# IMPLEMENTATION OF CASCADE CONTROL IN WATER TURBIDITY LEVEL SETTINGS FOR THE PROCESS CONTROL SYSTEM LEARNING MODULE

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**ABSTRACT**

Learning media is one of the means needed to achieve the perfect quality of education. In the Process Control System Practicum Laboratory of Malang State Polytechnic, the number of learning module plants is limited.. It is necessary to add a new learning module, therefore a plant is designed about regulating the level of water turbidity. In this plant, a cascade control method is used to regulate the mixture of clear water and water with high turbidity in order to obtain water with a certain level of turbidity. The results of the application of the cascade control method using the P controller in the inner loop (flow) with a value of $K_p = 155$ obtained rise time 3s, settling time 4s, and steady state error 15%, in the outer loop (turbidity) was also used P controller with a value of $K_p = 1.67$ resulting rise time 14s, settling time 30s, and steady state error 60%. The high steady state error occurs because the plant response of this system has characteristics that were too fast so that the cascade control was unable to overcome the error. In addition, the SEN0189 turbidity sensor with the accuracy of reading the water turbidity value of 10 NTU every 1mV voltage change and easily exposed to noise was also the cause of this system plant to produce a high steady state error.

**Keywords:** Learning Media; Quality of Education; Turbidity Sensor SEN0189; Cascade Control

## Introduction

Education is a necessity for humans to achieve success.[1] Without education, humans will find it difficult to develop and will even be underdeveloped. To achieve the perfect quality of education, a facility and infrastructure are needed to get the maximum results of the teaching and learning process. One of these facilities that can be used is learning media.2 Learning media can be understood as anything that can convey and distribute messages from a planned source so as to create a conducive learning environment.[3]

The Control System Practicum Laboratory of Malang State Polytechnic has limited plant as a student learning module. The module can be seen as a learning programme package consisting of components that contain learning objectives, teaching materials, learning methods, tools or media, as well as learning resources and evaluation systems.[4] It takes a variety of plant systems in order to foster interest in learning and increase understanding for students. Therefore, a turbidity sensor application trainer module is designed to control the level of water turbidity using the cascade control method which is expected to attract students in increasing their curiosity and increase student learning motivation.

In research conducted by Hua, et al,[5] entitled "Research of Fuzzy Control in Coagulation Progress for Tap Water" about the design of a cascade fuzzy self-tuning PID controller that can control the output of water with the right turbidity. This system does not require a precise mathematical model of the object. The results of this study show that this method has a fast response speed, can significantly reduce the amount of overshoot,

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has good stability, good accuracy, and improved dynamic performance.

In research conducted by Hadi, et al,[6] with the title "Sistem Penjernih Air Limbah Rumah Tangga dengan Kendali PID berbasis Arduino", the process of making a household wastewater purifier using an Arduino-based PID control system was carried out. This system is a combination of existing water purification technology with microcontroller technology in order to run the system automatically. Based on the test results, the best setpoint is obtained at 518 with the values of Kp = 1, Ki = 0.2, Kd = 0.01, and Ts = 0.1. Based on the results of laboratory-scale testing for the turbidity level of filtered water using this prototype system, a value of 2.48 NTU is obtained, indicating that the water that has gone through the purification process is suitable for consumption.

## Methods

In the input block there are 3 components, namely the water flow sensor, turbidity sensor, and push button. The water flow sensor functions to measure the flow rate at the output channel of tank B which has gone through the valve.[7] The turbidity sensor serves to measure the turbidity value of water in tank B and tank C. ADS1115 serves to expand the range of analogue values from the turbidity sensor output connected to Arduino, where the initial value was 10 bits to 16 bits so that the turbidity sensor reading data is more accurate.[8] And the last is a push button to activate the relay that will turn on the water pump. In the process block section there was an Arduino UNO R3 microcontroller to control the angle of the servo motor with a cascade control method based on reading data from the turbidity sensor and flow sensor.[9,10]

This Arduino has a role so that the water turbidity condition in tank C is in accordance with a predetermined setpoint, so that when there is an error in the water turbidity value in tank C, the Arduino will open the valve with a certain angle (according to the setpoint value of the water flow rate) to drain the turbid water in tank B to tank C so that the turbidity value in tank C matches the setpoint. Meanwhile, the output block consists of a 16x2 LCD, servo motor, DC water pump, and DC motor. The 16x2 LCD is used to display the water turbidity value in tank C and the water flow rate.[11] The servo motor is used to adjust the opening of the valve.[12] Relay is used to regulate the condition of the water pump. The water pump is used to drain turbid water in tank B to tank C, where the flow rate of turbid water in tank B is controlled using a valve. Driver L298N is used as a motor driver to adjust the speed of the DC motor during the stirring process. The DC motor (stirrer) is used to speed up the mixing process between clear water tank A and turbid water tank B in tank C.

In this plant, control of the water turbidity level in tank C is carried out to match the predetermined setpoint. Based on the control block diagram above, there are 2 control loops, namely the inner loop and outer loop. In the inner loop, there is a water flow sensor to measure the water flow rate at the output of tank B. This water flow sensor will detect whether there is an error in the value of the water flow rate against the predetermined water rate setpoint. If an error is found, the P controller (flow controller) will adjust the angle of the servo motor in opening the valve to drain the water so that the water rate returns to the predetermined setpoint. The outer loop uses a turbidity sensor to measure the turbidity value of the water in tank C. This turbidity sensor will detect whether there is an error in the turbidity value of the water in tank C compared to the predetermined setpoint. If an error is found, then controller P (turbidity controller) will be the setpoint of the inner loop to adjust the valve to drain turbid water B so that the mixture of clear water A and turbid water B in tank C turbidity value is in accordance with the predetermined setpoint.

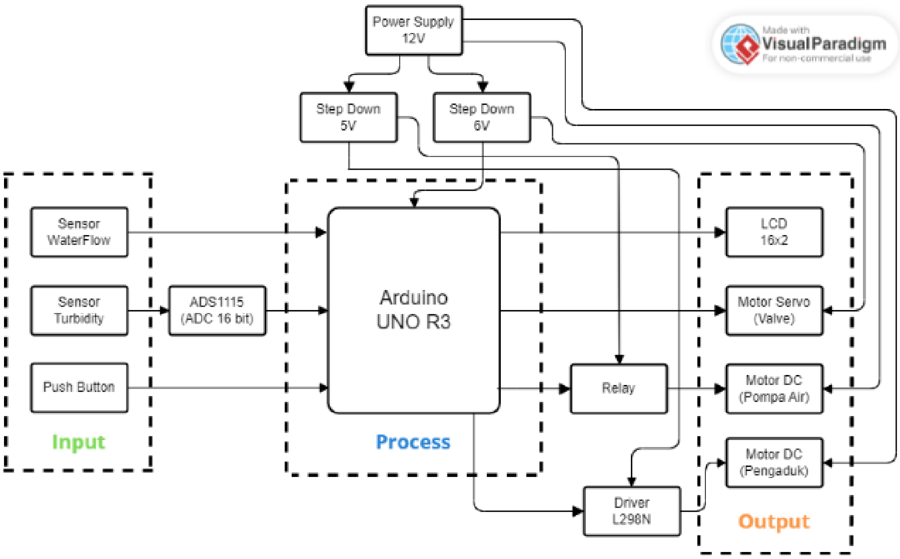


**Figure 1.** The block diagrams of the systems

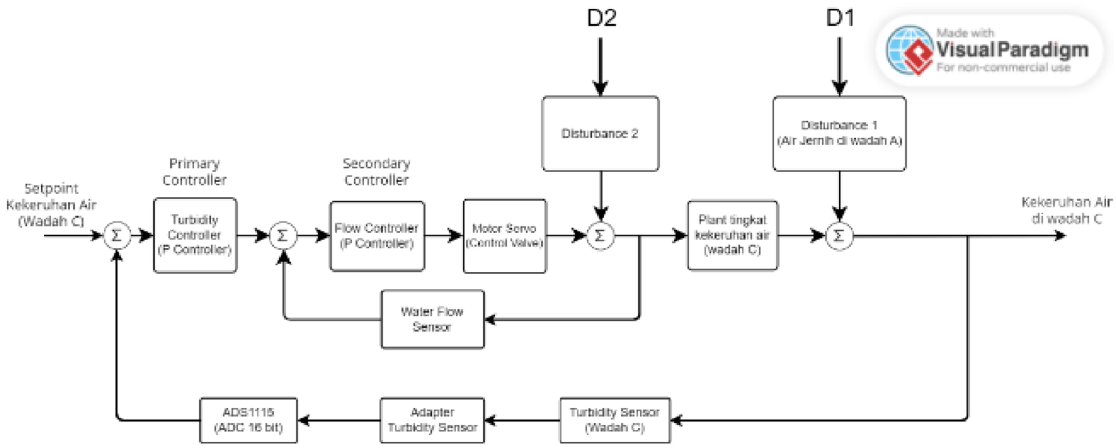


**Figure 2.** Block diagram of cascade control

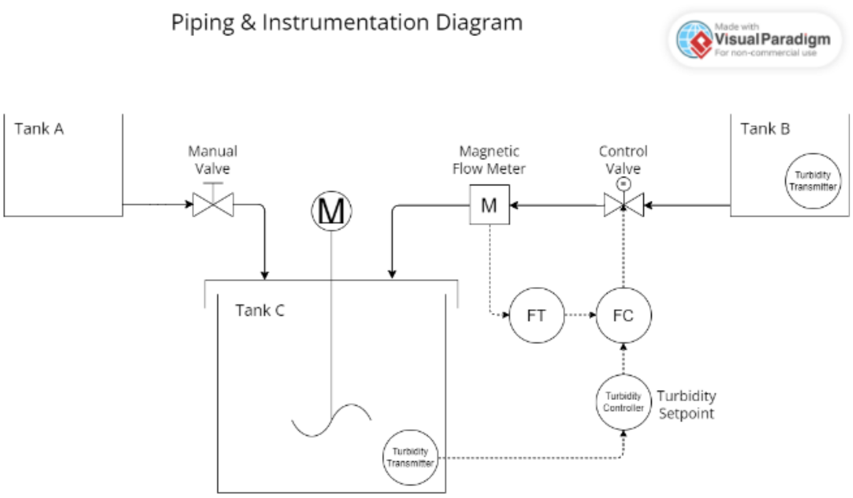


**Figure 3.** Cascade control system P&ID

**Mechanical Design**

A. Mechanical Specifications

1. Tank A and Tank B
   - Length = 8 cm
   - Width = 10 cm
   - Height = 15 cm
   - Capacity = 1,4 Litres
   - Material = Acrylic Aquarium
2. Tank C
   - Length = 30 cm
   - Width = 15 cm
   - Height = 15 cm
   - Capacity = 8 Litres
   - Material = Acrylic Aquarium
3. Electrical Box
   - Length = 45 cm
   - Width = 25 cm
   - Height = 7 cm
   - Material = Acrylic
4. Trainer Table
   - Length = 80 cm
   - Width = 60 cm
   - Height = 45 cm
   - Material = Wood and stainless stell

**Figure 4.** 3D drawing of mechanical design

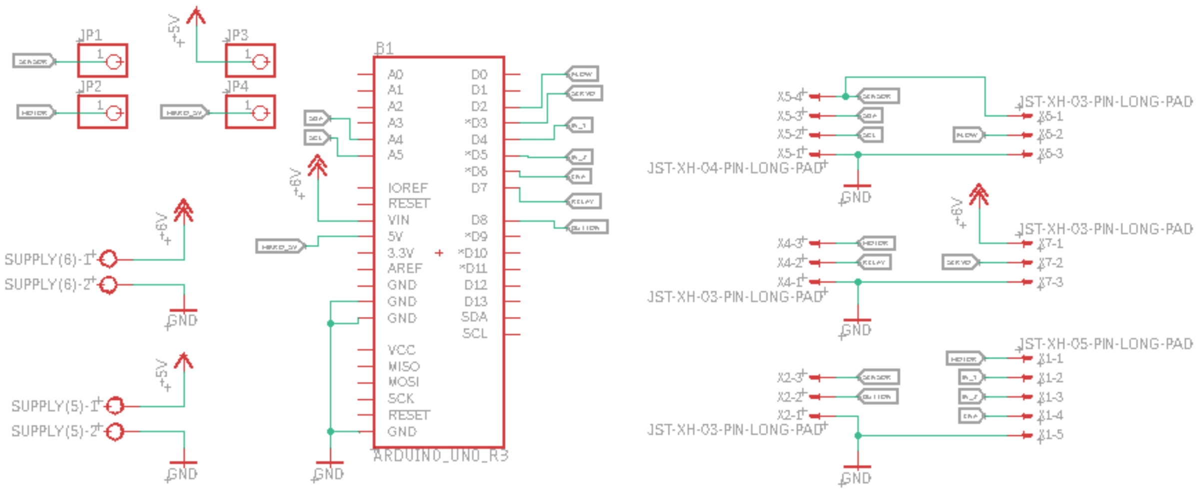


**Figure 5.** Main board schematic circuit

B. Electrical Specifications
1. Power supply type = 12V power supply
2. Microcontroller type = Arduino UNO R3
3. Display type = 16x2 LCD with I2C module
4. Sensor type = SEN0189 turbidity sensor interfaced with ADS1115 and YF-S401 water flow sensor
5. Actuator type = DC 12V 365B-7 water pump, DC 12V RS-555 motor and TD-8120MG servo motor.
6. Water turbidity range = 0 NTU - 100 NTU
7. Water flow range = 0.40 L/min - 0.70L/min
8. Water flow control using PID-Cascade method (inner loop)
9. Water turbidity control using PID-Cascade method (outer loop)

**Electrical Design**

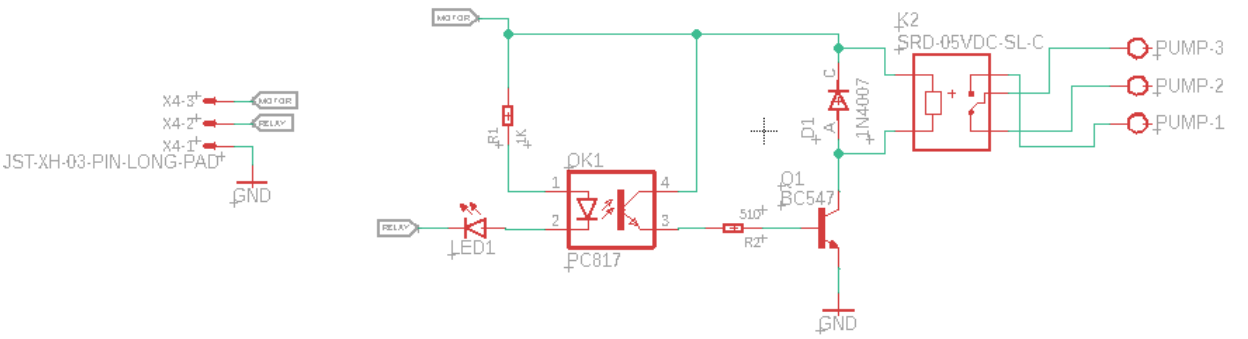


**Figure 6.** Relay schematic circuit

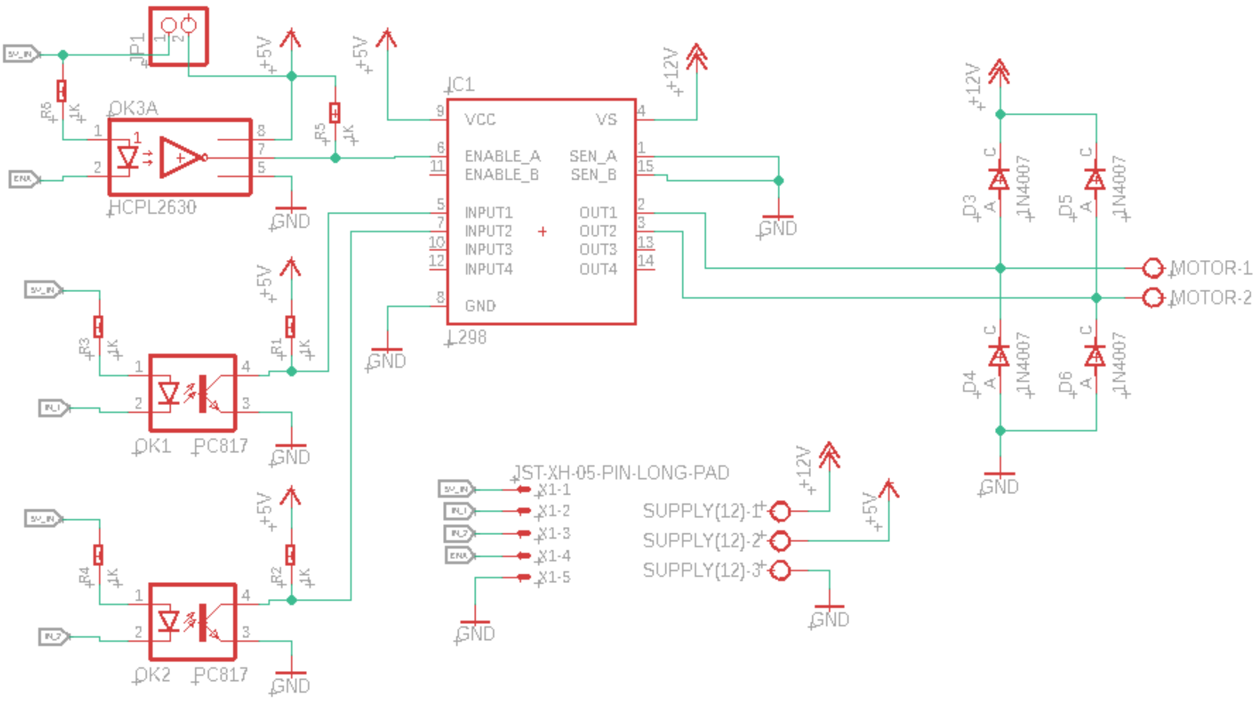


**Figure 7.** L298N motor driver schematic circuit

**Flow Controller Design**

This flow controller will be designed in the Arduino UNO using program code. Tuning PID Ziegler-Nichlos method 2 (oscillation method) is used to get the right controller parameter values.[13] In this method, it is done by increasing the value of $K_p$ from 0 to the critical value of $K_{cr}$ or $K_u$ where the output results are obtained in the form of a continuous oscillation graph. After getting the $K_{cr}$ value, then proceed to determine the $P_{cr}$ or $P_u$ value. The $P_{cr}$ value is the distance between wave crests. The following is a graph of the flow system when experiencing continuous oscillations.

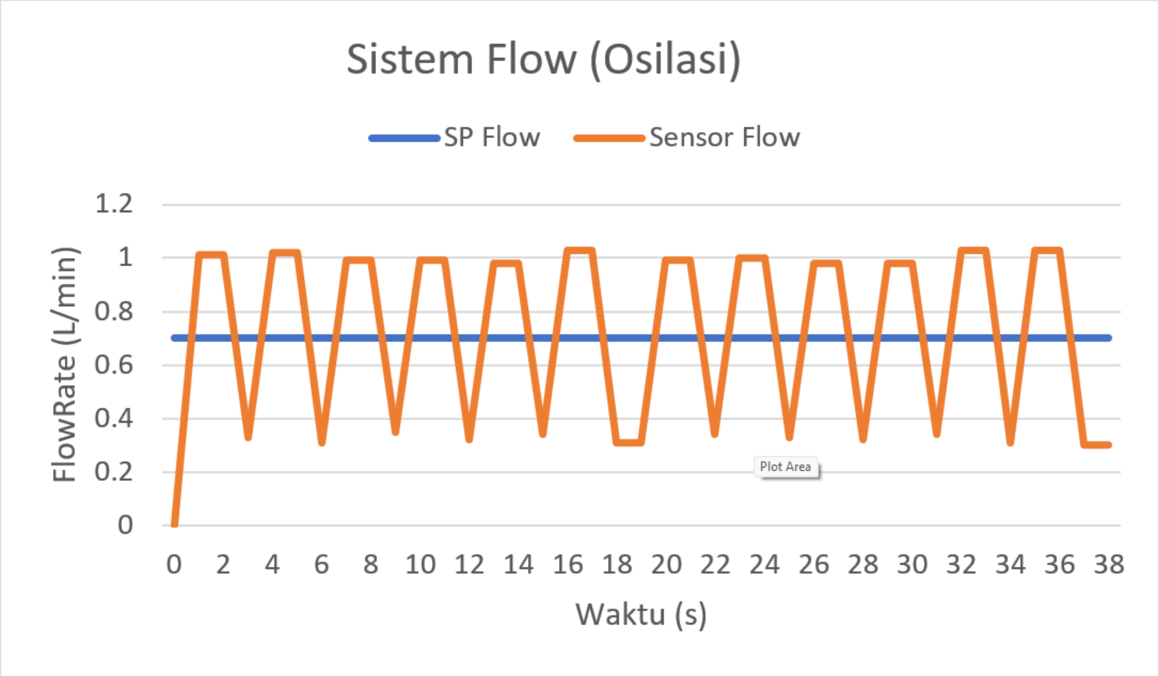


**Figure 8.** Flow controller design when $K_p = K_u = 290$

### Turbidity Controller Design

This turbidity controller will be designed in the Arduino UNO using program code. Ziegler-Nichlos PID tuning method 1 (reaction curve method) is used to get the right controller parameter values.[13] This system plant produces an S-shaped response curve. This S-shaped system plant response curve is what we will use to find the delay time (L) and time constant (T). The following is a graph of the characteristics of the turbidity system without a controller.

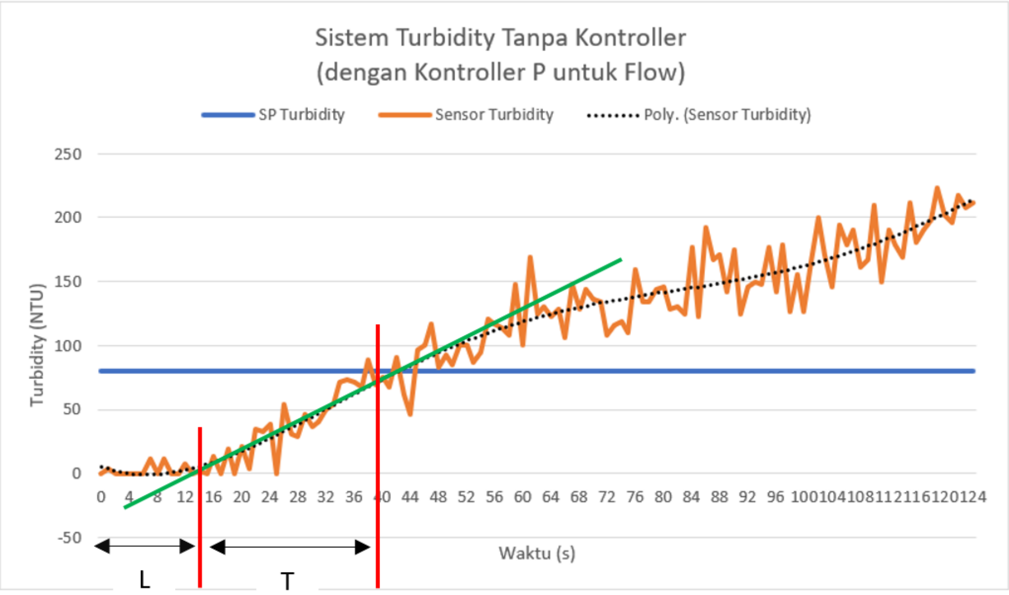


**Figure 9.** Turbidity system graph without controller

**Table 1.** Test results of SEN0189 turbidity sensor

| No | SEN0189 Turbidity Sensor (NTU) | Turbidimeter (NTU) | Error (%) |
|---|---|---|---|
| 1 | Sensor 1 = 751.15 | 752 | 0.11 |
| | Sensor 2 = 753.19 | 752 | 0.16 |
| 2 | Sensor 1 = 496.67 | 496 | 0.13 |
| | Sensor 2 = 496.67 | 496 | 0.13 |
| 3 | Sensor 1 = 399.58 | 400 | 0.10 |
| | Sensor 2 = 398.55 | 400 | 0.36 |
| 4 | Sensor 1 = 295.33 | 293 | 0.79 |
| | Sensor 2 = 293.29 | 293 | 0.09 |
| 5 | Sensor 1 = 204.37 | 205 | 0.30 |
| | Sensor 2 = 205.04 | 205 | 0.02 |
| 6 | Sensor 1 = 144.08 | 147 | 1.98 |
| | Sensor 2 = 146.12 | 147 | 0.62 |
| 7 | Sensor 1 = 103.20 | 103 | 0.19 |
| | Sensor 2 = 100.13 | 103 | 2.78 |
| 8 | Sensor 1 = 42.80 | 45 | 4.8 |
| | Sensor 2 = 41.88 | 45 | 6.93 |
| 9 | Sensor 1 = 0 | 1.97 | 1.97 |
| | Sensor 2 = 0 | 1.97 | 1.97 |
| | Average percentage error of sensor 1 | | 1.15 |
| | Average percentage error of sensor 2 | | 1.45 |

**Table 2.** Test results of YF-S401 waterflow sensor

| No | YF-S401 Water Flow Sensor (L/min) | Calculation (L/min) | Error (%) |
|---|---|---|---|
| 1 | 1.23 | 1.22 | 0.81 |
| 2 | 1.19 | 1.20 | 0.84 |
| 3 | 1.15 | 1.13 | 1.74 |
| 4 | 1.11 | 1.09 | 1.8 |
| 5 | 1.06 | 1.05 | 0.94 |
| 6 | 0.88 | 0.86 | 2.27 |
| 7 | 0.70 | 0.69 | 1.43 |
| 8 | 0.48 | 0.50 | 4.16 |
| 9 | 0.40 | 0.42 | 5 |
| | Average percentage error | | 2.11 |

## Result and Discussion

### SEN0189 Turbidity Sensor Testing

The test was conducted by comparing the output of the SEN0189 turbidity sensor with the HACH 2100Q Portable Turbidimeter.[14]

Based on the test data above, it can be seen that the average percentage error of sensor 1 is 1.15% and the percentage error of sensor 2 is 1.45%. So it can be concluded that both SEN0189 turbidity sensors can work well and are suitable for use.

### YF-S401 Waterflow Sensor Testing

Testing is done by comparing the YF-S401 water flow sensor with a stopwatch by calculating the length of time of the 1L water flow rate from tank B to tank C, where the output line from tank B to tank C is installed with a water flow sensor.

Based on the test data above, it can be seen that the average percentage value of the YF-S401 water flow sensor error is 2.11%, so it can be concluded that this water flow sensor works well and is suitable for use.

### TD-8120MG Motor Servo Testing

The test was conducted by comparing the movement angle of the TD-8120MG servo motor with a 180° arc measuring instrument.[15]

**Table 3.** Test results of TD-8120MG motor servo

| No | Motor Servo TD-8120MG Angle (°) | Arc Ruler Angle (°) | Error (%) |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 2 | 20 | 21 | 5 |
| 3 | 45 | 48 | 6.6 |
| 4 | 60 | 62 | 3.3 |
| 5 | 90 | 93 | 3.3 |
| 6 | 100 | 100 | 0 |
| 7 | 130 | 130 | 0 |
| 8 | 140 | 140 | 0 |
| 9 | 145 | 148 | 2.07 |
| 10 | 175 | 175 | 0 |
| | Average percentage error | | 2.03 |

Based on the test data in Table 3, it can be seen that the TD-8120MG servo motor is feasible to use, as evidenced by the small average percentage value of the servo angle error of 2.03% compared to the arc measuring instrument.

### Relay Testing

The purpose of this test is to determine the performance of the relay. Testing is done by changing the input logic of the relay, namely HIGH logic and LOW logic, and then observing the condition of the water pump.

**Table 4.** Test results of relay

| Relay Condition | Water Pump Condition |
|---|---|
| LOW | ON |
| HIGH | OFF |

Based on the test data in Table 4, it is obtained information that when the logic value of the relay is HIGH, the water pump does not turn on (off). Meanwhile, when the logic value of the relay is LOW, the water pump will be active (on). So it is known that this relay circuit is active when given a LOW trigger, and inactive when given a HIGH trigger. Therefore it can be concluded that the relay circuit functions properly and is suitable for use to turn on or turn off the water pump.

### L298N Motor Driver Testing

Testing is done by changing the PWM value and measuring the output voltage. The purpose of testing the motor driver is to ensure that the motor driver can function properly.

**Table 5.** Test results of L298N driver motor

| No | PWM Value | Output Voltage (V) |
|---|---|---|
| 1 | 0 | 0.04 |
| 2 | 20 | 6.88 |
| 3 | 40 | 7.53 |
| 4 | 60 | 8.25 |
| 5 | 80 | 8.92 |
| 6 | 100 | 9.49 |
| 7 | 120 | 10.04 |
| 8 | 140 | 10.5 |
| 9 | 160 | 10.91 |
| 10 | 180 | 11.24 |
| 11 | 200 | 11.51 |
| 12 | 225 | 11.71 |
| 13 | 255 | 11.75 |

Based on the test data in Table 5, it can be seen that the greater the PWM value used, the greater the motor driver output voltage, so the DC motor rotation will also be faster. Vice versa, the smaller the PWM value used, the smaller the motor driver output voltage, so the DC motor rotation will also be slower.

**Overall Testing**

From the test results that have been carried out, it shows that the process of mixing clear water and turbid water in tank C four times produces a large enough error value of around 60% to 80% for the water turbidity variable. This is because the SEN0189 turbidity sensor is less sensitive to small changes and experiences floating ADC value readings even in the absence of noise. The ADC value of this sensor is converted to voltage, where each 1mV represents a turbidity value of 10 NTU so that when there is a floating change in the value of 3mV, there will be a change in turbidity value to 30 NTU. The value of 30 NTU when compared to the setpoint, there is an error of 37.5%. While the test results for the flow variable produce a relatively small error value of around 11% to 15%. This is because the inner loop uses type P controller which has the characteristics of a fast rise time so that the settling time is also fast, but the P controller does not make corrections to small errors.

In this research, a capacitor component has been added which is installed in parallel to the water pump load and servo motor. The purpose of adding this capacitor component is to reduce system noise. Based on the results of our system testing, the capacitor component can reduce the noise from the load (servo motor and water pump), but the cause of the high system error from the steady state is the inaccurate reading of the water turbidity value by the SEN0189 sensor and the selection of an inappropriate control method. Therefore, it is recommended to use a water turbidity sensor whose working principle is not based on light, in addition to using a control method that is suitable for fast system response and can perform predictive control.

## Conclusion

The application of the cascade control method to the water turbidity level regulation system plant is not going well because a large steady-state error is generated, which is around 60%. This can occur because the plant water turbidity level regulation system requires a response that tends to be fast, which is less than 30 seconds has reached the desired turbidity value. The large steady state error (60%) in the application of the cascade control method in this water turbidity system plant can also occur due to the accuracy of the SEN0189 turbidity sensor which can only read every change in water turbidity value of 10 NTU. In addition, when the system does not have noise from the load, the turbidity sensor reading can also occur floating data either up or down by 20 NTU to 30 NTU. Especially when there is noise from the servo motor load, the turbidity sensor reading will have an error of up to 60 NTU.

## Acknowledgement

My gratitude goes to all lecturers who have helped in the process of designing and testing this tool. My thanks also go to my parents, family, and friends who always provide support and prayers so that I can complete the design of this tool well.

**Table 6.** Test results of the entire system using the cascade control method

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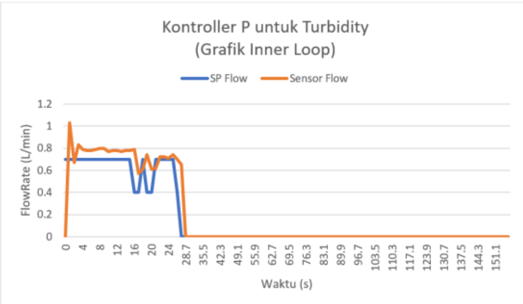
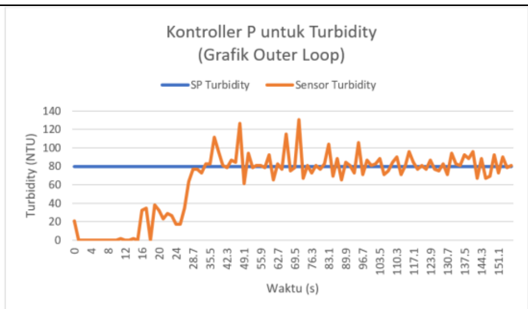
<tr><td>1st test</td><td>
</td><td>
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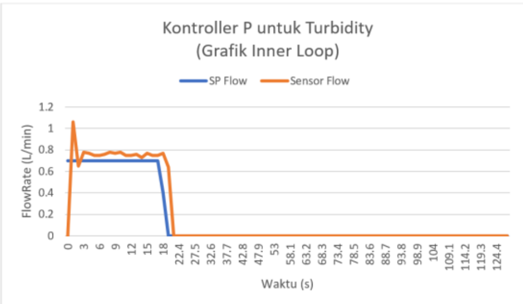
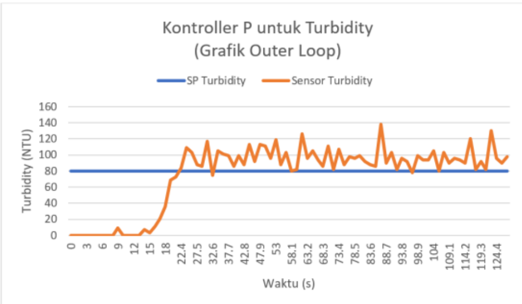
<tr><td>2nd test</td><td>
</td><td>
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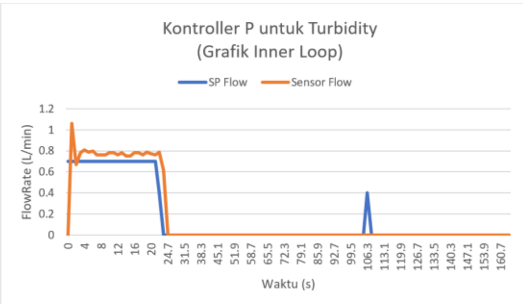
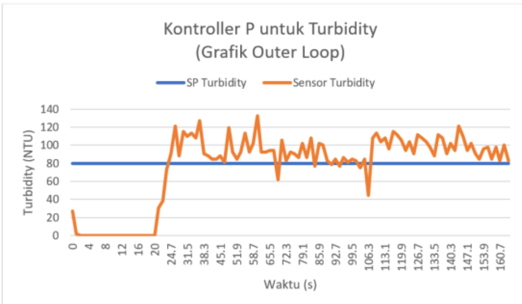
<tr><td>3rd test</td><td>
</td><td>
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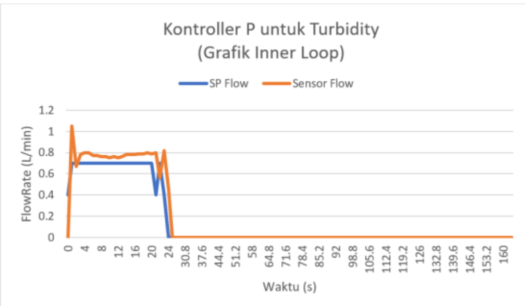
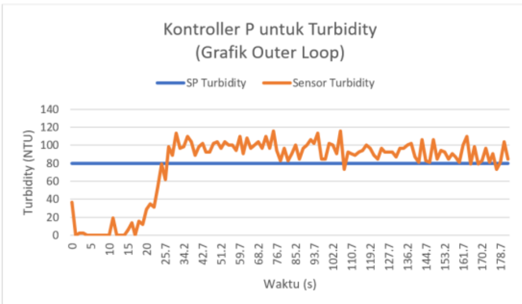
<tr><td>4th test</td><td>
</td><td>
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**Table 7.** System response results using the cascade control method

| Test number | System | Delay Time (s) | Rise Time (s) | Settling Time (s) | Error Steady State (%) |
|---|---|---|---|---|---|
| 1st test | Flow | 1 | 3 | 4 | 15% |
| | Turbidity | 20 | 14 | 30 | 60% |
| 2nd test | Flow | 1 | 2 | 3 | 11% |
| | Turbidity | 18 | 6 | 21 | 80% |
| 3rd test | Flow | 1 | 2 | 3 | 11% |
| | Turbidity | 21 | 3 | 23 | 60% |
| 4th test | Flow | 1 | 2 | 3 | 13% |
| | Turbidity | 21 | 5 | 24 | 80% |

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