JTEP Jurnal Keteknikan Pertanian,
Vol. 13 No. 1, p 74-97, 2024
P-ISSN 2407-0475 E-ISSN 2338-8439

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

Design of Microclimate Monitoring and Graphical Interface System for Indoor Vertical Hydroponic Based on User-Centered Design Technique

Muhammad Achirul Nanda[1*], Kharistya Amaru[1], Sophia Dwiratna[1], Silmi Fauzan Yusup Jamaludin[1]

[1]Department of Agricultural and Biosystem Engineering, Faculty of Agro-Industrial Technology, Universitas Padjadjaran, Sumedang, West Java 45363, Indonesia.
*Corresponding author, email: m.achirul@unpad.ac.id

Article Info

Submitted: 12 December 2024
Revised: 17 Januari 2025
Accepted: 4 February 2025
Available online: 12 February 2025
Published: Maret 2025

Keywords:
Microclimate monitoring, vertical hydroponics, User-Centered Design, Real-time system, graphical interface.

How to cite:
Nanda, M. A., Amaru, K., Dwiratna. S., Jamaludin, S. F. Y.(2025). Design of Microclimate Monitoring and Graphical Interface System for Indoor Vertical Hydroponic Based on User-Centered Design Technique, 13(1): 74-97 https://doi.org/10.19028/jtep.013.1.74-97.

Abstract

Monitoring microclimate conditions, including temperature, humidity, and light intensity, is crucial for maintaining plant health and productivity in vertical indoor hydroponic systems. These conditions directly influence essential physiological processes such as photosynthesis and respiration, affecting growth and yield quality. Manual monitoring methods often suffer from inefficiencies such as slow data collection, operator dependency, and human error. This can delay responses to sudden microclimate changes, leading to plant stress and reduced productivity. This study aims to design a real-time microclimate monitoring and graphical interface system for indoor vertical hydroponics using a User-Centered Design (UCD) approach. The system integrates DHT11 and BH1750 sensors to measure temperature, humidity, and light intensity, respectively, with data processing performed using a Raspberry Pi 3 Model B+. The system performance was evaluated over 24 h using the root mean square error (RMSE) and accuracy metrics. Based on this analysis, the RMSE values for temperature, humidity, and light intensity were 2.398, 1.483, and 392.225, respectively, with an overall accuracy of 97.33%, demonstrating high reliability. Two interface prototypes, Design A and Design B, were developed using distinct visual approaches and evaluated by ten respondents across six criteria: appearance, color, layout, information, icon, and font. Design A outperformed Design B, achieving a higher average score (49 versus 43.4), reflecting its superior clarity and intuitive design. These findings highlight the potential of the proposed system to enhance microclimate management and optimize plant growth in indoor vertical hydroponics.

Doi: https://doi.org/10.19028/jtep.013.1.74-97

1. Introduction

The cultivation of crops using hydroponic systems continues to evolve in response to the growing demand for food and limited land availability, particularly in densely populated urban areas (Sashika et al. 2024, Sousa et al. 2024). The popularity of hydroponics in Indonesia began to emerge in the 1970s and has continued to grow to the present day (Siregar and Novita, 2021). One of the latest innovations in this field is the indoor vertical hydroponic system, which allows more efficient space utilization. This system combines vertical farming methods with hydroponics, utilizing horizontal and vertical spaces to optimize plant productivity in controlled environments (Chowdhury et al. 2020). According to Atamurodov et al. (2022), hydroponic technology can save 5–10 times more water and achieve up to 10 times higher productivity than traditional soil-based farming methods, making it an ideal option in areas with limited land resources.

In indoor vertical hydroponic systems, monitoring microclimate conditions, including temperature, humidity, and light intensity, is essential for plant health and productivity (Dwiratna et al.2022a, Ahamed et al. 2023; Sugiyanto & Kasih, 2024). Studies show that optimal temperature for hydroponic plants ranges from 20–30°C (Usman 2017), ideal humidity levels are between 65–78% (Mujab et al. 2024), and the required light intensity is approximately 2152.78–4305.56 lux (Supriani et al. 2021). These factors directly influence key physiological processes such as photosynthesis and respiration, which are crucial for plant growth and yield quality (Nitu et al. 2024). The management of these microclimate parameters ensures better productivity and crop quality (Dwiratna et al. 2022b).

Utilizing lux meters and Thermo hygrometers for manual microclimate monitoring is time-consuming, relies on the operator, and is prone to human error. Periodic manual checks often miss sudden changes in temperature, humidity, or light intensity, leading to plant stress and significant loss of productivity. For instance, heat stress can reduce yields with a 1°C rise in global temperature, potentially lowering global crop yields by 4–6% (Asseng et al. 2015). Thus, manual monitoring is insufficient for maintaining stable microclimate conditions in complex vertical hydroponic systems.

To address these limitations, the advancement of Internet of Things (IoT) technology offers a reliable solution for hydroponic management (Maraveas and Bartzanas 2021). IoT-based monitoring systems enable the integration of various sensors to track temperature, humidity, and light intensity in real-time. According to Sharifnasab et al (2023) IoT irrigation system will save up to 35% of water compared with conventional irrigation, with the added advantage of automated data analysis that provides alerts when action is required. These data are directly accessible to users through applications or user interfaces without manual intervention, allowing quicker and more accurate decisions to be made to maintain the ideal conditions for hydroponic crops. In addition to IoT-based methods, microclimate monitoring systems can be developed using local wired technology (non-IoT), which is generally more cost-effective and does not require internet connectivity. Non-IoT methods utilize analog or digital sensors to measure microclimate parameters; however, the data are retrieved directly from devices without being transmitted over a network. This approach is advantageous in terms of cost, as it eliminates operational expenses related to internet connectivity. Moreover, non-IoT methods are more suitable for users seeking local monitoring solutions at a lower initial cost. However, the primary limitation of non-IoT systems is their inability to transmit real-time data to

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

remote devices, which requires users to monitor plant conditions directly on sensors or via local displays.

Although IoT technology facilitates remote monitoring, the traditional non-IoT approach remains relevant, particularly for users with limited budgets or in areas with restricted internet access (Bahga & Madisetti 2014, Jiang et al. 2019). This cost-effective option enables accurate microclimate control without requiring internet connectivity. Both methods (IoT and non-IoT) provide customizable solutions tailored to user needs, in terms of efficiency and cost. IoT technology simplifies monitoring, and ensuring that the system is user-friendly and aligned with user requirements is crucial. In this context, an intuitive and easy-to-use user interface is essential, especially for microclimate monitoring in hydroponics, because users require clear data visualization to support quick and accurate decision-making. The User-Centered Design (UCD) technique prioritizes user needs during the design process (Tongsubanan and Kasemsarn 2024).

For microclimate monitoring, the UCD ensures that the user interface effectively displays data, such as temperature, humidity, and light intensity, in an easily understandable format. For instance, graphical temperature displays with color-coded or intuitive visual indicators can help users quickly grasp the plant conditions. This approach is vital, as accurate data must be presented simply and informally for immediate user decision making (Ali et al. 2023). This study aims to design a microclimate monitoring and graphical interface system for indoor vertical hydroponics using the UCD approach. The interface is expected to enhance real-time monitoring of hydroponic plant conditions, ultimately optimizing plant growth and productivity. Supported by the relevant data, the proposed system is efficient in monitoring and addressing user needs by providing accurate and structured information for more effective hydroponic cultivation.

2. Materials and Methods

2.1 UCD Technique

UCD is a design technique that places users at the core of the system-design process. It is also known as an interactive system development approach, specifically aimed at creating useful systems, with early design and continuous application to produce products that meet market needs. UCD is an iterative process involving design and evaluation, from the initial stages to ongoing implementation. The UCD technique comprises four main steps (ISO, 1999). The first step, specifying the use context, aims to identify users and understand the conditions under which the application will be used. This information was gathered through observations and brief interviews with the prospective users. The second step, specifying user and organizational requirements, focused on identifying user needs for the developed application. The third step, producing design solutions, involves creating design solutions, including prototyping, which prospective users will test to address identified issues.

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

Finally, the evaluation design step ensures that the design meets user needs by testing the developed design.

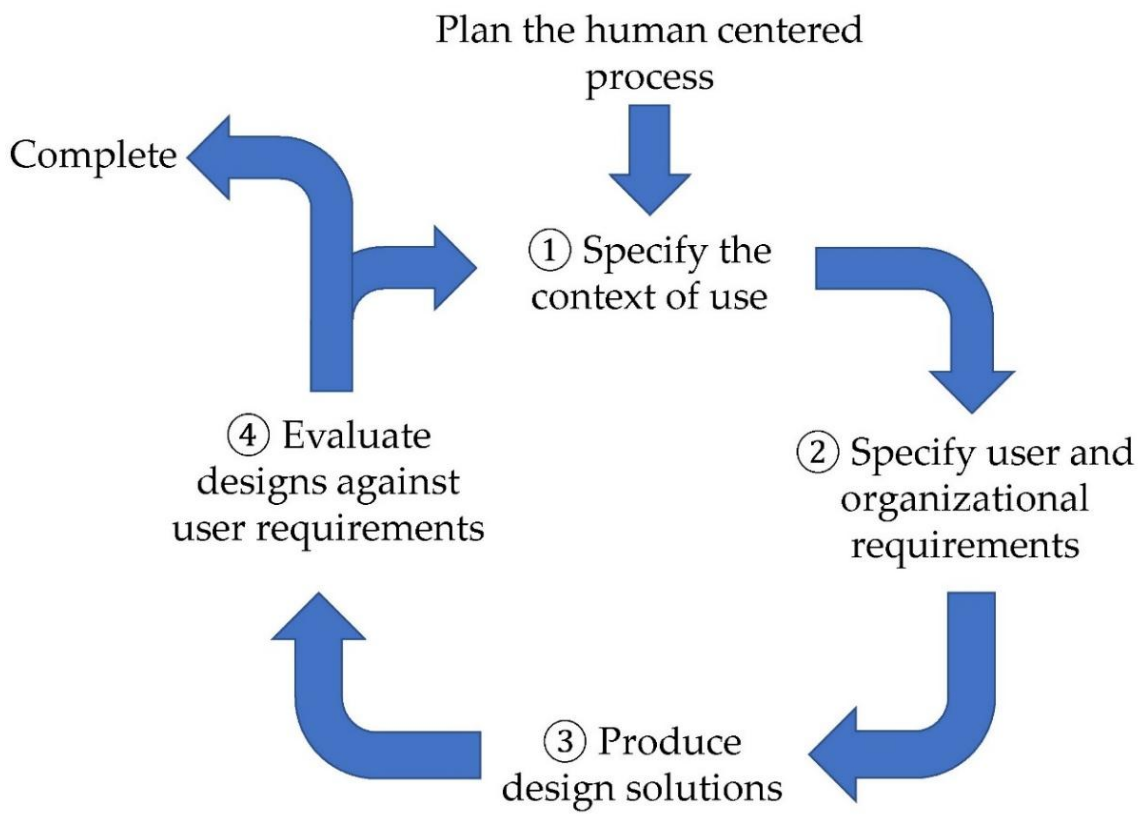


Figure 1. The four main steps in UCD.

The study began with a survey to identify user needs. The survey involved distributing questionnaires to ten respondents: three hydroponic practitioners, three agricultural technology users, two students, and two members of the general public. The categories were selected based on the diversity of backgrounds relevant to the research topic. The survey findings offer a representative snapshot of the needs of various user groups, each with distinct characteristics and perspectives, despite the limited number of respondents. The list of questions and answer options in the questionnaire is presented in Table 1. The respondents were allowed to select more than one answer for each question.

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

Table 1. List of questions and answer options in the questionnaire.

No.	Question	Answer Options
1	According to you, what factors are essential in hydroponics?	a. Microclimate b. Nutrients c. Growing media d. Irrigation
2	In terms of microclimate, which parameters are most important to know?	a. Temperature b. Humidity c. Light intensity d. Wind speed e. Rainfall
3	Which system do you think is suitable for developing hydroponics technology?	a. IoT b. Non-IoT
4	Are you willing to spend more money on IoT technology?	a. Willing b. Not willing
5	What information is needed for user interface design?	a. Parameter values b. Units c. Status

2.2 Data Processing Method

This study employs an engineering method with a design-build approach comprising two main aspects: hardware and software. For the hardware aspect, sensors were connected to a Raspberry Pi to collect environmental data, which were then processed and displayed visually on a 7-inch In-Plane Switching Liquid Crystal Display (IPS-LCD) with a resolution of 1024×600. The software aspect involves a Python program developed on Raspberry Pi to process sensor data and manage the displayed output, ensuring that the user interface operates efficiently and optimally.

2.2.1 System Confirugarations

The microclimate monitoring and graphical interface system was designed using a Lenovo Ideapad Slim 5 laptop with an Intel processor and 16 GB of RAM to support data processing and programming tasks. The proposed system utilizes various sensors to monitor microclimate parameters, including the DHT11 sensor for measuring temperature and humidity and the BH1750 sensor for measuring light intensity. These sensors serve as the primary components for collecting environmental data. All sensors were connected to a Raspberry Pi 3 Model B+, which was the central data-processing unit (Figure 2). Raspberry Pi was programmed using Thonny Python to read data

JTEP Jurnal Keteknikan Pertanian,
Vol. 13 No. 1, p 74-97, 2024
P-ISSN 2407-0475 E-ISSN 2338-8439

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

from the sensors, process it, and store the results in a digital format. The processed data are then displayed on an IPS-LCD screen, which provides a user-friendly interface that allows users to monitor results in real time.

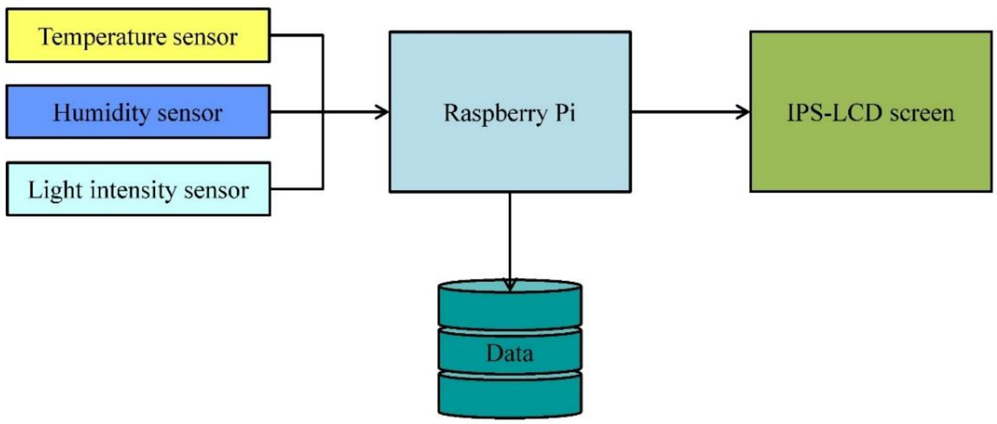


Figure 2. Sensor configuration in the microclimate monitoring system.

The circuit diagram illustrates the connections between electrical and electronic components. It depicts the pathways linking the two primary sensors, DHT11 and BH1750, to Raspberry Pi 3 Model B+. This circuit diagram serves as the foundation for system implementation. This study's structured approach to hardware and software design aims to create an effective and efficient system that meets user needs for monitoring microclimate parameters through an intuitive interface.

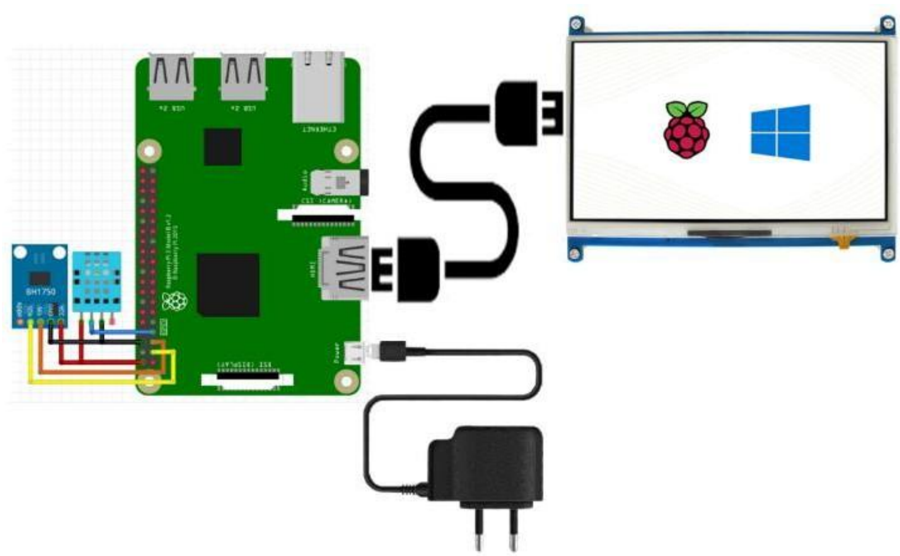


Figure 3. Electrical circuit diagram in the microclimate monitoring system.

jTEP Jurnal Keteknikan Pertanian,
Vol. 13 No. 1, p 74-97, 2024
P-ISSN 2407-0475 E-ISSN 2338-8439

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

2.2.2 Sensor Calibration

Sensor calibration is an essential step for improving the accuracy of sensor data by aligning readings with standard or reference values. This process minimizes the deviations between the detected and actual values of the sensor. In this context, a mathematical approach based on linear equations is commonly used to represent the relationship between sensor output and standard values. This relationship typically exhibits linear characteristics, which simplify the correction process.

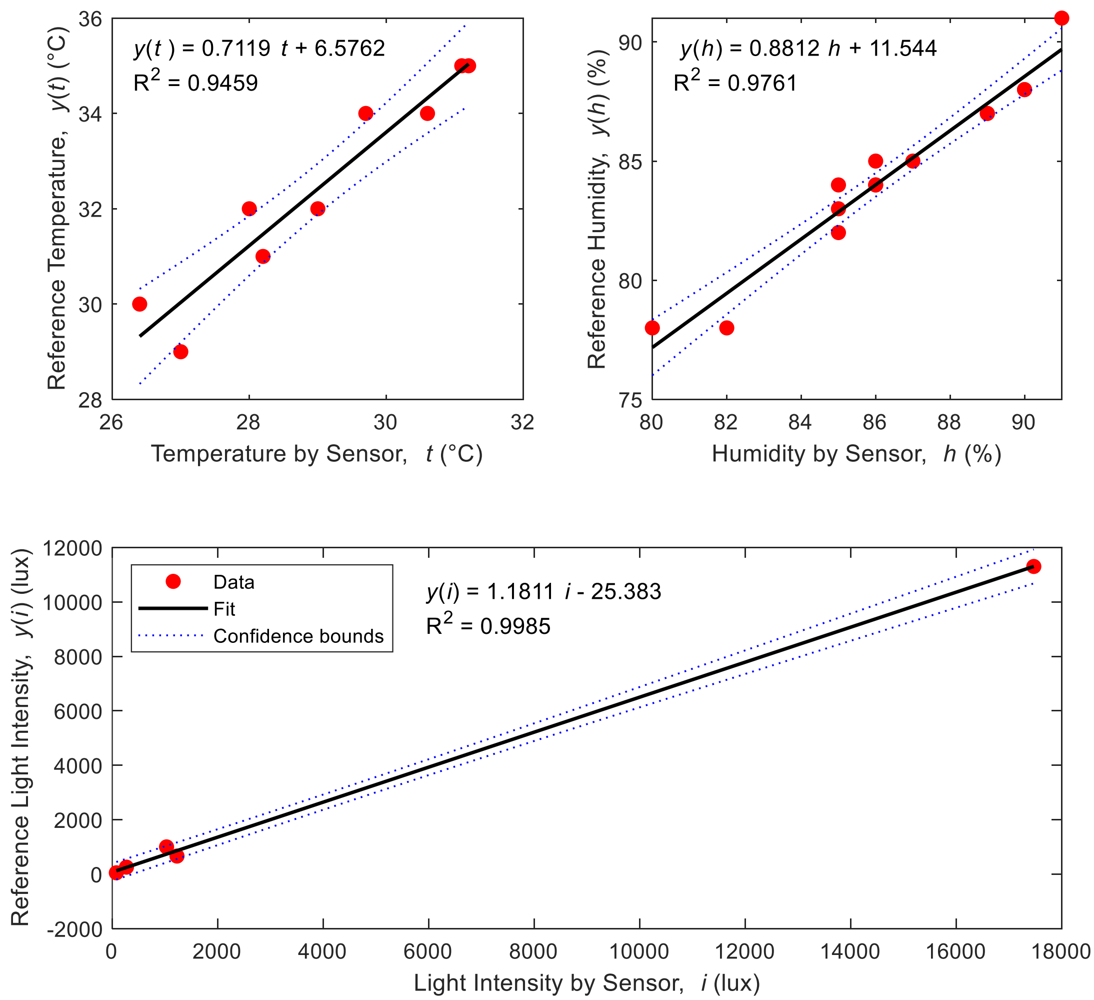


Figure 4. Calibration equation for various microclimate parameters linking the sensor output with reference values from standardized measuring instruments.

JTEP Jurnal Keteknikan Pertanian,
Vol. 13 No. 1, p 74-97, 2024
P-ISSN 2407-0475 E-ISSN 2338-8439
Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

The initial calibration stage involves collecting the sensor output data against reference values in a controlled environment. The data were then analyzed to develop a mathematical model based on a one-variable linear equation. This analysis yielded a coefficient of determination (R^2) that indicated the accuracy of the model (Novianty et al. 2023, Nanda et al. 2024). This study showed R^2 values above 0.93 for all parameters (temperature, humidity, and light intensity), demonstrating that the linear model has high accuracy and good validity (Jumrianto 2021). Once the model was obtained, the calibration equation was integrated into the microcontroller to correct the sensor output automatically.

2.2.3 Decision Logic

This system was designed to support the cultivation of leafy vegetable plants using hydroponics with the decision logic implemented in the microclimate monitoring system. The user interface of this system displays the parameter values and their status. The ideal parameters for leafy plants are a temperature of 20-30°C, humidity of 65-78%, and light intensity of 2152.78-4350.56 lux (Table 2). A microclimate was considered unsuitable if the parameter values were outside these ranges. For example, the ideal range for environmental temperature is 20-30°C. If the sensor reads a temperature of 29°C, the status displayed is "suitable." However, if the temperature falls below or above this range, the status will change to "unsuitable." This logic also applies to all the other parameters.

Table 2. Decision logic for suitable and unsuitable for microclimate status.

Parameter	Microclimate status for leafy vegetable		Reference
	Suitable	Unsuitable	
Temperature (°C)	20 – 30	20 > Temperature > 30	Nabilah and Pratiwi (2019) and Usman (2017)
Humidity (%)	65 – 78	65 > Humidity > 78	Hastini et al. (2022)
Light intensity (lux)	2152.78 – 4350.56	2152.78 > Light intensity > 4305.56	Supriani et al. (2021)

2.3 Graphical Interface Design

The user interface design was specifically developed to effectively monitor the microclimatic conditions of plants. Key LCD elements, such as the title, symbols, logo, parameter values, and status, make it easier for users to understand hydroponic conditions in real time. In this study, we developed a user interface using Tkinter, a popular Python module used for building a graphical user interface (GUI). The Tkinter enables the creation of interactive, simple, and user-friendly GUI applications,

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

making it an ideal choice for this monitoring system. Two interface prototypes, Design A and Design B, are created using different visual approaches. Two interface designs were presented to allow a comparative analysis. This helps to explore various design concepts and assess their strengths and weaknesses, ensuring that the final design is robust and better aligned with user preferences. Users evaluate both the designs to determine their effectiveness and usability. The initial sketches of the interface designs are shown in Figure. 5 (a) and (b).

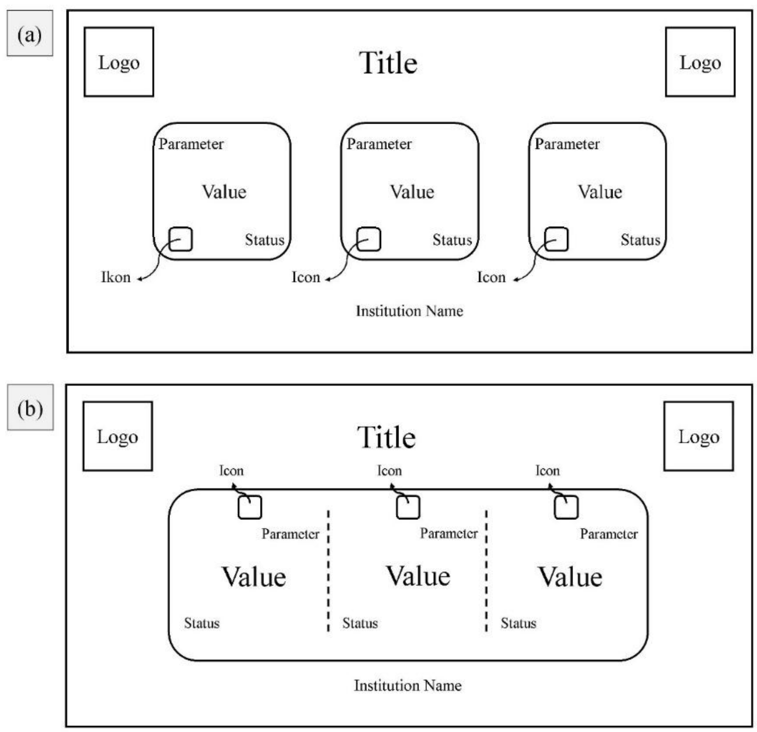


Figure 5. Two proposed graphical user interface designs for microclimate monitoring: (a) Design A and (b) Design B.

2.4 Evaluation

2.4.1 System Monitoring Evaluation

The microclimate monitoring system was comprehensively evaluated over 24 h to assess its accuracy and reliability in monitoring key parameters including temperature, humidity, and light intensity. Sensor data were collected and compared to measurements from standard instruments to determine the error rate. This evaluation used the root-mean-square error (RMSE) metric to quantitatively measure the difference between the sensor outputs and reference values. Lower RMSE values indicate higher precision. In addition to evaluating sensor accuracy, the analysis also validated

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

the system's decision logic in classifying microclimate status as "suitable" or "unsuitable". This classification evaluation employed an accuracy metric by comparing the system's decisions with actual conditions. Data for accuracy calculations were derived from 25 samples collected hourly over a 24 h period. The classification accuracy was further visualized using a confusion matrix, which recorded the true positive, true negative, false positive, and false negative values, offering a comprehensive overview of the system performance. This system is expected to deliver accurate results and support reliable decision making in microclimate management for hydroponic crop cultivation.

2.4.2 User Interface Evaluation

A user interface design evaluation was conducted by involving 10 respondents. The assessment included design suitability, interface comprehensibility, and arrangement of icons, menus, and colors. If any discrepancies are identified, the system undergoes improvement and enhancement. The evaluation was based on six parameters rated on a scale of 1–5, with higher scores indicating better quality (Table 3). The six evaluation aspects were appearance, color, layout, information, icons, and font. The final score was calculated using Equation (1), where, T represents the final score, A_i is the score for each evaluation aspect ($i = 1, 2, 3, \dots, 6$), and n is the total number of evaluated aspects.

$$T = \frac{\sum A_i}{n} \tag{1}$$

Table 3. User Interface Design Evaluation Questionnaire.

No.	Aspect	Question	Assessment Scale
1	Appearance	Does the user interface design attract attention and encourage user interaction?	1-5
2	Color	Are the chosen color combinations easy to read and do not cause discomfort to users?	
3	Layout	Are the arrangements of interface elements intuitive and easy to understand?	
4	Information	Is the information sought by users easy to find?	
5	Icon	Are the icons used easily recognizable and understandable by users?	
6	Font	Is the font type used easy to read and clear?	

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

3. Results and Discussion

3.1 Needs Indetification

The needs identification process aims to gather information regarding the requirements of individuals, groups, or organizations, particularly hydroponic users. The study began with a survey to identify user needs. Based on the analysis, Figure 6(a) shows that a microclimate is required in an indoor vertical hydroponic system, with 50% of the respondents indicating its importance. As shown in Figure 6(b), the most dominant monitoring parameters were temperature (36%), light (32%), and humidity (27%). In contrast, rainfall and wind speed were given a lower priority at 0% and 5%, respectively. This highlights the importance of designing an interface that can monitor the temperature, light, and humidity to create optimal plant growth conditions.

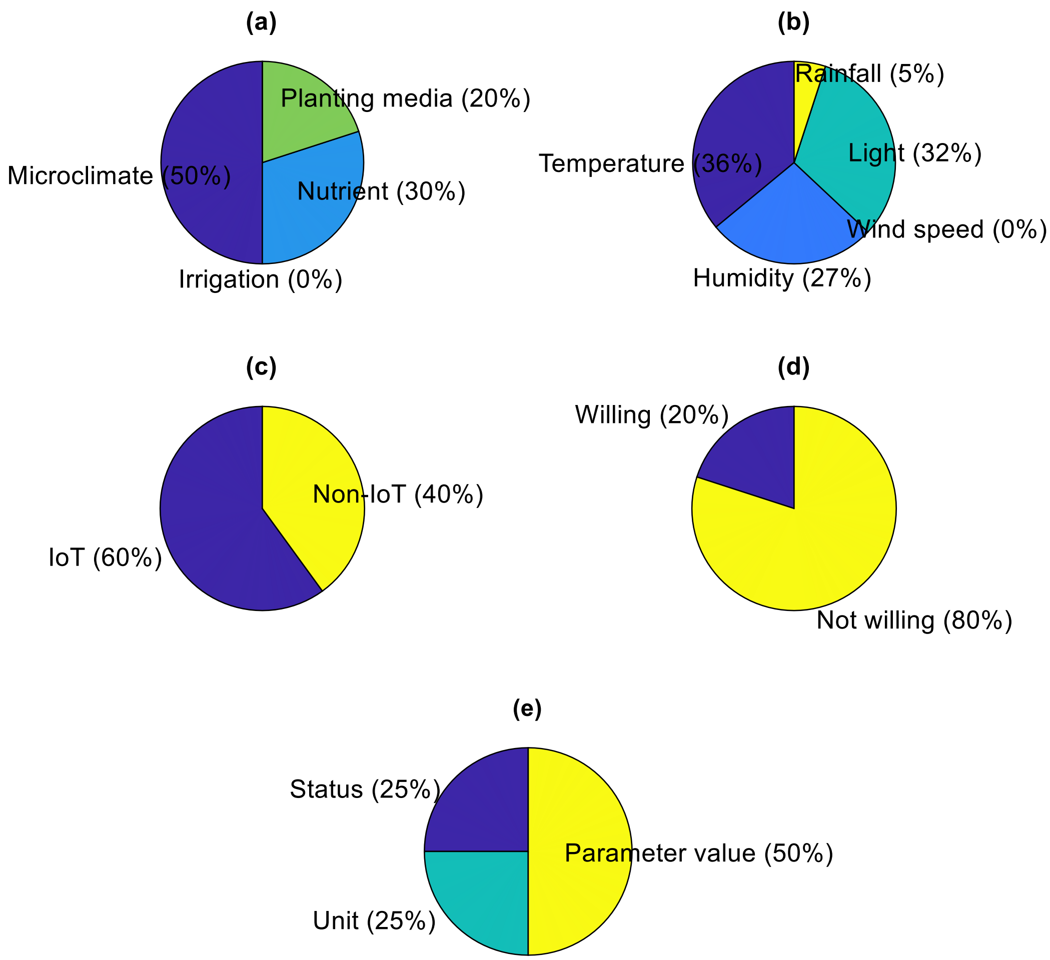


Figure 6. Survey results of needs identification: (a) plant factors, (b) microclimate parameters, (c) system devices, (d) system costs, and (e) information for user interface design.

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

Figures 6(c) and 6(d) illustrate the use of the IoT technology in the system. Sixty% of the respondents chose a non-IoT method, whereas 40% preferred IoT. However, regarding willingness to pay additional costs for an IoT interface, 80% of the respondents were unwilling to pay, while 20% were willing to do so. Figure 6(e) depicts user perceptions of the information on the interface. The "value" aspect received the highest score (50%), indicating that users need relevant information. Each unit and status aspect received a score of 25%, suggesting a need to improve the presentation of information on the interface.

These results indicate that an effective user interface design should focus on providing clear and structured information regarding microclimate conditions. The analysis revealed that the microclimate is the dominant factor in plant growth within indoor vertical hydroponic systems, with temperature and light as the most critical parameters. Zhou *et al.* (2022) stated that optimizing the temperature and light intensity in plant factories can enhance the photosynthetic characteristics and lettuce yield.

Based on needs analysis, a GUI was designed to monitor the microclimate parameters of temperature, humidity, and light intensity. The system is designed without the IoT to reduce costs and align with user needs. The GUI serves as a bridge between the system and the user, with engaging visual elements such as colors, shapes, and fonts (Buana and Sari 2022). The user interface is about aesthetics and aims to facilitate efficient human-system interaction (Rochmawati 2019). The main objective of the interface design is to make the system easier to use while presenting relevant and structured information.

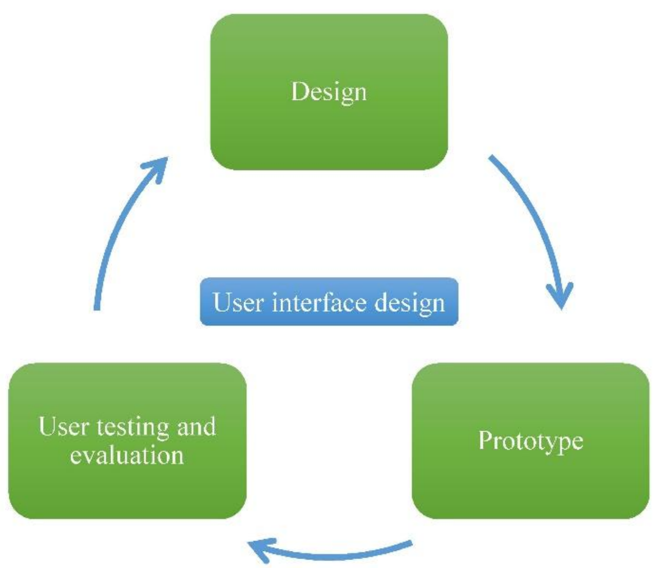


Figure 7. User interface design process.

JTEP Jurnal Keteknikan Pertanian,
Vol. 13 No. 1, p 74-97, 2024
P-ISSN 2407-0475 E-ISSN 2338-8439
Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

The user interface design and development process comprises three main steps: design, prototyping, and user testing and evaluation. These steps are performed iteratively until the best UI design that meets the user expectations is achieved (Multazam *et al.* 2020). User-centered design emphasizes that users must be involved throughout the design cycle. This process is highly iterative, allowing the design to be tested and evaluated repeatedly to ensure that the results meet the user requirements (Stone *et al.* 2005).

3.2 Estimation of sugarcane brix content using Artificial Neural Network

Microclimate monitoring system testing was conducted to evaluate the accuracy of the sensors in measuring temperature, humidity, and light intensity parameters in a vertical indoor hydroponic system. The evaluation process used a calibration model based on a linear equation to improve measurement accuracy. The accuracy of the sensor outputs was analyzed based on the RMSE calculation, which is the mean squared difference between the sensor measurements and standard measuring instruments.

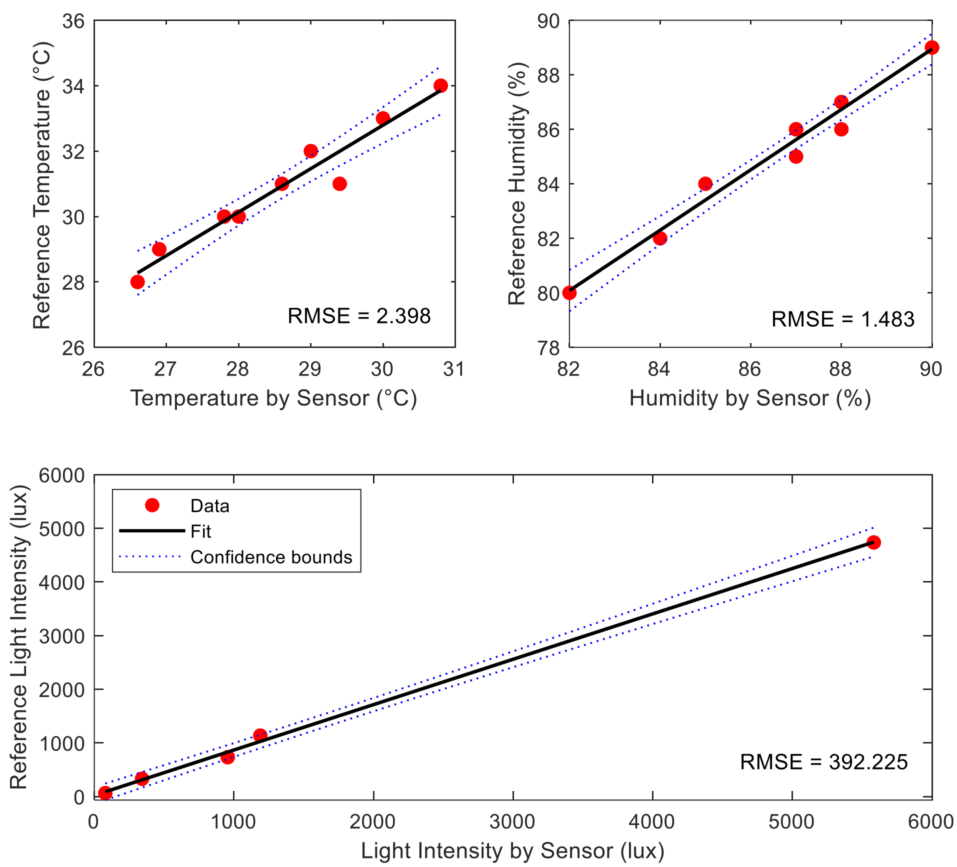


Figure 8. Evaluation of sensor accuracy in measuring the microclimate based on RMSE values.

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

The test results in Figure 8 show the RMSE values for each sensor. The RMSE values for the temperature, humidity, and light-intensity parameters were 2.398, 1.483, and 392.225, respectively. The solid red circles close to the fit line indicate the success of the calibration model in improving measurement accuracy. Smaller RMSE values indicate higher accuracy.

Based on the analysis, the test results also showed that the DHT11 sensor reliably measured the temperature and humidity, while the BH1750 sensor accurately measured the light intensity. Bamodu *et al.* (2018) reported that the DHT11 sensor can provide accurate temperature and humidity measurements with a humidity accuracy of 5% in the range of 20-80% and a temperature accuracy of ±2°C in the range of 0-50°C. Abuzanouneh *et al.* (2022) also confirmed that the BH1750 sensor can measure light intensity with high accuracy through its built-in 16-bit AD converter, which converts light detection into a 16-digit value.

Based on these results, the sensors can be integrated into the user interface and designed to display the real-time microclimatic conditions. This interface allows users to monitor the microclimate effectively and responsively, thereby creating an optimal environment for plant growth in indoor vertical hydroponic systems. The reliability of the tested sensors strengthened the validity of the system and ensured data consistency for practical applications in both commercial settings and for further research.

3.3 Graphical Interface

3.3.1 UI Desain Results

User interface design is crucial for visualizing real-time data to effectively monitor the microclimate conditions. Figures 9(a) and 9(b) show the interface design that monitors temperature, humidity, and light, along with the parameters, values, and sensor icons. This design provides informative visualization, allowing users to understand the microclimate conditions and easily monitor dynamic changes. An effective interface supports efficient and accurate monitoring, and enhances plant productivity and health. Manual systems without visualization and real-time data often result in delayed responses to changes in the climatic conditions.

The difference between the designs in Figures 9(a) and 9(b) lies in the color scheme and layout. Figure 9(a) shows a white grid pattern background with orange accents on the information boxes, creating a clean attention-grabbing appearance. By contrast, Figure 9(b) features a light-green background with white information boxes, providing a fresh and natural feel. Previous research has emphasized the importance of an intuitive and informative interface to support quick decision-making in environmental management. A visually appealing and functional interface has been shown to enhance user engagement and the effectiveness of microclimate-monitoring systems.

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

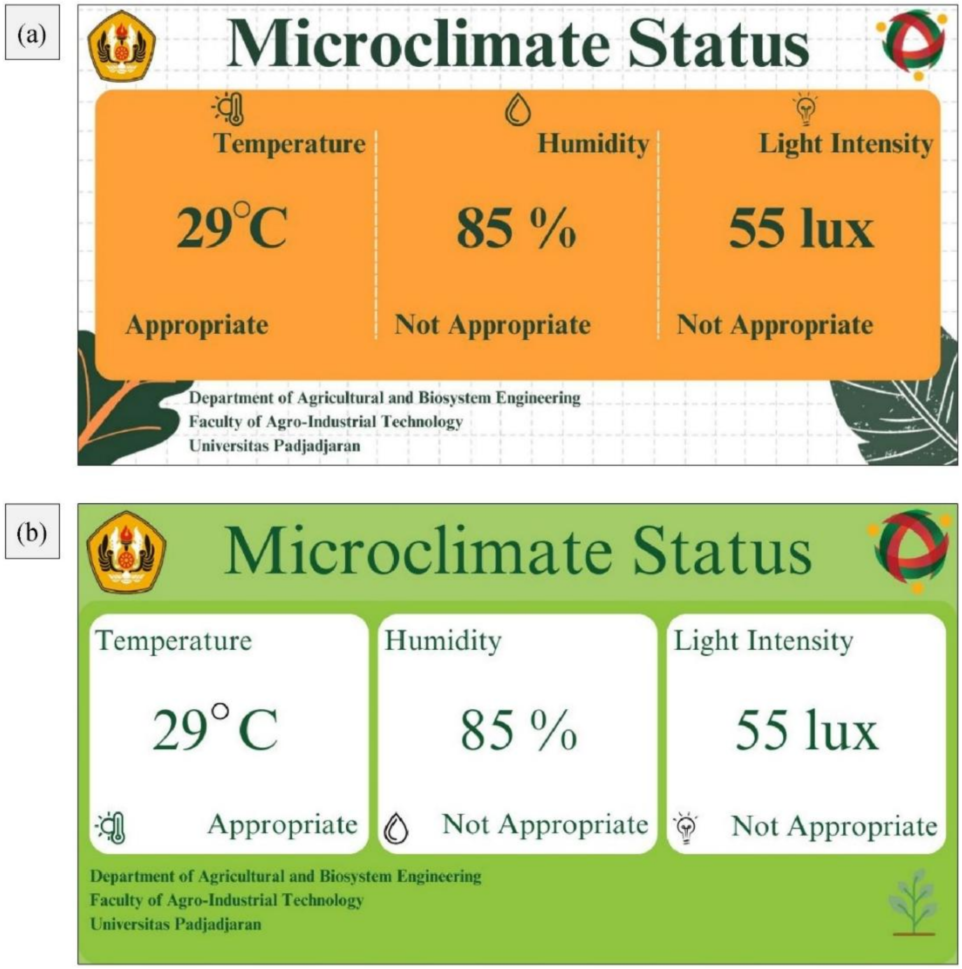


Figure 9. Results of the user interface design for monitoring the microclimate.

The user interface is a product display that serves as the interaction medium between the system and user. According to Hadi (2010), the interface has several key components: (a) color, which is used to clarify text and icons, as shown in Figure 9(a) with a combination of white, orange, and green, and Figure 9(b) with green and white. White conveys a clean impression, orange grabs attention, and green symbolizes freshness and nature. (b) Fonts using standard types such as Times New Roman to facilitate readability. (c) Font size, with titles set at 60 pt, body text at 25 pt, main content at 50 pt, and subtext at 15 pt, to ensure readability. (d) Icons, which accelerate interactions and enhance the visual appeal of the user interface.

In addition to the UCD technique, other techniques, such as the House of Quality (HoQ) and Kansei Engineering (KE), can be adopted to design graphical interfaces, each with its unique advantages. The HoQ matrix introduced by Hauser and Clausing (2009) is a tool for aligning technical

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

specifications with customer expectations through interfunctional planning. It includes six components (Chakraborty and Dey 2007): customer requirements (HOWs), technical requirements (WHATs), planning matrix for market insights, interrelationship matrix linking technical and customer needs, roof matrix for technical correlations, and technical priorities that define benchmarks and targets for design improvements. The KE, developed in the 1970s in Japan, connects customers' emotional responses to product design by translating feelings into measurable specifications (Vieira et al. 2017). "Kansei" refers to intuitive impressions from stimuli, making KE effective for enhancing customer satisfaction. KE methods, including Type I, II, III, Hybrid, and Virtual, vary in complexity, with Type II, adapted by Schütte (2002), widely applied across industries. This approach involved defining the target domain, gathering up to 800 semantic descriptors, categorizing them into high-level Kansei words, and aligning them with product properties to create designs that resonate with user impressions.

UCD emphasizes the iterative involvement of end users to ensure that the system meets their needs and usability expectations, making it particularly effective in enhancing user satisfaction and functionality. In contrast, HoQ, originating from Quality Function Deployment, systematically translates customer requirements into technical specifications, offering a structured and quantitative approach to prioritizing design features. KE focuses on integrating customers' emotional and intuitive responses into measurable design attributes, thereby effectively bridging affective impressions and tangible interface elements. While UCD excels in usability, HoQ in structured problem solving, and KE in emotional resonance, combining these methods could yield a more holistic interface-design process.

3.3.2 UI Evaluation

Evaluating the user interface design is a crucial step in assessing the effectiveness and quality of the visual experience, as seen in the comparison between Design A and Design B, based on six key aspects: appearance, color, layout, information, icons, and fonts (Figure. 10). The results showed that Design A consistently scored higher than Design B in most aspects. For example, in appearance, Design A scored 40, whereas Design B scored only 32. The largest difference was observed in the color aspect, where Design A scored 41, which was significantly higher than Design B's score of 33. The smallest difference occurred in the information aspect, with Design A scoring 43, and Design B scoring 41. The overall average shows that Design A significantly outperformed Design B, scoring 49, compared to Design B's score of 43.4.

The advantages of Design A reflect its effectiveness in presenting clear information and using more intuitive icons, which are critical factors for monitoring the microclimate conditions in vertical hydroponic systems. This suggests that Design A is preferred, and makes it easier for users to operate and manage hydroponic systems. Therefore, the results of this evaluation provide strong evidence that Design A successfully meets user needs, particularly in the context of smart-hydroponic-based farming management systems. Effective visualization of environmental parameters enables users to make quick and informed decisions, demonstrating the importance of clear information presentation in optimizing hydroponic farming operations (Untoro and Hidayah 2022). Rizzardi et al. (2024) state that monitoring the microclimate environment can significantly enhance management efficiency and user experience, especially in innovative applications like greenhouses and technology-based agricultural systems.

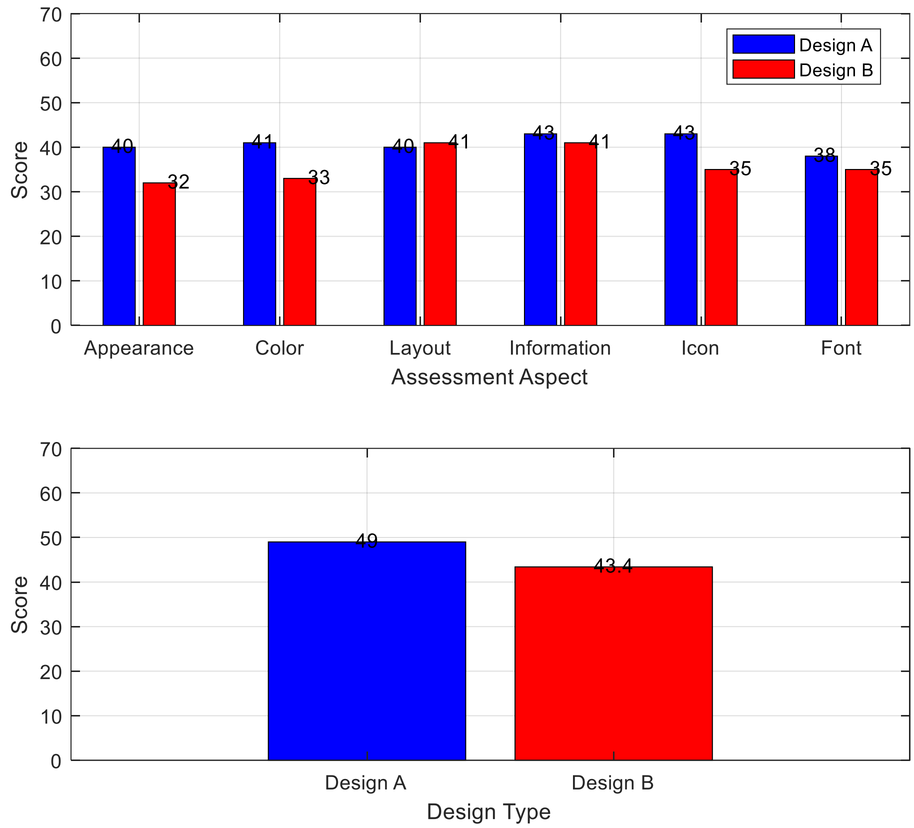


Figure 10. Evaluation of UI design in Design A and Design B.

Evaluating the performance of a microclimate classification system is essential for ensuring the accuracy and reliability of environmental management in vertical hydroponic systems. The evaluation results using the confusion matrix to monitor temperature, humidity, and light intensity showed high accuracy. In the temperature measurement (Figure 11), the system achieved an accuracy of 92.00%, with 20 samples classified correctly and three samples matching the actual conditions, despite two misclassified samples. Furthermore, the humidity and light intensity measurements demonstrated

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

perfect performance, with accuracies of 100.00% each, with no misclassifications across all observed samples. The overall average accuracy of the system reached 97.33%, indicating high reliability in monitoring the temperature, humidity, and light intensity. This high accuracy reflects the ability of the system to support microclimate monitoring, particularly in technology-based agricultural applications.

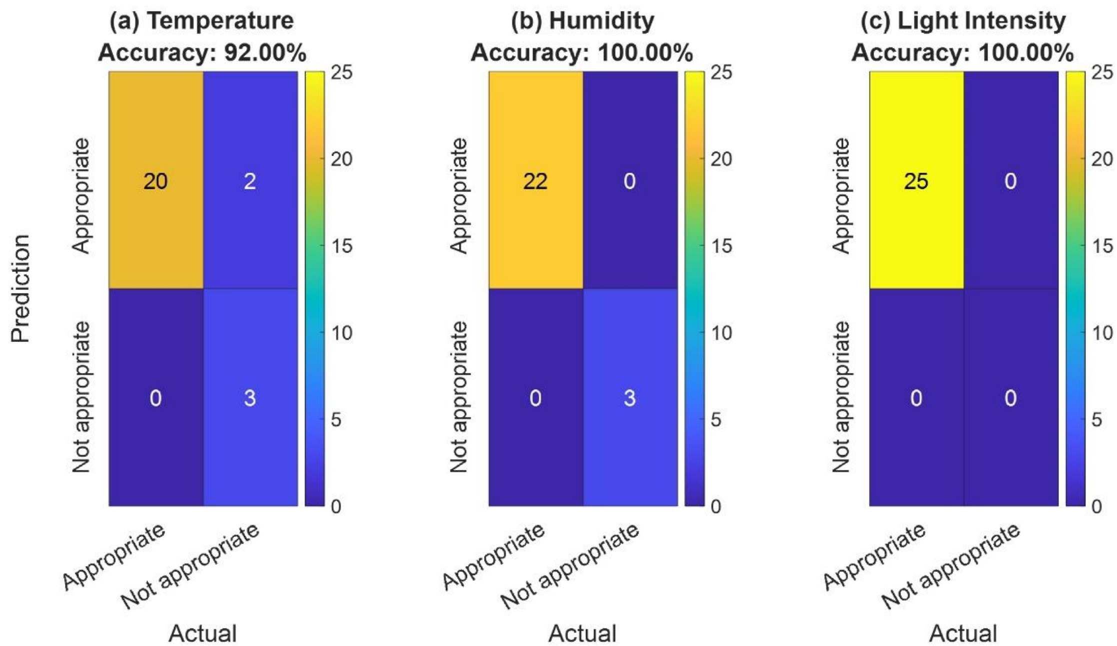


Figure 11. Performance evaluation in microclimate monitoring: (a) temperature, (b) humidity, and (c) light intensity.

This high accuracy indicates that the proposed system can be used to support microclimate management in technology-based applications. The user interface design for an indoor vertical hydroponic system must display the prediction results clearly and accurately. This is crucial to ensure that the system can precisely monitor and control microclimate conditions, which play a key role in supporting hydroponic plant growth. An intuitive, informative, and easy-to-understand interface will help users make quick adjustments based on the prediction results, improve system management efficiency, and ensure that plants grow under optimal conditions.

3.4 Implementation

This study evaluated microclimate monitoring over 24 h, providing valuable insights into the dynamics of temperature, humidity, and light intensity to support the optimal conditions for leafy vegetable growth. Figure 12 illustrates the patterns of variation in three key parameters: temperature, humidity, and light intensity. Based on the analysis, the DHT11 and BH1750 sensors demonstrated consistent measurements without significant anomalies, indicating a reliable performance. The data obtained support the regulation of temperature, humidity, and light intensity within optimal ranges for healthy hydroponic plant growth.

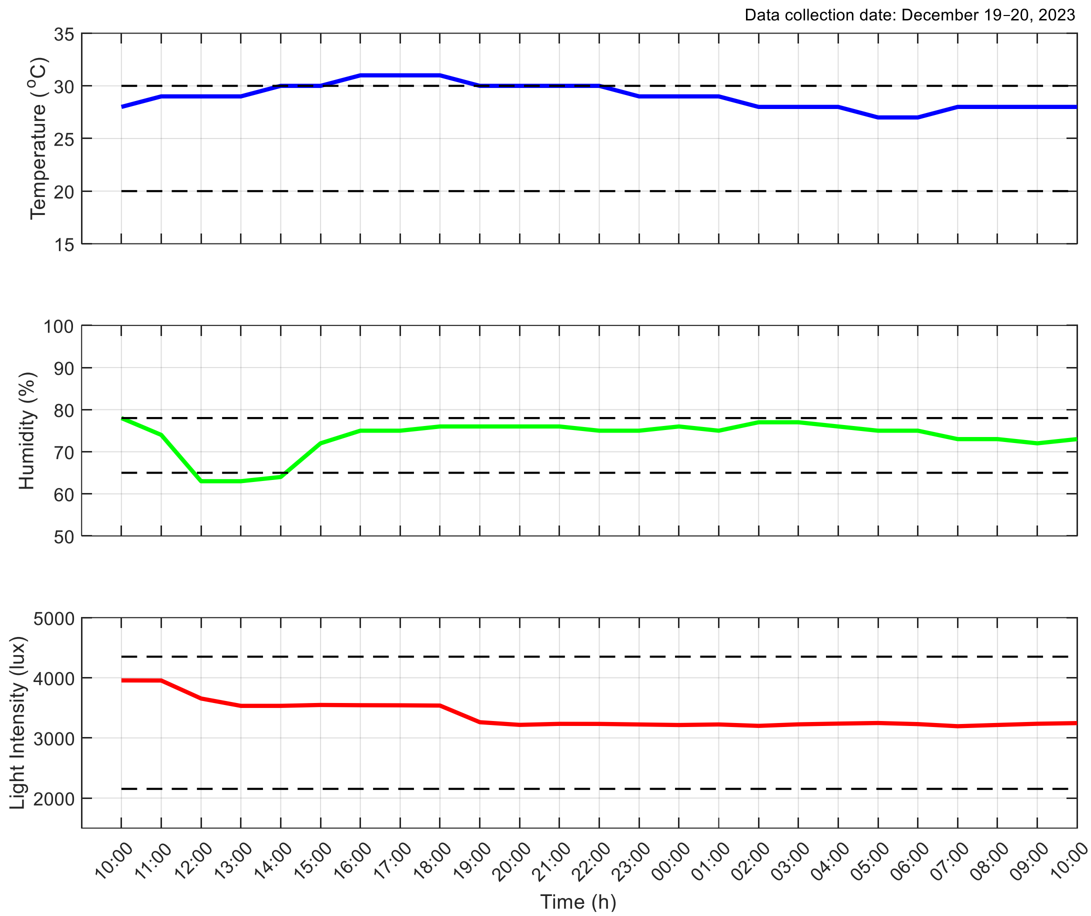
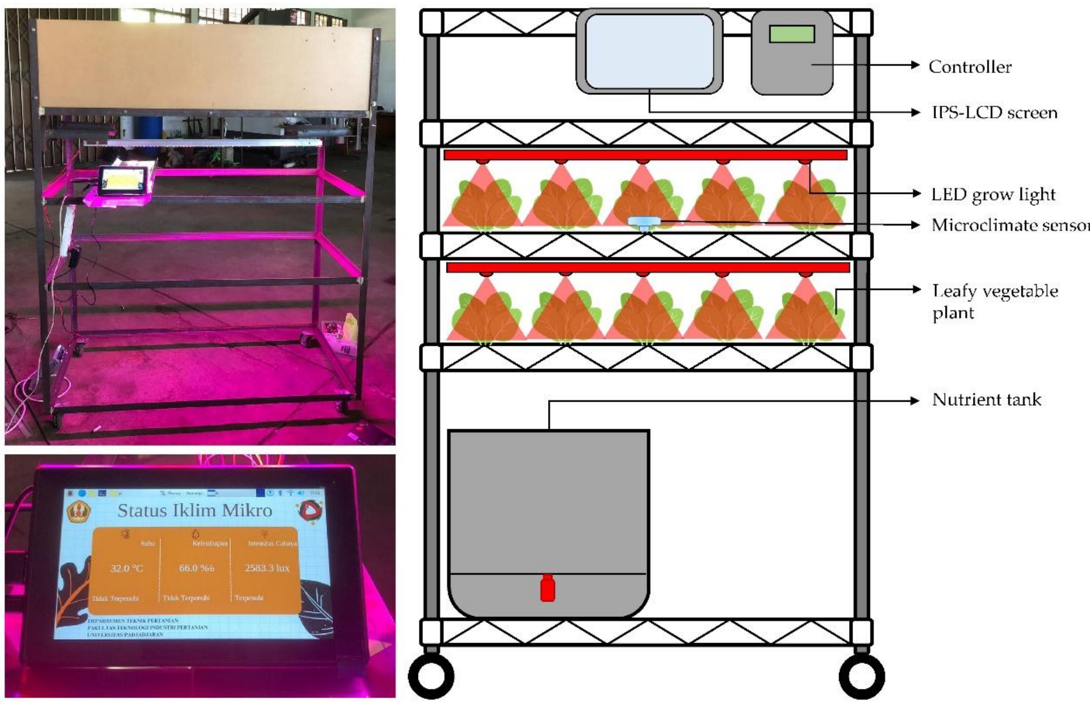


Figure 12. Microclimate monitoring was conducted over 24 h, including temperature, humidity, and light intensity. Dashed lines indicate the optimal minimum and maximum ranges of leafy vegetable growth.

The temperature remained stable with minor fluctuations around the optimal temperature range of 31°C. During the daytime, the temperature was relatively steady and increased slightly in the afternoon (4:00–6:00 PM) to reach 31°C before gradually declining overnight to early morning, with the lowest temperature recorded at 27°C (5:00–6:00 AM). This stability reflects effective environmental control that supports plant physiological processes. According to Mishra et al. (2023), heat stress impedes plant growth by disrupting the root and shoot development. Meanwhile, the relative humidity showed a sharp decline during the day, with a minimum value of 63% (12:00–1:00 PM),

JTEP Jurnal Keteknikan Pertanian,
Vol. 13 No. 1, p 74-97, 2024
P-ISSN 2407-0475 E-ISSN 2338-8439 Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

before rising again to a peak of 78% (10:00 AM). The optimal humidity range for hydroponic plants is 65–78% (Hastini et al. 2022). A drop in humidity below the optimal threshold during the day can potentially induce plant stress, which requires close monitoring to maintain its stability. Chia and Lim (2022) stated that low relative humidity enhances plant water uptake and accelerates transpiration, posing significant challenges for species with limited stomatal control. Thus, tighter humidity monitoring during this period is crucial.



(a) (b)

Figure 13. Implementation of a graphical interface in the microclimate monitoring system for indoor vertical hydroponics: (a) graphical interface application (Design A) on an indoor vertical hydroponic system; and (b) master plan of the indoor vertical hydroponic design with key components, including the display, LED lights, sensor, controller, plants, and nutrient tank.

Figure 13 illustrates the implementation of the interface design in a microclimate monitoring system for indoor vertical hydroponics. The figure demonstrates that microclimate parameters such as temperature, humidity, and light intensity were successfully displayed through an interactive and user-friendly interface. Future studies will involve testing this interface with actual plants to monitor the microclimate in real-time. Additionally, the design of the indoor vertical hydroponic system will be refined and integrated, incorporating essential components such as a display, LED growth lights, sensor, controllers, and a nutrient reservoir to enhance the system's sustainability. Involving UI design experts can improve user engagement and the overall quality of the interface design.

4. Conclusion

In conclusion, the proposed real-time microclimate monitoring system for indoor vertical hydroponics demonstrates high accuracy and reliability for monitoring temperature, humidity, and light intensity. Based on the UCD technique, the system achieved RMSE values of 2.398, 1.483, and 392.225 for temperature, humidity, and light intensity, respectively, with an overall accuracy of 97.33%. This highlights the effectiveness of the system for optimizing plant growth. Among the two interface prototypes, Design A proved superior in terms of clarity and ease of use, outperforming Design B with a higher average score (49 vs. 43.4). These findings suggest that this system can significantly enhance microclimate management and improve plant health and productivity in indoor hydroponics.

Acknowledgment

This research was supported by Universitas Padjadjaran, Indonesia, under the Associate Professorship Acceleration (RPLK) scheme for 2022 fiscal year (project no. 2203/UN6.3.1/PT.00/2022). We sincerely thank the reviewers for their insightful feedback, suggestions, and comments, which have greatly enhanced the quality of this article.

5. References

Abuzanouneh KIM, Al-Wesabi FN, Albraikan AA, Al Duhayyim M, Al-Shabi M, Hilal AM, Hamza MA, Zamani AS, Muthulakshmi K. 2022. Design of machine learning based smart irrigation System for precision Agriculture. *Computers, Materials & Continua*. 72(1): 109-124. https://doi.org/10.32604/cmc.2022.022648.

Ahamed MS, Sultan M, Monfet D, Rahman MS, Zhang Y, Zahid A, Bilal M, Ahsan TA, Achour Y. 2023. A critical review on efficient thermal environment controls in indoor vertical farming. *Journal of Cleaner Production*. 138923. https://doi.org/10.1016/j.jclepro.2023.138923.

Ali AM, Khamaj A, Kang Z, Moosa M, Alam MM. 2023. User-centered design (UCD) of time-critical weather alert application. *International Journal of Advanced Computer Science and Applications*. 14(1). https://doi.org/10.14569/IJACSA.2023.0140188.

Asseng S, Ewert F, Martre P, Rötter RP, Lobell DB, Cammarano D, Kimball BA, Ottman MJ, Wall GW, White JW. 2015. Rising temperatures reduce global wheat production. *Nature climate change*. 5(2): 143-147. https://doi.org/10.1038/nclimate2470.

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

Atamurodov B, Sobirov K, Najmiddinov M. 2022. Development of Irrigation Procedures by the Method of Hydroponics. *American Journal of Social and Humanitarian Research*. 3(7): 40-44. https://doi.org/10.31150/ajshr.v3i7.1302.

Bahga A, Madisetti V. 2014. *Internet of Things: A Hands-On Approach*. India: VPT.

Bamodu O, Osebor F, Xia L, Cheshmehzangi A, Tang L. 2018. Indoor environment monitoring based on humidity conditions using a low-cost sensor network. *Energy Procedia*. 145: 464-471. https://doi.org/10.1016/j.egypro.2018.04.093.

Buana W, Sari BN. 2022. Analisis User Interface Meningkatkan Pengalaman Pengguna Menggunakan Usability Testing pada Aplikasi Android Course. *DoubleClick: Journal of Computer and Information Technology*. 5(2): 91-97. https://doi.org/10.25273/doubleclick.v5i2.11669.

Chakraborty S, Dey S. 2007. QFD-based expert system for non-traditional machining processes selection. *Expert Systems with Applications*. 32(4): 1208-1217.

Chia S, Lim M. 2022. A critical review on the influence of humidity for plant growth forecasting. *IOP conference series: materials science and engineering*. pp. 012001.

Chowdhury ME, Khandakar A, Ahmed S, Al-Khuzaei F, Hamdalla J, Haque F, Reaz MBI, Al Shafei A, Al-Emadi N. 2020. Design, construction and testing of IoT based automated indoor vertical hydroponics farming test-bed in Qatar. *Sensors*. 20(19): 5637. https://doi.org/10.3390/s20195637.

Dwiratna S, Amaru K, Nanda MA. 2022a. The Modified Hydroponic Kit Based on Self-Fertigation System Designed for Remote Areas. *Horticulturae*. 9(948): 1-14. https://doi.org/https://doi.org/10.3390/horticulturae8100948.

Dwiratna S, Amaru K, Nanda MA. 2022b. The Potential of Hydroponic Kit-Based Growing on a Self-Fertigation System for Pagoda Mustard (Brassica narinosa L) Production. *The Scientific World Journal*. 2022: 1-13. https://doi.org/https://doi.org/10.1155/2022/1984297.

Hadi H. 2010. Rekayasa kebergunaan pada sistem informasi kehumasan IPB (Skripsi). Indonesia: IPB University.

Hastini E, Sumarsono J, Amuddin. (2022). "Pemantauan Suhu dan Kelembapan Tanaman Selada (Lactuca sativa L.) pada Sistem Hidroponik Menggunakan Nexton 3.2 HMI." Retrieved 20 July 2024, 2024, from https://fatepa.unram.ac.id/wp-content/uploads/2022/09/6.-Abstrak_Evi-Hastini-Evi-Hastini.pdf.

Hauser JR, Clausing D (2009). The house of quality. Harvard Business Review (1988), May-June.

ISO (1999). Human-centred design processes for interactive systems (ISO 13407). Geneva, International Organization for Standardization.

Jiang A, Yuan H, Li D, Tian J. 2019. Key technologies of ubiquitous power Internet of Things-aided smart grid. *Journal of Renewable and Sustainable Energy*. 11(6). https://doi.org/10.1063/1.5121856.

 Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

Jumrianto J. 2021. Kalibrasi Sensor Tegangan dan Sensor Arus dengan Menerapkan Rumus Regresi Linear menggunakan Software Bascom AVR. *Journal of Systems, Information Technology, and Electronics Engineering*. 1(1): 1-14.

Maraveas C, Bartzanas T. 2021. Application of Internet of Things (IoT) for optimized greenhouse environments. *AgriEngineering*. 3(4): 954-970. https://doi.org/10.3390/agriengineering3040060.

Mishra S, Spaccarotella K, Gido J, Samanta I, Chowdhary G. 2023. Effects of heat stress on plant-nutrient relations: An update on nutrient uptake, transport, and assimilation. *International Journal of Molecular Sciences*. 24(21): 15670. https://doi.org/10.3390/ijms242115670.

Mujab RS, Supriyanto H, Purnomo W. 2024. Implementasi Komunikasi LoRaWAN dan Platform Antares pada Monitoring Supply Pupuk Tanaman Selada Hidroponik Berbasis Website. *The Indonesian Journal of Computer Science*. 13(4). https://doi.org/10.33022/ijcs.v13i4.4182.

Multazam M, Paputungan IV, Suranto B. 2020. Perancangan user interface dan User experience pada placeplus menggunakan pendekatan user centered design. *Automata*. 1(2).

Nabilah RA, Pratiwi A. 2019. Pengaruh pupuk organik cair kulit buah pisang kepok (Musa paradisiaca L. var. balbisina colla.) terhadap pertumbuhan tanaman bayam (Amaranthus gracilis Desf). *Symposium of Biology Education (Symbion)*.

Nanda MA, Amaru K, Rosalinda S, Novianty I, Sholihah W, Mindara GP, Faricha A, Park T. 2024. Higuchi fractal dimension and deep learning on near-infrared spectroscopy for determination of free fatty acid (FFA) content in oil palm fruit. *Journal of Agriculture and Food Research*. 18: 101437. https://doi.org/10.1016/j.jafr.2024.101437.

Nitu OA, Ivan EŞ, Tronac AS, Arshad A. 2024. Optimizing Lettuce Growth in Nutrient Film technique hydroponics: evaluating the impact of elevated oxygen concentrations in the Root Zone under LED illumination. *Agronomy*. 14(9): 1896. https://doi.org/10.3390/agronomy14091896.

Novianty I, Sholihah W, Mindara GP, Nurulhaq MI, Faricha A, Sinambela R, Purwandoko PB, Nanda MA. 2023. Shannon entropy on near-infrared spectroscopy for nondestructively determining water content in oil palm. *International Journal of Electrical & Computer Engineering (2088-8708)*. 13(5).

Rochmawati I. 2019. Analisis user interface situs web iwearup.com. *Visualita*. 7(2): 31-44. https://doi.org/10.33375/vslt.v7i2.1459.

Sashika MN, Gammanpila H, Priyadarshani S. 2024. Exploring the evolving landscape: Urban horticulture cropping systems–trends and challenges. *Scientia Horticulturae*. 327: 112870. https://doi.org/10.1016/j.scienta.2024.112870.

Schütte S. 2002. Designing feelings into products: Integrating kansei engineering methodology in product development Linköping University Electronic Press.

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.1.74-97

Sharifnasab H, Mahrokh A, Dehghanisanij H, Łazuka E, Łagód G, Karami H. 2023. Evaluating the use of intelligent irrigation systems based on the iot in grain corn irrigation. *Water*. 15(7): 1394. https://doi.org/10.3390/w15071394.

Siregar M, Novita A. 2021. Sosialisasi Budidaya Sistem Tanam Hidroponik Dan Veltikultur. *Ihsan: Jurnal Pengabdian Masyarakat*. 3(1): 113-117. https://doi.org/10.30596/ihsan.v3i1.6826.

Sousa Rd, Bragança L, da Silva MV, Oliveira RS. 2024. Challenges and solutions for sustainable food systems: The potential of home hydroponics. *Sustainability*. 16(2): 817. https://doi.org/10.3390/su16020817.

Stone D, Jarrett C, Woodroffe M, Minocha S. 2005. *User interface design and evaluation*: Elsevier.

Sugiyanto E, Kasih TP. 2024. Microclimate Control in Strawberry Production with Hydroponic System in Indoor Vertical Farming. *Jurnal Syntax Admiration*. 5(3): 984-996. https://doi.org/10.46799/jsa.v5i3.1077.

Supriani E, Budiyanto S, Sutarno S. 2021. Respon Tanaman Selada Keriting Hijau Terhadap Penyinaran Lampu LED dan Konsentrasi CaCl2 pada Sistem Hidroponik. *AGROVITAL: Jurnal Ilmu Pertanian*. 6(2): 99-103. https://doi.org/10.35329/agrovital.v6i2.2713.

Tongsubanan S, Kasemsarn K. 2024. Developing a Design Guideline for a User-Friendly Home Energy-Saving Application That Aligns with User-Centered Design (UCD) Principles. *International Journal of Human–Computer Interaction*. 1-23. https://doi.org/10.1080/10447318.2024.2398324.

Untoro MC, Hidayah FR. 2022. Iot-based hydroponic plant monitoring and control system to maintain plant fertility. *INTEK J. Penelit*. 9(1): 33. https://doi.org/10.31963/intek.v9i1.3407.

Usman N. 2017. Kawasan hortikultura dengan konsep greenhouse di makassar. *Skripsi. Universitas Islam Negeri Alauddin Makassar*.

Vieira J, Osório JMA, Mouta S, Delgado P, Portinha A, Meireles JF, Santos JA. 2017. Kansei engineering as a tool for the design of in-vehicle rubber keypads. *Applied Ergonomics*. 61: 1-11. https://doi.org/10.1016/j.apergo.2016.12.019.

Zhou J, Li P, Wang J. 2022. Effects of light intensity and temperature on the photosynthesis characteristics and yield of lettuce. *Horticulturae*. 8(2): 178. https://doi.org/10.3390/horticulturae8020178.