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On-Off Water Level Control and IoT Monitoring for Aquaponics Systems

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ABSTRACT

Aquaponic systems are cultivation methods that integrate fish and plant farming (aquaculture) with hydroponics in a mutually beneficial manner, utilizing symbiotic mutualism. In traditional systems, water level control is typically managed through conventional manual methods. This research aims to develop an effective automated control system for regulating aquaponic water levels, featuring an on/off control mechanism and remote monitoring capabilities via the Thinger.io platform. The research methodology includes the design and implementation of the control system, functional and performance testing of the system within aquaponics, as well as evaluating data loss and network delays when using the Thinger.io platform. The observed parameter is the water level. Results demonstrate that the on/off control system effectively maintains water levels without overshoot. The settling times were 9 minutes for a height of 20 cm, 22 minutes for 25 cm, and 34 minutes for 30 cm, with steady-state errors remaining within acceptable tolerance limits. The IoT-based system leveraging Thinger.io successfully transmitted and stored data throughout the testing phase. The platform enabled real-time remote water level monitoring and provided data exportable in Excel format. The average data loss rate was 1.81%, and the average network delay was 0.88%. Analysis revealed that the highest data loss and delay occurred between 00:00–06:00 GMT +8.

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1. INTRODUCTION

Aquaponics is an innovative cultivation system that combines aquaculture (fish farming) and hydroponics (soil-free plant cultivation), forming a symbiotic relationship. The system benefits fish by using plant roots as natural biofilters to improve water quality, reducing the need for frequent water replacement. Simultaneously, plants utilize the nutrients from fish waste, supporting their growth and development. Commonly cultivated plants in aquaponics include water spinach (Ipomoea aquatica), land spinach (Ipomoea reptans), and lettuce (Lactuca sativa), while popular fish species include goldfish, catfish, and tilapia [1].

A stable water level is crucial in aquaponics to ensure the health and growth of both fish and plants. However, maintaining water levels manually can be time-consuming and error-prone, often leading to insufficient or excessive water, which can harm the ecosystem. Automating water level control and integrating Internet of Things (IoT) technology for monitoring offers an efficient solution. IoT systems enable real-time remote monitoring and control, providing convenience for farmers [2].

This study investigates the application of an on/off control system for water level regulation in aquaponics, paired with IoT monitoring through the Thinger.io platform. The research aims to enhance the stability and efficiency of aquaponics systems by automating water level management and offering real-time data access via IoT.

2. MATERIALS AND METHODS

2.1 Time and Place
This research was conducted from June 2023 to August 2023, located in Unhas Lecturer Housing, Al-Biruni Street, Perintis Kemerdekaan VIII, Tamalanrea Jaya, Tamalanrea District, Makassar City, South Sulawesi.

2.2 Tools
The tools used are laptop, Arduino IDE software, Thinger.io Platform, Smartphone, Wi-Fi Modem, 12 volt power supply, jumper cable, 12 volt DC selenoid valve, ESP-32, step down, HC-SR04 ultrasonic sensor, 20x4 I2C LCD, Solid State Relay (SSR), scissors, hot glue gun and pvc pipe.

2.3 Material
The materials used in this study are water, kale plants and tilapia.

2.4 Literature Review
The literature study was conducted by collecting information from books, national and international journals and other media. Information needed in the form of aquaponics and control systems and IoT platforms used.

2.4.1 Control and Monitoring System Design
The design of the control and monitoring system for aquaponics, the controlled water surface is the water surface of the fish pond, the criteria are that the system is able to control the water level of the fish pond, the system is able to send water level data to the platform.

2.5.1 Functional Design

The functional design of this research is to adjust the water level according to the given setting point and monitoring using the Thinger.io platform. Where there are several functions, namely:

a. Function reads and displays water level sensor reading data.
b. Water level control function.
c. Data sending function to Thinger.io platform.

2.5.2 Structural Design

The structural design is as follows:

a. The software used to create the program is the Arduino IDE software.
b. The system is run using a 12 volt power supply as a source of electrical energy to supply the device to be controlled.
c. The system uses ESP-32 as the control center of the system to be controlled as well as to connect to the internet and monitor and send data to the Thinger.io platform.
d. The system uses an HC-SR04 sensor to read the water level.
e. The system uses a Solid State Relay (SSR) as an actuator that controls the electric current to the solenoid valve.

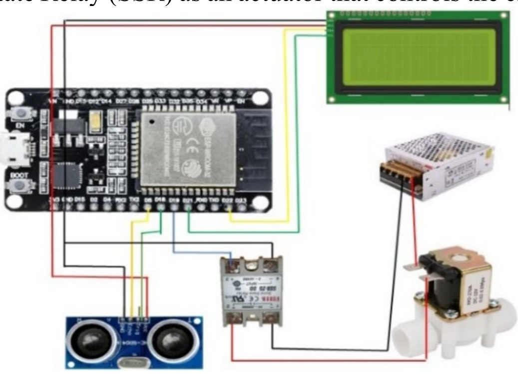


Figure 2. Hardware design of selenoid valve control system.

Table 1. *Wiring* NodeMCU ESP-32 with HC-SR04 sensor.

ESP-32		HC-SR04
Gnd	↔	Gnd
D18	↔	Echo
D5	↔	Trig
Vin	↔	VCC

Table 2. *Wiring* NodeMCU ESP-32 with *Solid State Relay* (SSR)

ESP-32		*Solid State Relay* (SSR)
Gnd	↔	Gnd
+	↔	+
D19	↔	IN

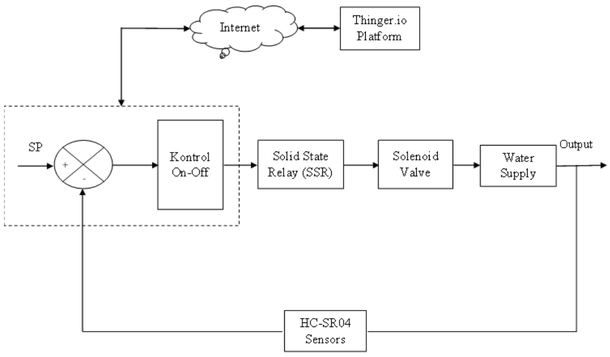


Figure 3. Block diagram of control system with monitoring.

1. ESP-32 is a microcontroller as a control center to run the control rules set and connect to the internet and also to send data to the Thinger.io platform.
2. The sensor used is an HC-SR04 ultrasonic sensor to measure the water level in aquaponics.
3. The Thinger.io platform is used for monitoring sensor data and viewing sensor reading graphs via handphone.
4. SSR as actuator to give and disconnect electric current.
5. Solenoid valve controlled used to fill water in aquaponics.

2.6 Functional Test

The functional test stage is carried out to determine whether the system runs according to the expected success indicators. The tests carried out are:

a. Testing the HC-SR04 sensor, to see if the sensor accurately reads the height of the water surface. By trying at some distance then compared with measuring instruments (calibration).
b. Testing controlling several levels of water surface height. At heights of 15 cm, 20 cm, 25 cm and 30 cm.

2.7 Performance Test

Performance tests were conducted to determine the performance of the control and monitoring system applied to aquaponics. The tests carried out are:

a. Changes in water level detected by the HC-SR04 sensor provide action to the solenoid valve for 5 days of testing.
b. Transient response to determine overshoot and setling time to reach set point.
c. Steady state response to determine the stability of the control made.
d. Packet loss and delay testing.
   Packet loss calculation equation:

$$\text{Packet Loss} = \frac{\text{Data packets sent-data packets received}}{\text{Data packets sent}} \times 100\%$$

   Delay calculation equation:

$$\text{Delay} = \frac{\text{Total delay}}{\text{Data packets sent}} \times 100\%$$

Table 1. Packet Loss and Delay test results.

Category	Delay (s)	Packet Loss (%)
Very Good	<150	0-2
Good	150-300	3-14
Medium	300-540	15-24
Poor	>450	>25

Source: TIPHON (Telecommunications and Internet Protocol Harmonization Over Network).

2.8 Data Analysis

Data analysis is carried out to determine the success of the control and monitoring system that has been applied to aquaponics. The data analysis are:

a. Transient and steady state response

   This stage of data analysis is carried out to see how stable the water level control applied to aquaponics is, while the testing stage is carried out by activating the device and observing changes in water level after that plotting the data in graphical form and analyzing the overshoot response, settling time and steady state error.

b. Packet loss & delay data

   For data analysis at this stage is to see the missing data and see the response time for each data in network recording. If there is missing data, it is considered as packet loss on the IoT network. If to see the delay, what is considered is the response time.

2.4.2 Watershed Delineation

The process of delineating the boundaries of the Mamasa sub watershed is done with DEM data which is processed automatically by the SWAT model and will form the outer boundaries of the sub watershed in the SWAT model, namely the basin.

2.4.3 Land Cover

Land cover is obtained from the interpretation of Landsat 7 images in 2011 and Landsat 8 images in 2016 and 2020 for input to the SWAT model. Furthermore, image classification is carried out using unsupervised and supervised methods with the maximum likelihood tool to identify spectral classes which are divided into 10 classes (water bodies, bush, primary forests, secondary forests, habitation, dry land agriculture, dry land agriculture mixed with bush, savanna, rice fields and open land).

2.4.4 HRU (Hydrology Response Unit)

Hydrology Response Unit (HRU) analysis was conducted by overlaying the land cover map, soil type map and slope data. Each HRU formed contains specific information about the land including land cover, soil type and slope. The land cover and soil type data used in the HRU analysis are in ESRI raster format while the slope class classification is derived from the DEM dataset.

2.4.5 Weather Generator

Climatological data for rainfall is obtained from 3 rainfall measurement stations around the Mamasa watershed area, while data on temperature, relative humidity, solar radiation, and wind speed are obtained from NASA Power. The climatological data is then processed using SWAT weather database software so that it can be connected to SWAT and as an input to the weather generator in SWAT.

2.4.6 Running SWAT

Running the SWAT model is done after the process of combining HRU with climatological data is complete. SWAT simulation can be determined by the year to be simulated and the time unit of the desired output. In this study, SWAT simulations were carried out using a 1-year period with 3 simulations, namely 2011, 2016 and 2020 with daily simulations. The type of output issued from this simulation is RCH output which contains the results of discharge data. Furthermore, running the SWAT model again 3 times using 2020 climate data on different land cover conditions so that the effect of land change on river discharge can be known.

2.4.7 Validation

Validation is done by comparing the discharge results from the model (simulated discharge) with the measured discharge in the field (observation discharge). To test the efficiency of the model, two methods were used, namely Nash Sutcliffe Efficiency (NSE) analysis.

$$NSE = 1 - \frac{\sum_{i=1}^{n} (Q_{act} - Q_{sim})^2}{\sum_{i=1}^{n} \left(Q_{act} - \underline{Q}_{act}\right)^2} \qquad (1)$$

Qact is discharge actual (m3/s), Qsim is discharge simulation (m3/s), and _(Q) act is average discharge actual (m3/s). The efficiency of the Nash-Sutcliffe model is categorized into four classes as follows:

1. Excellent, if $0.75 \leq$ NSE
2. Good, if $0.65 \leq$ NSE ≤ 0.75
3. Pretty good, if $0.50 \leq$ NSE ≤ 0.65
4. Not good, if NSE ≤ 0.50

In looking at the accuracy of the model output pattern with field observations, deterministic coefficients or linear equations are used:

$$R^2 = 1 - \frac{(X - \underline{X})^2 - (X - Y)^2}{(X - \underline{X})^2} \qquad (2)$$

X is the amount of observation discharge, $\bar{X}$ is the average observation discharge and Y is the model calculation discharge. The calculation of R2 shows the evaluation of the feasibility of the model, if R2 is close to 1, there is a close relationship between the model predictions and field observations.

3. RESULTS AND DISCUSSION

3.1 Description of Aquaponics

The study utilized a DFT (Deep Flow Technique) aquaponic system with kale plants and tilapia fish. The setup included a 150-liter plastic fish pond, a 24-liter water source bucket, and a solenoid valve with an output of 0.025 liters/second. The hydroponic section comprised 8 parallel pipes, each containing 13 netpot holes (see Figure 4 for details)

Figure 4. Aquaponic.

3.2 Control System

The on-off control system for aquaponics consists of several components, namely the HC-SR-04 ultrasonic sensor, NodeMCU ESP-32, 20x4 I2C LCD, SSR (Solid State Relay), step down, power supply, breadboard and jumper cables.

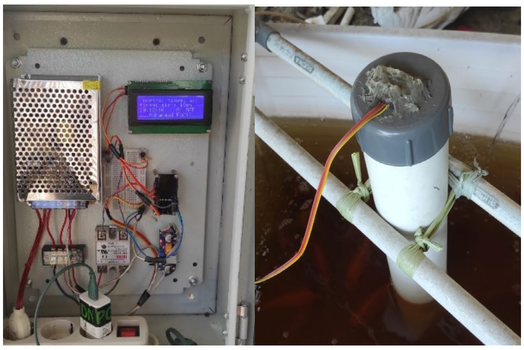


Figure 5. Design results of the water level control system.

The ESP-32 nodeMCU sends sensor data to the Thinger.io platform via the internet. Thinger.io visualizes water level data in real time, provided the connection is stable, and allows free download of data as Excel CSV files. Thinger.io is an IoT platform offering cloud-based device connectivity and data visualization features [3]. The platform showed an average packet loss of 1.81% and a delay of 0.88%, both of which are within acceptable ranges according to TIPHON standards.

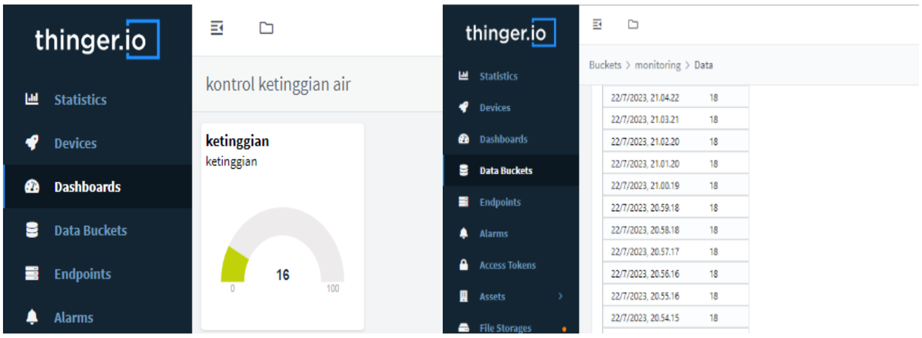


Figure 6. Display of sent data on Thinger.io.

3.3 Functional Test

3.3.1 HC-SR04 Sensor Calibration Results

The HC-SR04 sensor accurately measured water levels, with a regression value of 0.9985, indicating high precision. The on/off control system successfully maintained water levels without overshoot. Settling times were 9 minutes for 20 cm, 22 minutes for 25 cm, and 34 minutes for 30 cm. Steady-state errors remained within acceptable limits, with minor deviations of 1 cm.

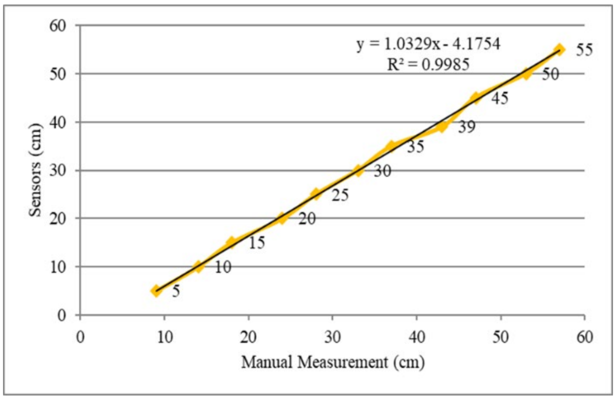


Figure 7. HC-SR04 sensor calibration results.

3.3.1 Control System Test Results at Multiple Elevation Levels

The test results at several levels of height are carried out to determine whether the control can work at different heights (SP), there are 4 heights tested, namely 15 cm, 20 cm, 25 cm, and 30 cm. The results of the data obtained can be seen in Figure 8. Based on the results of the tests carried out where the solenoid valve on-off mechanism occurs too often, the results can be seen in Figure 8.

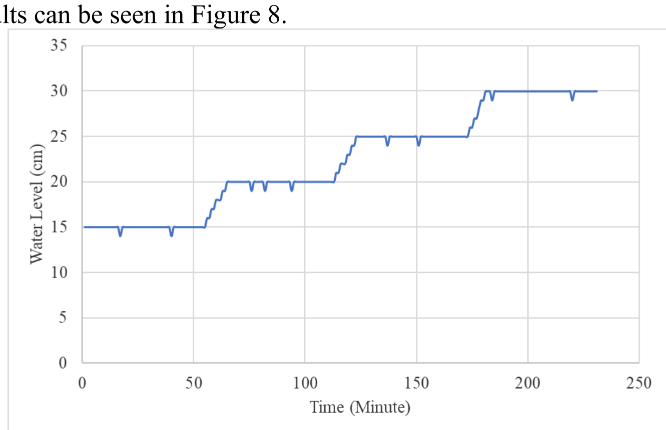


Figure 8. Test results at multiple heights.

3.4 Performance Test Results

The results of the performance test in this study are as follows.

3.4.1 Control System Testing

Testing of the on-off control system is carried out for 5 days at each set point determined with the aim of knowing whether the on-off control system made works as expected, where in this study the water level control system is automatically based on the set point value, as for the data presented in the following Figures 9-11.

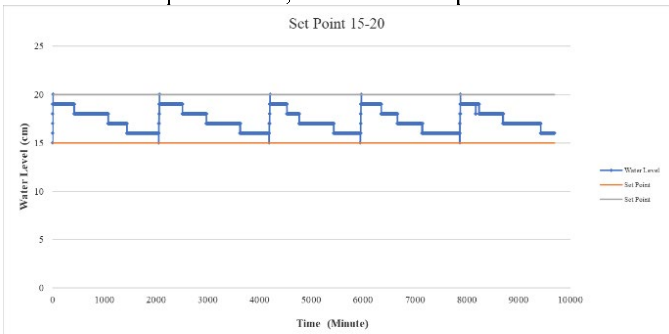


Figure 9. Control system response to water level value at set point 20.

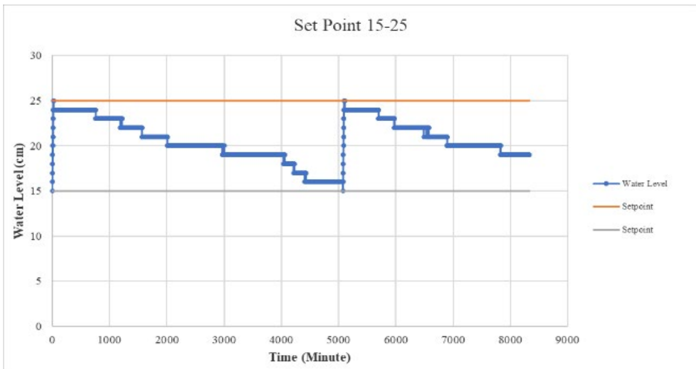


Figure 10. Control system response to water level value at set point 25.

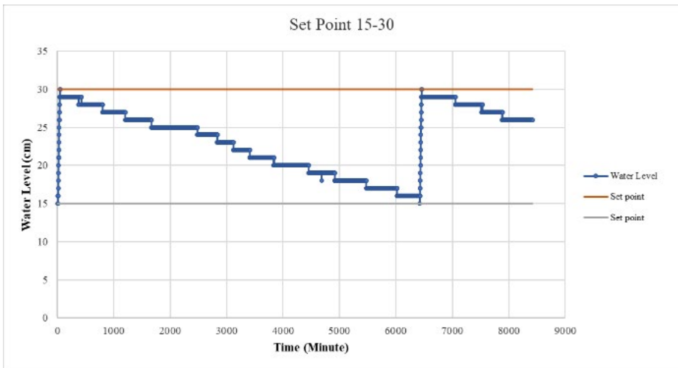


Figure 11. Control system response to water level value at set point 30

The control system response to the water level detected by the HC-SR04 sensor, where the controlled component is the solenoid valve. The solenoid valve will activate or turn on if the water level value detected by the HC-SR04 sensor is less than or equal to the lower limit setting point and will turn off at a water level value more or equal to the upper limit setting point. The lower limit setting point is set to prevent fish and plants from experiencing a lack of water that can interfere with their growth process. While the upper limit setting point is set to prevent excess water. This setting point will give orders to the microcontroller automatically to flow water to the fish pond when it needs water and stop the flow of water if the water needs have been met. In addition, giving the upper and lower limit Setting Point values to reduce the on-off mechanism on the solenoid valve which can make the solenoid valve heat up quickly. Based on the data obtained, it shows that the application of the on-off automatic control system for 5 days in aquaponics can make the water level stable according to the given setting point. This is in accordance with the statement of [4], that the control method used uses the on-off control method with the provision of a differential gap. The differential gap is given with the aim of reducing the on-off mechanism that occurs, and reducing the oscillations that occur.

3.4.2 Transient Response of Water Level in Aquaponics

The results of the transient response analysis aim to see how much overshoot and settling time on the control system that has been tested, more details are presented in Figures 12-14.

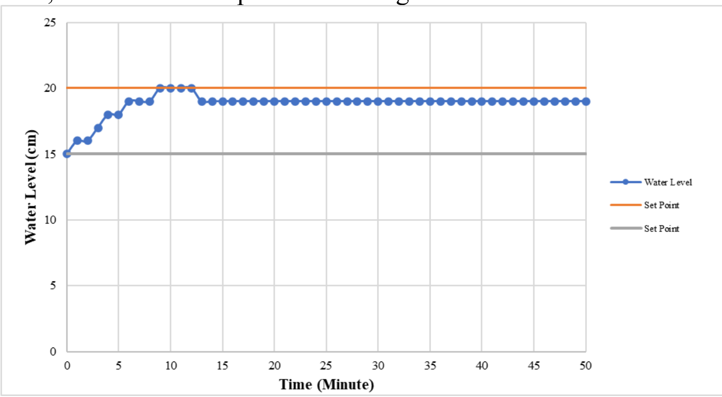


Figure 12. Transient response of water level per minute at set point 20.

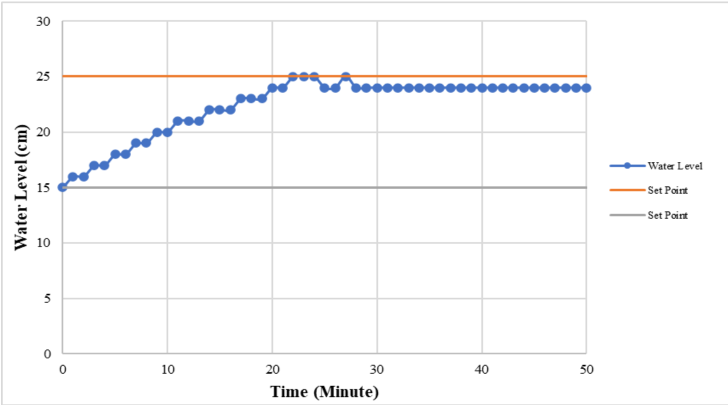


Figure 13. Transient response of water level per minute at set point 25.

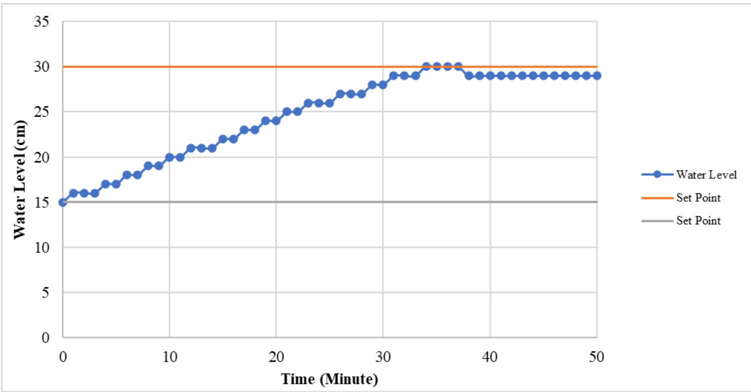


Figure 14. Transient response of water level per minute at set point 30.

Figures 12-14 show that the water level on-off control system in aquaponics does not overshoot for the three set points tested. The settling time reached for a height of 20 cm is 9 minutes, a height of 25 cm for 22 minutes and for a height of 30 cm takes 34 minutes. Based on the tests carried out where no overshoot occurs and the time to reach the setting point is not long. This is in accordance with the statement of [5], a good control system is a system that does not experience overshoot and short settling time.

3.4.3 Transient Response of Water Level in Aquaponics

The results of the steady state response analysis aim to see how stable the control system that has been tested is, more details are presented in Figures 15-17.

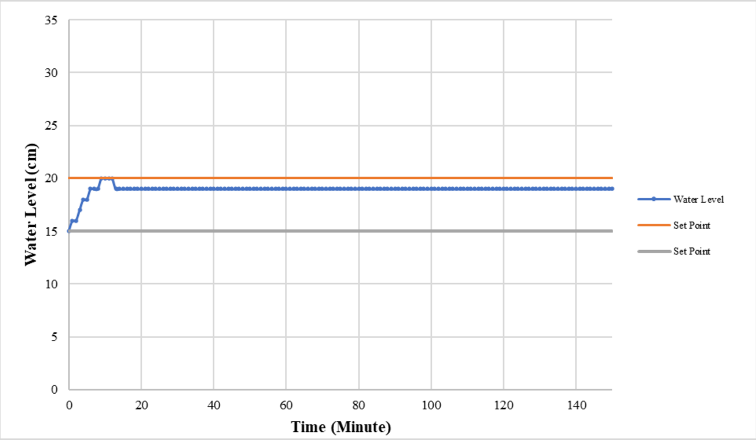


Figure 15. Respon *steady state* set point 20.

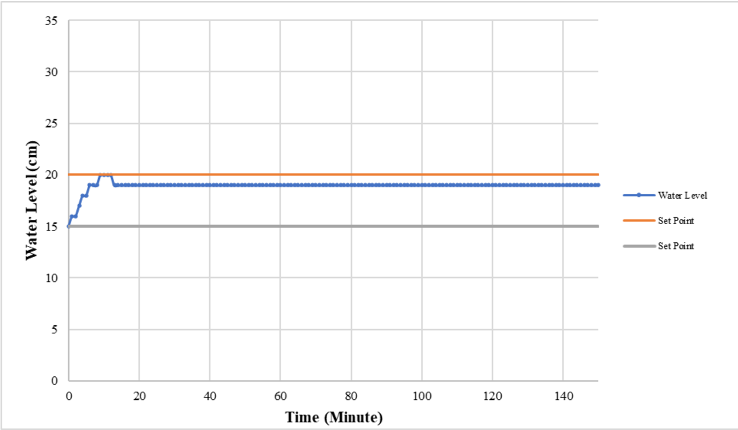
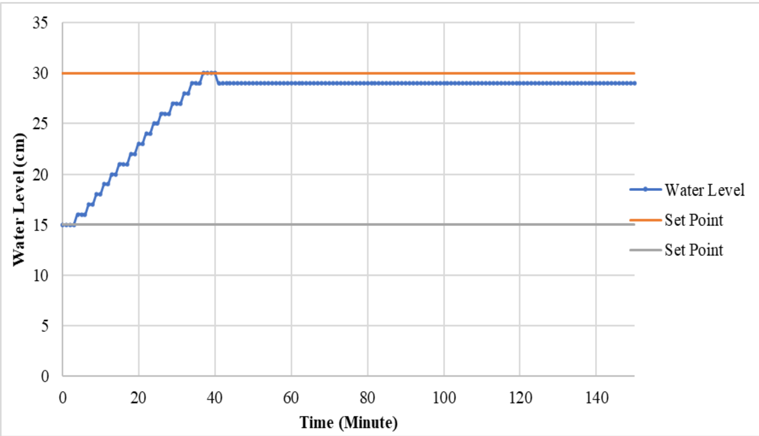


Figure 16. Respon *steady state* set point 25.



Gambar 17. Respon *steady state* set point 30

Based on the data obtained in Figures 15-17. It is found that the application of the on-off control system to the aquaponic water level can make the water level stable, while the error value that occurs at the 20 cm set point is 3.3%, the 25 cm set point is 4% and the 30 cm set point is 5%, where each error has a difference of only 1 cm with the set point. This steady state error value is not within the tolerance limit as stated of [5], this is due to several factors, for example the output of the solenoid valve is less and the sensor reading is only an integer not a decimal value.

3.4.4 Packet Loss and Delay Testing

Water level monitoring data is sent automatically to the Thinger.io Platform with the time interval used is 60 seconds or 1 minute. The packet loss and delay are caused by unstable network conditions so that the internet connection is disrupted and causes the data transmission process to be delayed. More details in Table 2 and Table 3 data is mapped every six hours.

Table 2. Percentage of data sent and data lost.

Time	Packet sent	Packet loss	Percentage
00-06 GMT +8	351	9	2.50%
06-12 GMT +8	352	8	2.22%
12-18 GMT +8	357	3	0.83%
18-00 GMT +8	354	6	1.67%
Avarage	353.5	6.5	1.81%

Based on Table 2. shows the results of packet loss testing. In the packet loss parameter, the amount of data obtained from the process is 1414 data and there is a data loss of 26 data, in other words, the total percentage of data loss is 1.81%, the average value is included in the very good category according to the TIPHON (Telecommunications and Internet Protocol Harmonization Over Network) standard.

Table 3. Percentage of delay

Time	Delay total (second)	Packet sent	Percentage
00-06 GMT +8	444	351	1.26%
06-12 GMT +8	350	352	0.99%
12-18 GMT +8	183	357	0.51%
18-00 GMT +8	258	354	0.73%
Avarage	308.75	353.5	0.88%

Based on Table 3. The delay parameter produces an average test value of 308.75 seconds with a percentage of 0.88% which is included in the moderate category according to the TIPHON (Telecommunications and Internet Protocol Harmonization Over Network) standard. In the table, the largest percentage of packet loss and delay is at 00-06 WITA, where at that time the internet connection is interrupted so that the data transmission process is hampered.

4. CONCLUSION

Based on the results of the research that has been done, it can be concluded that:

1) The system is able to control the water level properly according to the specified set point, which is able to open and close the solenoid valve according to the set point.
2) The control system is said to be successful because of the absence of overshoot and settling time at a height of 20 cm, which is 9 minutes, a height of 25 cm for 22 minutes and for a height of 30 cm for 34 minutes and the steady state error that occurs is still within the tolerance limit.
3) Thinger.io platform can monitor and record water level data from time to time, packet loss percentage of 1.81% with a very good category and a delay percentage of 308.75 seconds, including in the medium category according to TIPHON (Telecommunications and Internet Protocol Harmonization Over Network).

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