BIO Web of Conferences **146**, 01096 (2024) https://doi.org/10.1051/bioconf/202414601096
BTMIC 2024

Hydroponic NFT agricultural monitoring website: Temperature control based on PID

Sri Wahyuni[1*], *Amin* Rusydi[1], and *Muhammad* Fuad[1]

[1]Trunojoyo University of Madura, Mechatronic Department, Bangkalan-Madura, Indonesia

Abstract. This study aims to develop an automated control system for hydroponic growing media to optimize temperature and nutrient conditions tailored to various plant types. The control method proposed in this study uses the Proportional Integral Derivative (PID). PID control allows for precise adjustments in temperature and nutrient levels, enhancing plant growth. A web-based interface enables users to monitor and adjust the system settings according to their chosen plant type. The vegetables planted for the trial testing of this system are caisim, pok choy, spinach, lettuce, broccoli, and cauliflower, which can grow in lowlands and highlands. Users will also get a reminder of the estimated harvest of plants being planted through the monitoring website so that users do not have to bother calculating the length of the planting process. The system achieves a remarkable control accuracy of 99.9% in maintaining optimal conditions, although it struggles to cool water to the desired 25°C during peak daytime temperatures. This is because the Peltier work is very dependent on the ambient temperature. Future research may explore alternative cooling methods or adjustments to the Peltier for a more efficient cooling process or continue to use the Peltier but think about a better heat exchange concept in both the heat exchanger water so that the hot water resulting from the cooling process using the Peltier does not settle in one container. It is expected to make it easier for someone to grow vegetables for food-oriented development (FOD) and urban farming.

1 Introduction

Indonesian society needs to be aware of the decreasing food supply in Indonesia [1]; as the population continues to grow, the need for food also increases. This increase needs to be balanced by the amount of agricultural land, as noted by [2] [3], which is currently decreasing. The development of urban areas and the increasing population will reduce the availability of agricultural land. Urban areas certainly provide little space for farming functions [4], but rather, land use changes into industrial, commercial, and residential land. Meanwhile, farmers have been feeling other problems related to land ownership for a long time. On average, farmers only work on 0.5 hectares of land; this condition is far from the ideal, which should be two hectares [5]. This often causes Indonesia to experience food shortages, causing the Indonesian government to import food to meet the community's food needs. With the increasing demand for sustainable food production methods, hydroponics has emerged as a practical alternative to conventional farming.

Hydroponics is a farming method considered more practical than conventional methods, including avoiding pests and diseases from the soil and reducing the cost of soil fertilization, insecticides, and fungicides [6]. Hydroponic farming only requires the main components of water and nutrients [7] [8] for plant growth. To get maximum harvest, the water temperature and nutrient needs must be adjusted based on the type of plant. As in conventional planting media, not all plants can live in lowlands and highlands, so there are often groupings of plant types that can live in lowlands, highlands, and both. This is because some plants have ideal temperatures and weather for each plant to grow well, which are influenced by environmental factors and geographic location. In addition, the influence of water temperature also needs to be considered. The temperature of the nutrient solution that is flowed into the hydroponic planting media is ideally around 18°C - 28°C. A hot or too-high solution temperature can cause the dissolved oxygen level to decrease or even disappear.

One of the hydroponic systems commonly used in Indonesia is the Nutrient Film Technique (NFT). As the name suggests, this system means the flow of nutrients along a pipe with a film-thin flow height of 2-4 mm. Plants will absorb nutrients as they flow through the pipes, and then the nutrients will return to the water container. The Nutrient Film Technique is an active hydroponic system that utilizes pumps to circulate a thin layer of nutrient solution through shallow channels, allowing plant roots to access the necessary nutrients. This method is highly efficient and significantly reduces water consumption. An NFT in hydroponics offers key advantages: it efficiently delivers nutrients to plants, conserves water significantly, and promotes faster growth due to constant nutrient access [9]. The flow of

* Corresponding author: s.wahyuni@trunojoyo.ac.id

https://doi.org/10.1051/bioconf/202414601096

water is generally influenced by the slope of the pipe, which is between 0.5-4%. The flow rate of incoming nutrients ideally ranges from 1 to 2 liters per minute [10]. The Nutrient Film Technique (NFT) allows plants to absorb nutrients from a thin film of water flowing through pipes, returning unused nutrients to a reservoir for recirculation. This makes NFT a sustainable choice for high-yield, resource-efficient cultivation. The ideal temperature of the nutrient solution flowing into the hydroponic growing medium is around 25-28℃ [11]. A solution temperature that is too hot or too high can cause the dissolved oxygen level to decrease or even disappear [12]. Despite the advantages of hydroponics, many practitioners lack the technical knowledge to maintain optimal conditions, leading to suboptimal plant growth. Hydroponic practitioners always check the nutrients and control the temperature. Still, only some of them understand the technical details of hydroponic growing media care for the ideal conditions of plants that must be maintained or achieved [11].

Based on this description, this research aims to control hydroponic growing media to obtain solutions for temperature conditions. The ideal nutritional requirements for plants will automatically be determined using the website according to the plant type. So that users can adjust the desired control value through the available plant options by changing the plants planted. This system makes it easy for ordinary users to use hydroponic technology and agriculture. It automatically regulates the temperature and nutrient values needed by determining the type of vegetables to be planted.

Furthermore, monitoring the growth period of plants can be done anytime and anywhere in real-time via the website without having to worry about plants being stunted or lacking nutrients. This tool allows users to monitor the system to ensure the control process is carried out with the correct dose for planted growth plants. Through the monitoring website, users will also get a reminder of the estimated harvest of plants being planted so that users do not have to bother calculating the length of the planting process. Temperature is one of the parameters for whether or not a plant grows well [13]. The control method proposed in this study uses Proportional Integral Derivative (PID) to control the temperature in setpoint 25 ℃, so it is expected to control hydroponic growing media precisely. In endurance testing, PID can prove that by changing the parameter 2-5%, the system can reach the minimum peak overshoot relatively quickly and with few steady-state errors [14].

The website monitoring and control system plays a crucial role in this research. It monitors the system output from the desired set point value based on the previously selected plant type. This website, accessible via the Internet, makes it easier for users to monitor the entire process, which runs efficiently and can be done anywhere. In addition, system control, which involves changing set points for plant types, can also be carried out through the monitoring website. The practicality of planting vegetables using hydroponic media at a web-based interface enables users to monitor and adjust the system settings according to their chosen plant type. It is expected to make it easier for someone to grow vegetables for urban farming and Food Oriented Development (FOD), namely agricultural activities carried out or implemented in urban areas.

2 Methodology

2.1 Proportional Integral Derivative (PID) control

Control methods are intended to reduce the error signal that occurs in a plan, causing the plan to be unstable in achieving the desired set point. The error signal itself is the difference between the set point value and the output value of a plan, so the smaller the error signal, the better the control given to the plan. PID control is a mechanism for calculating the error value against the output value of a plan with the desired set point value [15]. PID will reduce errors every time adjustments are made to the control variables. Proportional, integral, and derivative parameters in PID control have their respective functions in controlling the error value at the time the system is running. Proportional control is responsible for the current error value; integral control is responsible for the previous error value. In contrast, derivative control is the control that is responsible for the future error value. The PID control flow for a plan is described through a PID controller block diagram as in Figure 1.

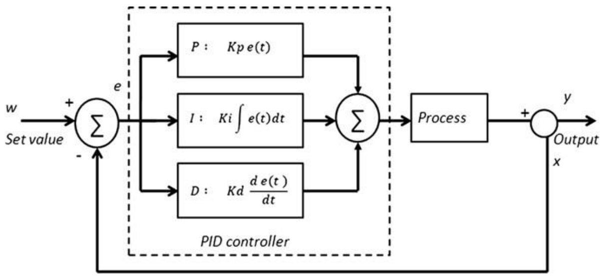


Fig. 1. PID control block diagram.

A plan receives a set point from the input to obtain the desired output [16]. Control is in the form of reducing the error value (e) in the system to the output value according to the predetermined set point (w) so that the output value (y) is submitted as the result of PID control of the actuator value at a particular time.

2.2 Flowchart

Control of growth factors in hydroponic media is automatically carried out by receiving data from temperature sensor readings, EC, and pH sensors. The microcontroller then processes the reading results of the three sensors to compare the readings with the specified set point values. The temperature, EC, and pH variables have their set points, which is the tool's purpose in controlling the system to achieve the specified set point. Comparison of sensor reading values from the system output will obtain an error value processed by the microcontroller using the PID method. PID processing is expected to produce control by correcting the error value as small as possible. Figure 2 is a flowchart of the hydroponic planting media control system, while the flowchart in Figure 3 explains the PID process.

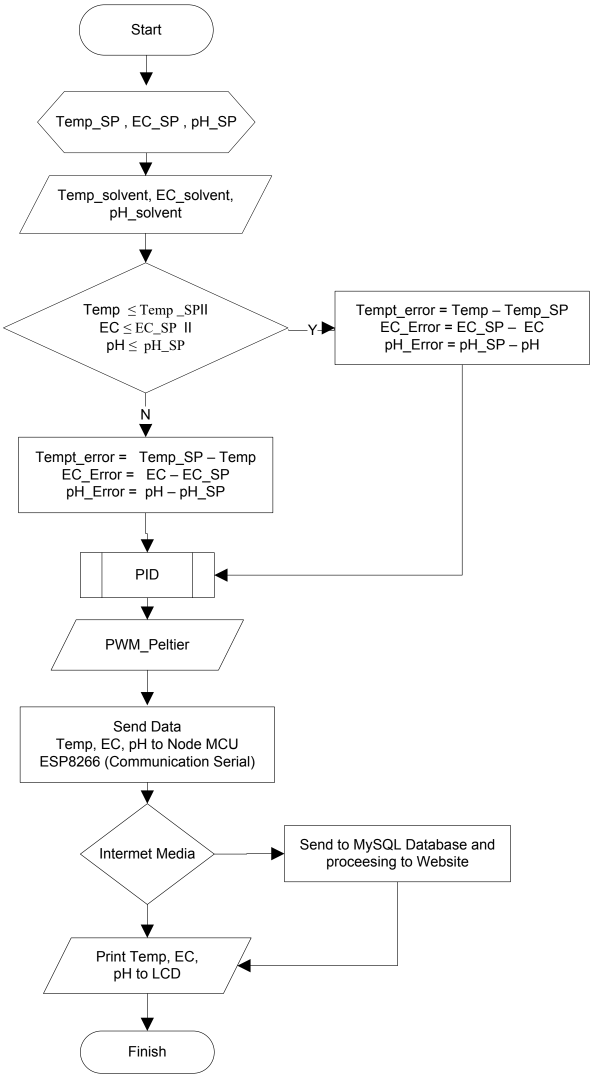


Fig. 2. Flowchart: entire system hydroponic monitoring website.

The flowchart in Figure 2 is a flowchart of the overall system of how a tool works, starting with determining the set point by the user based on the type of plant selected through the monitoring website. Each type of plant has parameters Kp, Ki, and Kd, which have been set based on trial and error. The parameters are then compared with the sensor reading values and adjusted to the set points that have been determined. The sensors in question are the temperature sensor, EC sensor, and pH sensor, which are used to compare their reading values against the set point values that have been determined so that reading errors from each sensor are produced. The error values obtained are then processed using the PID method to reduce or correct errors as minor as possible, as shown in Figure 2, and the PID process model is detailed in Figure 3. As in Figure 3, the PID process works if it gets input as an error value from the set point that has been determined. If the EC sensor error is less than 0 or has a negative value, the solution is in a condition of excess nutrients from the set point that has been determined, so the DC pump will turn on to add water to adjust the nutrient needs. The volume of the solution in the container is set at 30 liters; a volume of less than 30 liters causes the sensor to be unable to read the condition of the solution because the position of the solution surface is below or does not touch the probe. The output of the PID process is the sum of each control, namely proportional control, integral control, and derivative control. The PID output is the number of ml for both peristaltic pumps controlling nutrition, the number of ml for both peristaltic pumps controlling pH, and the PWM value for the Peltier (water cooler). If you look at the flowchart in Figure 3, the feedback value from the PID control carried out and read back by the temperature sensor, EC sensor, and pH sensor after being processed by the microcontroller is forwarded to the nodeMCU as an intermediary to forward to the website and obtain data from the website to be used as a set point. However, this process will only occur with an internet signal; otherwise, the sensor reading value will only be displayed on the LCD installed on the device.

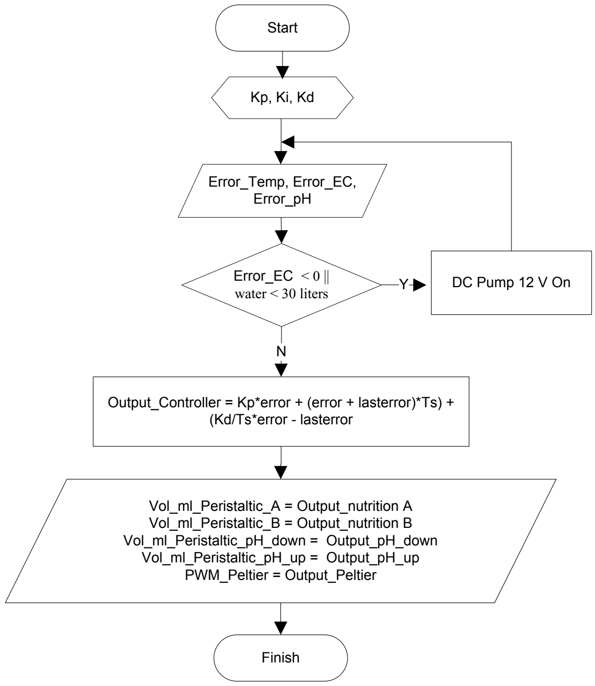


Fig. 3. Flowchart: PID process flowchart.

3 Result and discussion

3.1 Solution temperature control

Several studies that discuss smart hydroponic IoT need to convey the temperature-reducing components used, for example, research [17] [18] [19] [20]. The temperature of the nutrient solution flowing in the hydroponic growing medium ideally ranges from 18°C−28°C. Hot or too high a solution temperature can cause dissolved oxygen levels to become stagnant [21]. However, other experiments show that lettuce becomes larger in weight and is freshly grown at 21.1 °C compared to 18.3 °C of cold water [22]. This suggests that temperature is an essential factor in hydroponics. Temperature control in the solution container uses a thermoelectric cooler or Peltier, used on the cold side as a cooler. It dissipates heat on the hot side to obtain fast cooling. This research uses four penalties arranged in parallel. Peltier parallel circuit assuming R as the Peltier resistance looks like in Figure 4.

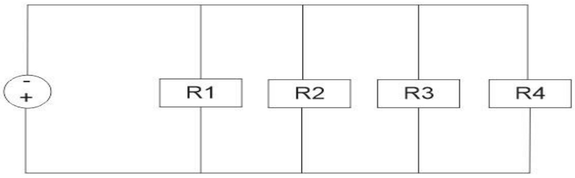


Fig. 4. Peltier parallel circuit.

$$\frac{1}{Rtotal} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \frac{1}{R4} \tag{1}$$

$$Vtotal = V1 = V2 = V3 \tag{2}$$

As shown in Figure 4, if R is assumed to be the resistance of a Peltier, then the four parallel penalties are written in Equation 3.1 and Equation 3.2. Equation 3.1 and equation 3.2 show that the amount of current (I) flowing in parallel resistors is the sum of each resistance in the circuit, while the voltage (V) that passes through each component is the same. In a parallel circuit, the calculation of the current required in the circuit is the sum of the current requirements of the four penalties. Suppose this research uses a peltier with type 12706, meaning that each peltier has a current of 6 amperes, and then six peltiers connected in parallel need at least 36 amperes to work. If a peltier has a current of 6.4 amperes, the total current from the four peltiers is 38.4 amperes. After knowing the amount of current in the four penalties, the required power (P) can be calculated through Ohm's law equation in equation 3.3.

$$P = V \times I \tag{3}$$

Where:

P = Power (W)
V = Voltage (V)
I = Current (Ohm)

PID modeling can be done by identifying the data obtained from a plan. Identification can be done using the toolbox identification system available in the Matlab application. The system identification process in the Matlab toolbox requires temperature and time parameters acquired by the ds18b20 temperature sensor from a plan being run. The data obtained in real-time is then analyzed using the identification system in Matlab to get a system response. For example, in an experiment, a graph of temperature data recording in real-time using a Peltier gives a PWM value of 255 to cool water in a container containing 1 liter of water, as seen in Figure 5.

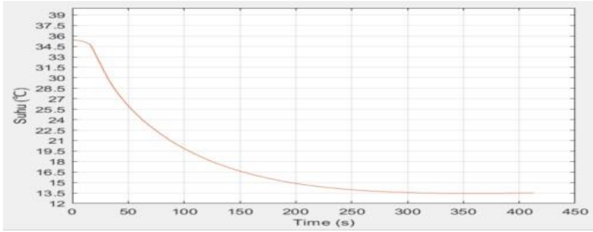


Fig. 5. Real time temperature.

In Figure 5, a graph shows data with the initial temperature measurement at 35.38°C; then, it decreases until the graph looks stable at 13.5°C in 300 seconds. The actual time temperature data obtained and stored in the temperature change experimental data log is then analyzed on the identification system by entering the data on the Matlab worksheet to get the transfer function from the plan. The chosen order will determine how much the best-fit value is obtained from the response step. The second-order transfer function obtained from the system is written in equation 3.4.

$$GS = \frac{0{,}0002424}{s^2 + 0.3544s + 0.004673} \tag{4}$$

After getting the transfer function, the step response from the data identification can be displayed in its form to determine how the system response from the transfer function is obtained. The step response of the transfer function in equation 3.4 is shown in Figure 6.

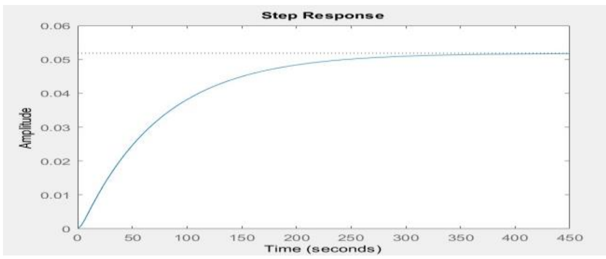


Fig. 6. Temperature response step.

The transfer function obtained in equation 3.4 can be entered in the block diagram for tuning the system's PID value. The block diagram on Simulink to get the PID value is shown in Figure 6. The system is tuned using the PID tuner to obtain the appropriate K, Ki, and Kd values, so a step response graph is obtained after tuning the PID tuner, as shown in Figures 7 and 8.

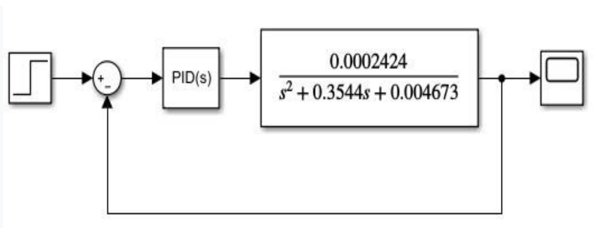


Fig. 7. Temperature control block diagram on Simulink.

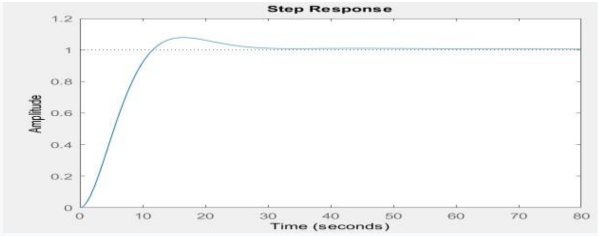


Fig. 8. Step response temperature after tuning.

After tuning, the values obtained are Kp = 35,362, Ki = 0.653, and Kd = 0, with a rise time of 7.73 seconds, settling time of 26.5 seconds, and overshoot of 7.9%. The values of these three variables can then be used in the program to obtain appropriate control over the temperature error values read on the system when running.

3.2 Implementation of website monitoring

In this research, the website is realized using the Codeigniter framework and is hosted online with the domain address https://www.greenberseri.com so that the monitoring can be done online during testing. CodeIgniter and Bootstrap are potent tools for website development. CodeIgniter is a lightweight PHP framework that simplifies creating dynamic web applications thanks to its easy-to-use structure, MVC (Model-View-Controller) design, and robust security features. It accelerates development by offering built-in libraries and helper functions, making it ideal for rapid project completion. Bootstrap, on the other hand, is a popular CSS framework that helps design responsive, visually appealing websites. It offers pre-designed components like navigation bars, buttons, and grids, which adapt well to different screen sizes, ensuring a consistent look across devices. On the front side of the website, the Bootstrap framework is used to make it easy to adjust the display easily; this also makes the website look responsive, as noted by [23] when accessed on different devices and makes it easier for users to access the website page monitoring automatic hydroponic control tools through their own devices. CodeIgniter and Bootstrap allow developers to build functional, secure, and responsive websites efficiently, combining robust backend processing with an attractive, user-friendly front end. As of 2022, publication [24] has enabled more significant control over each stage of system development, resulting in optimized time and resource usage.

Figure 9 illustrates the monitoring homepage, showcasing real-time data such as ambient temperature, EC environment, pH, sunlight graphs, weather forecast data, and notifications. On the homepage, users can also find notifications when the nutrient solution in the bottle runs out or when the pH solution in the bottle runs out, notifications when the vegetables have been harvested, and notifications when there is an internet problem with the device making it easy for users to track the system's status. Notifications alert users in real-time if the nutrient solution is low, enabling prompt action to prevent potential issues in plant growth.

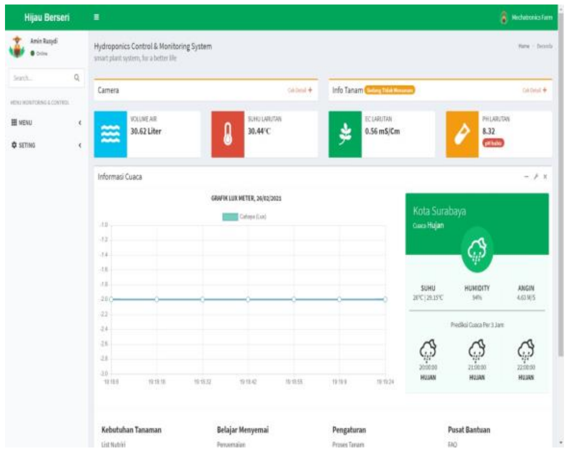
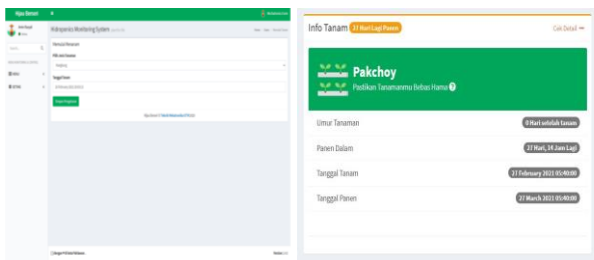


Fig. 9. Monitoring website home page display.

If the user wants to start the planting process through the website, there is a planting process page that the user can access to begin selecting the plants to be planted. Selectable crop options are provided as a drop-down menu with a planting date form available, automatically adjusting the system time. Figure 10 (a) is a page view of the planting process to start planting or view plant settings. On the planting process page, users only need to select the plants to be planted (claim, bok choy, spinach, lettuce, broccoli, cauliflower); they do not need to understand the nutrients required by plants and the appropriate pH for plants because the system already has nutrient and pH data stored in a database based on the type of plant. When the user presses the save settings button, all setting data on the selected plant type will be sent directly to the controller so that the controller starts working with settings based on the kind of plant received. When the user has pressed the save settings button, which means the tool will start the planting process, the user can no longer change the type of plant through the planting process page; the user can only cancel the planting process through the planting process page if the user wants to change the previously selected plant type. When the planting process takes place, users can find out the age of the plant and when the plant can be harvested through the home page on the plant info menu tab. The calculation of plant age is based on the harvest time data contained in the seed packaging for each type of plant; the data is then stored in a database so that it can be calculated from the date of planting and harvesting time of the plant to determine the age of the plant and the date the plant can be harvested. Figure 5 (b) is the view of the plant info tab on the homepage.



(a) (b)

Fig. 10. Page view (a) Planting process (b) Display the planting info tab on the monitoring website.

Things that need to be improved on this website, for example, are related to access via mobile phone [25]to increase the practicality of using the system as has been done by [17]. Even though it is Android-based, the system that was built does not handle changes in water temperature according to the ideal needs of plants. Also, since websites are accessible online, discussing any security measures taken to protect user data and ensure reliable monitoring could be added to future research topics.

4 Conclusion

PID temperature control does not fully achieve stability. Temperature control can be achieved in the afternoon until the morning returns, but during the day, even though the Peltier works optimally, it cannot cool the water to a set point of 25°C. This is because the Peltier work is very dependent on the ambient temperature. The level of control accuracy calculated based on data when Peltier conditions can reduce the temperature is 99.9 %. Alternative cooling actuators, such as compressor chillers in refrigerators, are more advisable than air cooling. This approach allows faster cooling with lower power consumption, enhancing effectiveness and long-term efficiency.

Based on the discussion results, hydroponic monitoring via the website provides practicality and convenience for users. Reducing monitoring time and measuring variables that are factors in plant growth and development (temperature, EC, and pH) is more specific. Hydroponic NFT Agricultural Monitoring can work according to the planned purpose through communication between the microcontroller and the website using an API connected to the Internet. However, it is necessary to develop security handling to improve performance further, considering that the system works online. In addition, things that need to be improved on this website, for example, are related to access via mobile phone.

References

1. M. Zuriati, M. Apriyani, A. Supriyatna, *Design and Implementation Automation System for Hydroponic Vegetable Cultivation*, International Conference On Agriculture and Applied Science (ICoAAS), 2020
2. R.S. Velazquez-Gonzalez, A.L. Garcia-Garcia, E. Ventura-Zapata, J.D. Barceinas-Sanches, J.C. Sosa-Savendra, *A Review on Hydroponics and the Technologies Associated for Medium- and Small-Scale Operations*, Agriculture MDPI, **12**, 646, 1-21 (2022)
3. A.A. Mamun, F. Naznen, G. Jingzu, Q. Yang, *Predicting The Intention and Adoption of Hydroponic Farming Among Chinese Urbanites*, Heliyon, **9**, 3, 1-14 (2023)
4. G. Rajaseger, K.L. Chan, K.Y. Tan, S. Ramasamy, M.C. Khin, A. Amaladoss, P.K. Haribhai, Hydroponics: Current Trends in Sustainable Crop Production, Bioinformation, **19**, 9, 925-938 (2023)
5. Bapennas, Rencana Pembangunan Jangka Menengah Nasional 2020-2024, Rancangan Teknokratik (2019)
6. V.L. CH, K. Avarna, N.B. D, S.S. G, *Hydroponics Farm Monitoring System Using IoT*, **3**, 10 (2020)
7. D.A.S. Vyshnavi, S. Agarwal, H. Dubey, C.J. L, A *Study on Hydroponic Farming*, International Journal for Multidisciplinary Research (IJFMR), **5**, 2, 1-12 (2023)
8. B. Benko, S.F. Uher, S. Radman, N. Opačić, Hydroponic Production Systems in Greenhouses, in Climate Smart Greenhouses - Innovations and Impacts, Book metrics overview, 150 (2023)
9. P. Greens, Pure Greens Container Farms, Pure Greens LLC, Available: https://puregreensaz.com/blog/nutrient-film-technique/
10. R. Rosliani, N. Sumarni, Budidaya Tanaman Sayuran dengan Sistem Hidroponik, Monografi, 1-38 (2005)
11. S. Wahyuni, M. Wahyudi, *Rekayasa Digitalisasi Pertanian Hdiroponik NFT dengan Model Kendali Suhu, pH dan Electrical Conductivity (EC)*, **14**, 1 (2021)
12. P. Rahmat, Bertanam Hidroponik Gak Pake Masalah, Jakarta (2015)
13. M.A. Nahdi, T.Y. Putro, Y. Sudarsa, IoT Based Hydroponic Plant Nutrient Monitoring Control System, Bandung (2019)
14. M.C. Subin, A. Singh, V. Kalaichelvi, R. Karthikeyan, C. Periasamy, Design and Robustness Analysis of Intelligent Controllers for Commercial Greenhouse, 11 (2020)
15. Y. Triwidyastuti, I. Puspasari, Harianto, *Comparison between PID and Fuzzy Controller to Hydroponic Temperature*, in International Conference on Information Technology Applications and Systems (ICITAS), 2021
16. I.A.L. Alipon, K.Y.G. Espiritu, A.G.G. Janeiro, K.F. Luna, A.F.S. Savellano, M.G.A.C. Bautista, *Design of an Automated Irrigation and Lighting System for a Two-Tier Nutrient Film Technique Hydroponics*, Journal of Computational Innovations and Engineering Applications, **6**, 1, 28-35 (2021)
17. D.A. Dudwadkar, T. Das, S. Suryawanshi, R. Dolas, T. Kothawade, *Automated Hydroponics with Remote Monitoring and Control Using IoT*, International Journal of Engineering Research & Technology (IJERT), **9**, 6, 928-932 (2020)
18. P. Thakur, D.M. Malhotra, D.R. Bhagat, *IoT-based Monitoring and Control System for Hydroponic Cultivation: A Comprehensive Study*, Research Square, 1-12 (2023)
19. H.J. Muhasin, A.Y. Gheni, N.I.I. Tajuddin, N.A. Izni, Y.Y. Jusoh, K.A. Aziz, *A systematic literature*

review for a smart hydroponic system, Bulletin of Electrical Engineering and Informatics, **13**, 1, 656-664 (2024)

20. M.C. Untoro, F.R. Hidayah, *IoT-Based Hydroponic Plant Monitoring and Control System to Maintain Plant Fertility*, INTEK Jurnal Penelitian, **9**, 1, 33-41 (2022)
21. P. Rahmad, Bertanam Hidroponik Gak Pake Masalah, Jakarta: Agromedia Pustaka (2015)
22. D. Thakulla, C. Goad, B. Dunn, N.O. Maness, *Nutrient Solution Temperature Affects Growth and Brix Parameters Seventeen Lettuce Cultivars Grown in an NFT Hydroponic System*, **7**, 321 (2021)
23. O.W. Purbo, *A Systematic Analysis: Website Development using Codeigniter and Laravel Framework*, Enrichment: Journal of Management, **12**, 1, 1008-1014 (2021)
24. F.L. Becerra-Suarez, V.A. Tuesta-Monteza, H.I. Mejia-Cabrera, *Usability testing of a web system for university academic Usability testing of a web system for university academic management implemented in CodeIgniter*, Research Gate (2022)
25. S.V.S.R. Raju, B. Dappuri, P.R.K. Varma, M. Yachamaneni, D.M.G. Verghese, M.K. Mishra, *Design and Implementation of Smart Hydroponics Farming Using IoT-Based AI Controller with Mobile Application System*, Journal of Nanomaterials, 1-12 (2022)