture irrigation. Sustainable farming techniques such as hydroponic agriculture should be employed to address these challenges. Hydroponic techniques have the advantage of growing media without using soil but with nutritious water, where in soil-based vegetable cultivation, precise watering is crucial to prevent failure, thus, excessive watering can be detrimental [1]. In contrast, hydroponic techniques involve vegetables constantly submerged in flowing water with optimal consumption [2]. Studies suggest hydroponically grown vegetables exhibit a crunchier texture [3], faster growth [4], and minimal susceptibility to pests [5] compared to soil-grown counterparts. Hydroponics offers a convenient method for obtaining fresh, hygienic vegetables, supported by innovations from various researchers [6], [7].

To produce hydroponic vegetables, several stages are required, including sowing seeds, grafting, adjusting nutrients, and adjusting water pH [8]. Water quality is also a special concern for producing a quality harvest [9]-[11]. Scheduled water pH measurement [12] can provide hydroponic vegetables with good nutrition for their growth as well as measured nutrients in hydroponic water [13], [14]. In addition, the light intensity of the sun is also one of the parameters that can help vegetables grow better [15]-[17]. According to Untoro and

Hidayah [18], a hydroponic automation system that is remotely controlled using a smartphone provides convenience in controlling and monitoring the color, temperature, nutrients, and pH of hydroponic plant water.

This study focuses on the application of internet of things (IoT) in controlling and monitoring systems. IoT-based hydroponics was also introduced by [19], where the sensor calibration method for each measurement parameter used for plants became the focus. The measurement data were uploaded and stored in an online database using an Android application. This application is used by hydroponic farmers to monitor the growth of hydroponic plants based on the generated parameters. However, the authors did not explain the parameters for the types of hydroponic plants that are placed indoors or outdoors. When applying the hydroponic technique indoors, the main factor that becomes an obstacle is the light intensity system that plants receive to perform the photosynthesize. Without light, plants cannot grow perfectly [20], [21]. On the other hand, excessive light conditions can also inflict damage to plant quality. Therefore, controlling well the light intensity, lighting duration, and light quality becomes a challenge in order to obtain the right parameters for optimum plant growth. Considering the facts and challenges that have besen mentioned by previous researches on the hydroponic techniques implementation, an innovative hydroponic system using portable smart showcase is proposed in this paper, as a solution to the existing problems. In addition, this innovative system can be used in closed spaces, such as apartment buildings.

2. RELATED WORKS

2.1. Hydroponics indoors

Indoors hydroponics has advantages over outdoor hydroponics that includes the increased productivity, water use efficiency [22], and a free of pest infestation [23]. However, the indoors hydroponics need light intensity to support the photosynthesis process of plants and room air humidity to keep plants growing perfectly. Research by Eldridge *et al.* [24] has overcome one problem of indoors hydroponics. The authors use aeroponics technique to expose plant roots using aerosol sprayer containing nutrients. In general, this technique is very well used in indoors plantation, where plant roots are not always submerged in water in a 24-hours cycle. However, this technique has not considered the relationship between plant conditions and its surrounding environmental, such as lighting, air circulation, temperature, and humidity. Plant growth conditions are strongly influenced by surrounding environmental factors [25]. Experimental research results by [26], [27] on lettuce plants confirmed that maintaining the air temperature, humidity, and pH of nutrients at the specified threshold can optimize lettuce growth by 75%.

In fulfilling the elements needed by plants in indoors applications, sensors are needed that can represent elements such as light intensity, temperature, humidity, and pH of nutrients. In other studies, sensors in aeroponic greenhouses can be remotely monitored using the IoT technology [28]. The designed sensor system was used to measure the air temperature and humidity in the greenhouse, the vapor pressure deficit (VPD), luminosity, water level, pH, and EC of the solution, and the thermography camera. In addition, some studies have used cloud servers to read sensor data as continuous analysis data to predict environmental factors for different hydroponic plants. Furthermore, by applying machine learning methods, it is possible to predict rapid growth, good yields, optimize the use of nutrients, and so on.

2.2. Hydroponics: vertical farming

Vertical crops are a concept in agriculture that uses plants that are arranged vertically using limited land [29], [30]. This vertical concept provides advantages in the efficient use of water for nutrients [31], where the process of water evaporation decreases because water is protected from the influence of intense sunlight. The concept of indoors vertical plants arranged in several layers is shown in Figure 1.

The ultraviolet (UV) feature produced by LED lights (Figure 1) acts as a substitute for sunlight in plant photosynthesis. The light intensity produced by LED lights affects plant growth. According to Zhou *et al.* [16], the effect of white light from LEDs with 250 moles affects the yield of lettuce plants. Alrajhi *et al.* [32] have succeeded in proving that different light spectra have different impacts on plants. The use of red/blue or red/blue/green light increases photosynthesis, which results in faster plant growth. In addition, Chia and Lim [33] explained from the results of the experimental, air humidity can affect the photosynthesis of plants. Based on the prediction results for lettuce plants, increasing humidity by 10% can increase the length and width of the leaves of lettuce plants.

Having done reviewing and understanding previous researches as discussed above, this research attempts to propose an innovative design of a hydroponic smart showcase system. The proposed system uses appropriate technology and implements a small scale of the proposed system for indoors plant system consists of up to 12 plants. The system can also monitor the process of plant cultivation remotely with a simple display, so that users can easily use it without having to have special skills or internet access.

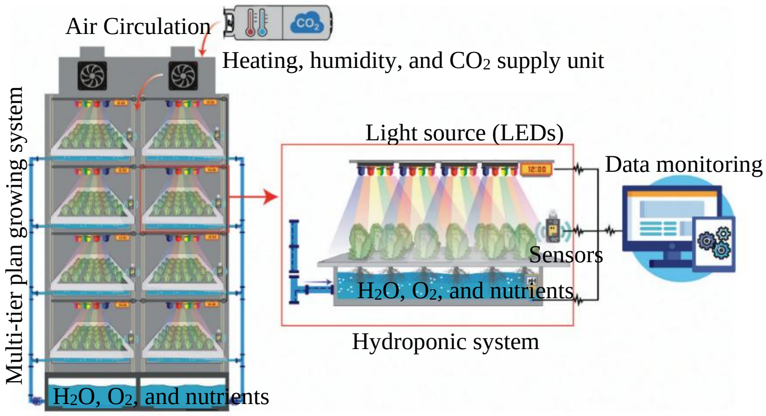

Figure 1. Indoors multilayer vertical plant concept with an automatic control system [31]

3. MATERIAL AND METHOD

The hydroponic system implemented in the smart showcase is the nutrient film technique (NFT) system. This system is suitable for indoors small-scale hydroponic application, where the circulation of nutrients contained in the water always flows to the roots [4], to provide a positive impact on plant growth. The challenge faced in this research is to adjust the intensity of sunlight, temperature, and humidity. As the indoors hydroponics do not receive direct sunlight, the proposed system is equipped with a smart system called a hydroponic smart showcase system. The overall stages of the proposed method as shown in Figure 2.

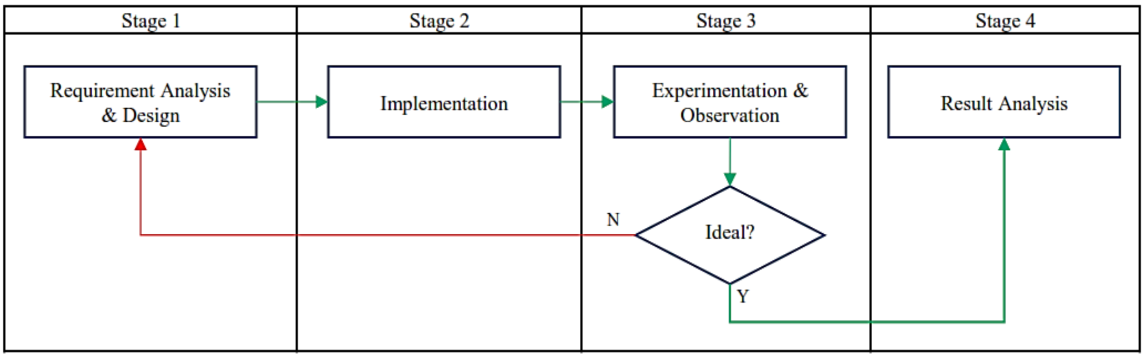

Figure 2. Stages in research method

The method starts with the requirement analysis and design stage, where an understanding of the room conditions in the apartment is conducted, including temperature, humidity, lighting, and air circulation factors. This is important to determine components, design the physical structure of the showcase, calculate water and nutrient capacity, and set up an effective and efficient control system.

Furthermore, the implementation stage involved the hydroponic system inside the showcase, including hydroponic containers, irrigation systems, water supply, and plant nutrients. In addition, the Blynk platform monitors the environment inside the showcase. Real-time monitoring of the environment inside the showcase includes temperature, humidity, and growth lights, to ensure optimal plant growth conditions.

The experimentation and observation stage evaluates performance and constraints during testing. Experiments were carried out in a predetermined location that resembles an apartment location, namely the hardware laboratory of the Faculty of Computer Sciences on the 3rd floor. The performance of the hydroponic system was recorded during the experiments. The data collected includes plant growth parameters, system performance, and environmental changes in the showcase.

The recorded test data is further analyzed to determine the experimental results, evaluate the success of the prototype, and identify parameters that need to be corrected or improved. As long as the performance results of the system are not yet suitable, feedback is performed to fulfill the needs of the system.

3.1. Requirement analysis and design

The smart-showcase hydroponic architecture shown in Figure 3 consists of three stages: input, processing, and output. At the input stage, the digital humidity and temperature-22 (DHT-22) sensor measures the temperature and humidity in the smart showcase system. If the temperature in the showcase is ≥30 °C, then the DC fan turns on, and if the temperature is ≤20 °C, then the DC fan turns off. The fan output is controlled using a fuzzy method to generate fan rpm. DC pumps for the distribution of A&B nutrient solutions to plants and growth lights to assist the photosynthesis of plants as a substitute for sunlight. Furthermore, the real time clock (RTC) module functions to get the time by the actual. The point is to get a time log on the performance of the sensors against environmental conditions in the smart-showcase. The NodeMCU ESP microcontroller functions to carry out all data processes in and out of sensors to control actuators.

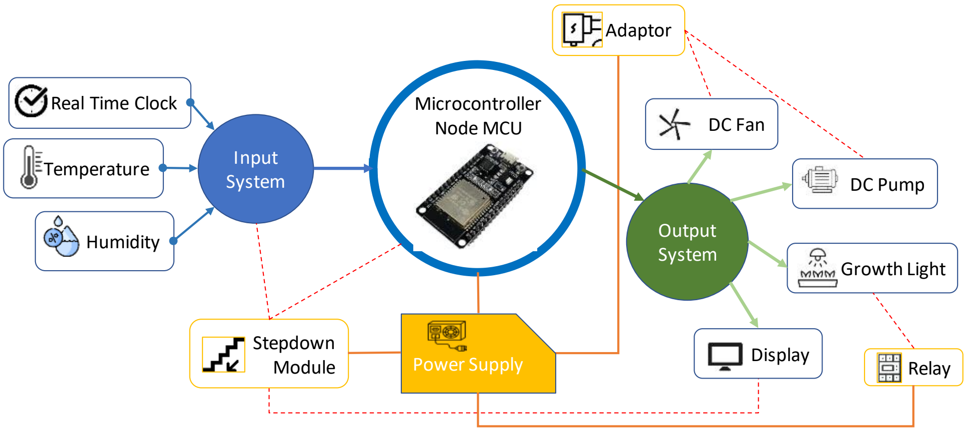

Figure 3. Hydroponic smart showcase architecture

On the output system, there are fans and DC pumps, growth lights, and LCDs. The fan speed is controlled based on the rpm value, while the DC pump distributes nutrients to plants. The growth lamp helps plant photosynthesis as a substitute for sunlight. The duration of the lamp is 12 hours, based on the time from the RTC module. Finally, the LCD module will display the information needed directly. Overall, almost all devices use 5 V power source except the pump which is 12 V. Therefore, it is necessary to add a step-down module to supply the voltage below. This is done to reduce the use of excessive voltage source devices.

3.2. Implementation of a hydroponic smart showcase

To prove the functionality of the designed hydroponic smart showcase product, an experimentation stage is required using leafy vegetable plants. Some vegetables that are suitable for hydroponic cultivation are lettuce, kale, mustard greens, spinach, and pokcoy (*Brassica Rapa L.*). In this research, the leafy vegetables used were those that had a fast harvest period within 3 months, i.e.,: pokcoy.

3.2.1. Hardware system for the hydroponic smart showcase

The hydroponic smart-showcase prototype is designed to involve several integrated components to automate and monitor hydroponic plant growth conditions efficiently. To determine the needs of the designed system, including the placement of components such as temperature and humidity sensors, water pumps, nutrient tanks, irrigation systems, lighting systems, and microcontroller control systems, it is necessary to make an initial sketch in the form of a 3D design (Figure 4(a)) to describe the function of the designed showcase. Then make a prototype showcase based on the 3D sketch that has been made with a dimension structure of length (l)×width (w)×height (h), which is 100×35×40 centimeters. The results of the hydroponic showcase prototype design as shown in Figure 4.

As shown in Figure 4(b), the showcase space is divided into two parts: upper and lower levels. The upper level is used for the entire hydroponic system, which includes temperature and humidity sensors using DHT sensors, maintaining air circulation using a 12-volt DC fan with a diameter of 12 inches, light intensity using growth light, a control system box as the main control system, and an NFT system box for the hydroponic technique applied. The lower level is used to provide a clean water container consisting of a nutrient tank for fertilizing hydroponic plants, a DC pump to flow nutrients to plants, and an irrigation system to channel nutrients to the upper level, then from the upper flow back to the storage tank using inlet and outlet hoses.

(a) (b)

Figure 4. Hydroponic smart showcase prototype; (a) 3D sketch design and (b) showcase front side and inner side

3.3. Experimentation and observation of a hydroponic smart showcase

Furthermore, the stage of implementing plants to be cultivated in the hydroponic showcase prototype that has been designed is pokcoy. There are two types of pokcoy seedlings: soil and water media. This research uses the water media type of pokcoy. This pokcoy is characterized by its light green color, small leaves, and crunchier texture. The liquid fertilizer system used used a mixture of nutrients A and B which were mixed manually in the nutrient tank. The size of the nutrient mixture is measured using a measuring cup. The mixing ratio is 5 milliliters (ml) of nutrients A and B respectively for 1 liter of water. Figure 5 shows the implementation of the pokcoy plants in the hydroponic smart showcase system. Figure 5(a) depicts a situation where smart showcase is not illuminated, while Figure 5(b) illustrates the situation where the grow light lamp in the smart showcase was turn on.

(a) (b)

Figure 5. Implementation of pokcoy plants in a smart showcase; (a) lamp off and (b) lamp on

The investigation scheme for pokcoy seeding was performed by placing the seedlings on rock wool. Within 3–7 days, we observed the growth of seedlings that had 2–3 leaves. Next, the seedlings were transferred to the net pots in the smart showcase to see if pokcoy plants could live in the smart showcase. Observations were recorded and visualized onto a graph using the ThingsBoard platform. The duration of grow-light lighting is 14–16 hours a day, which was controlled using the Blynk platform and inversion of pokcoy growth is carried out for up to 23 days.

4. RESULTS AND DISCUSSION

The current research presents the design and development of a small-scale IoT-based hydroponic system prototype that can be used especially in urban apartment environments. The technology embedded in the prototype allows for remote monitoring. The hydroponic system in the smart showcase can maintain the parameters of air temperature and humidity as well as the nutrient solution and the intensity of the growth light set inside the showcase within the optimal limits for growing pokcoy. The experimental results and inversion of the pokcoy plants in the smart showcase are shown in Figure 6.

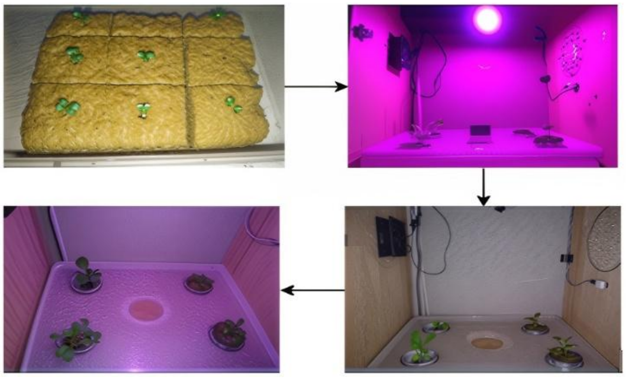

Figure 6. The results of pokcoy plants in the smart showcase are follows: pokcoy seedlings aged 3 days outside the showcase, pokcoy growth after being put into the showcase, and pokcoy plants aged ± 8 days

Furthermore, the ideal room temperature inside the showcase is around 18–24 °C with a relative humidity of around 50–70%. Therefore, an air exhaust fan is used to neutralize the temperature and humidity conditions by controlling the rpm value of the fan. In addition, a full-spectrum LED lamp specialized in plant growth is used to overcome the limited sunlight. Finally, we declare that the hydroponic smart showcase prototype offered in this research is suitable for pokcoy cultivation because it meets the requirements of outdoor environmental conditions.

The investigation results shown in Figure 7 explain that of the 4 pokcoy plants tested, the fastest average growth was pokcoy 1, with an average growth of 6.38 cm, and the lowest was pokcoy 3, with an average growth of 2.73 cm. This proves that the nutrients received by each plant using the NFT technique in this smart showcase are uneven, which will be the focus of further research. After testing and investigating the pokcoy plants against the hydroponic smart showcase, as shown in Figure 6, the IoT platform used for monitoring is explained in this section. The data for the testing is obtained from the DHT-22 sensor with the IoT system on the Bylnk and ThingSpeak platforms through monitoring the output or display in the Bylnk and ThingSpeak user interface. Data collection was done every 1 hour and every 10 hour for 2 days, as shown in Figure 8.

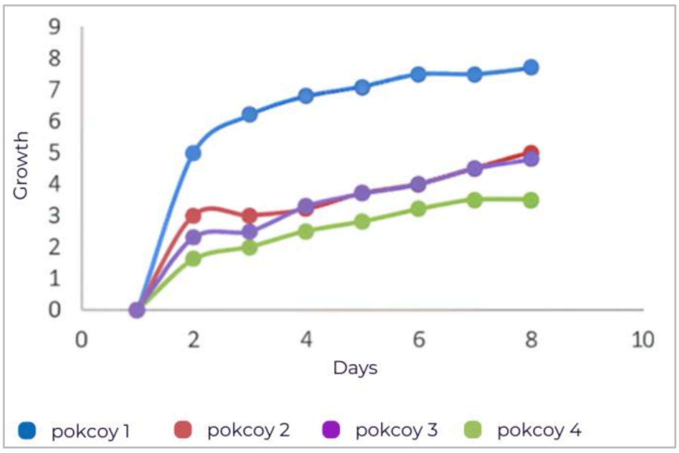

Figure 7. Growth chart of pokcoy plants until ± 8 days

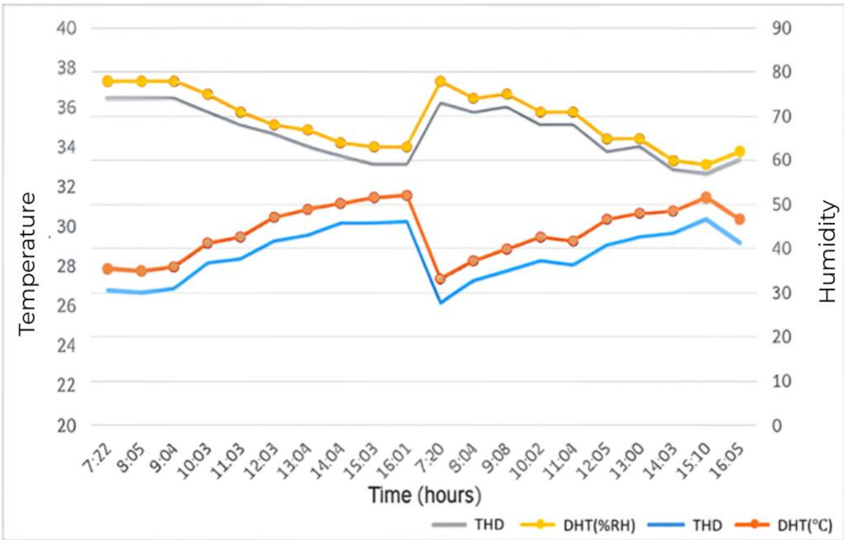

Figure 8. Comparison of showcase air temperature and humidity using a thermo hydro digital (THD) measuring instrument

The graph displayed in Figure 8 shows the temperature and humidity values inside the smart showcase. The average value of temperature and humidity produced is ± 29 °C and 69% RH. Based on the characteristics of pokcoy plants, the temperature and humidity that are suitable for pokcoy growth are 20-30 °C and 60%-80% RH. Thus, the authors claim in this study that the hydroponic smart showcase design can be used for the cultivation of leafy vegetables such as pokcoy, especially in indoors environment.

The use of an IoT-based platform is for monitoring the condition of the space inside the hydroponic smart showcase, namely temperature and humidity. This study uses the ThingsBoard platform to monitor the condition of the showcase online. Figure 9 shows the results of the monitoring.

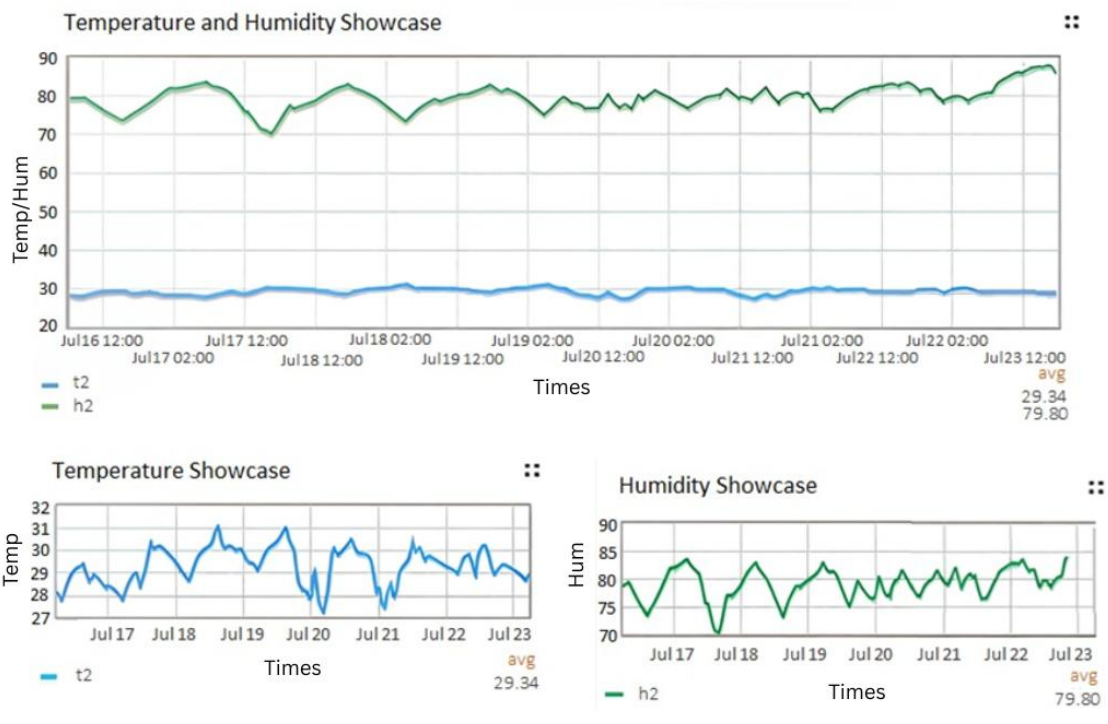

Figure 9. Hydroponic smart showcase temperature and humidity monitoring dashboard

In addition to temperature and humidity, monitoring is carried out using grow light lamps and air circulation fans. However, the on-off system of lights and fans is still controlled semi-automatically, which is controlled remotely using the Blynk platform. Figure 10 illustrates the remote control using Blynk.

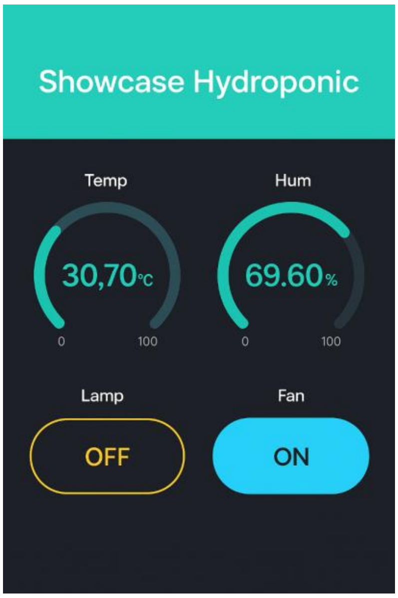

Figure 10. Hydroponic smart showcase control of grow lights and circulation fans using the Blynk platform

The grow light lamp is used for lighting inside the showcase as a substitute for sunlight. The working time of the lamp is determined from 06.00 a.m. to 16.00 p.m. The fan is turned on when the monitored temperature in the showcase is more than 30 °C, and when the temperature reaches 28–29 °C, the fan is turned off. This research will also develop an automation system in the future in addition to nutrient processing as well as control of lights and fans with machine learning methods. So that this hydroponic smart showcase system can automatically adapt to the conditions of the showcase space where there are cultivated plants.

5. CONCLUSION

This research has introduced an innovative design for the development of IoT-based hydroponic system that can be used indoors, called as smart showcase. This smart showcase successfully maintains the parameters of air temperature, humidity, and light intensity for pokcoy plants. The hydroponic technique applied is the NFT, where the nutrient solution is continuously flowed to the plant roots at a fixed flow rate. This system does not use a global parameter for various types of plants, which indicates that this system doesn't allow the use of plants with preserved parameter requirements. The designed hydroponic smart showcase prototype could be helpful for people in apartment environments small and medium-sized to achieve sustainability in growing leafy healthy consumption.

The hydroponic system is easy to implement and intelligently provides remote management of the plant growing process. The monitoring system can be monitored and controlled using the Blynk platform. In addition to monitoring, Blynk is also used to control grow-light lamps to help plant growth in the showcase. The authors consider the use of a ThingsBoard to monitor and store sensor data as parameters for further research and development. Furthermore, benefit analysis of such a system should be performed in order to evaluate its efectifity for the indoor growing of vegetables under the climate conditions of Indonesia.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Kemahyanto Exaudi	✓	✓	✓	✓	✓	✓		✓	✓	✓				
Sarmayanta Sembiring		✓		✓		✓			✓					
Aditya Putra Perdana Prasetyo		✓	✓	✓			✓		✓		✓			
Deris Stiawan		✓			✓					✓	✓			
Hanif Fakhrurroja	✓									✓				
Rahmat Budiarto					✓					✓				✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

This research does not relate to or interact with humans or animals.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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