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CONTROLLING TWO CHAMBERS TANK DEBIT BY ETHERNET WITH PROPORTIONAL INTEGRATIVE CONTROL METHOD

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Abstract

This paper proposes a proportional integrative control method for two chambers tank by Ethernet using Arduino. An Ethernet module was used for data communication between PC and twin tank. An ultrasonic sensor was mounted in top of two chambers tank to measure a height that can be converted to calculate the debit of the water. We make a dynamic model of the twin tank using linearization model. Then, from the linearized model, we control the debit of the twin tank using proportional integrative (PI) controller to meet required responses.

Keywords: linearization; debit control; PI controller

1. Introduction

The water needs cannot be avoided. Everyone would need water, either for drink, food, bathing, washing clothes or for other daily necessities. In some areas it is still difficult to get clean water-even it is possible that the water is not evenly distributed resulted from bad distribution. Regarding the issues, we want to make a tool that is able to control the amount of output water flow. The debit is regulated via web browser, to determine the amount of output discharge that can be arranged remotely via the internet. Therefore, people can get water by the amount they desire, which can be set via remote.

In this paper, we make such a tool to control the debit of twin tank by Ethernet with proportional integrative control method. This tool is designed to use two tanks, which are connected by pipes underneath. The hole sections at the upper part are aimed at adjusting the water pressure in the first tank and the second tank. Meanwhile, the bottom of the pipe is for draining the water from the first tank to the second tank. When water flows from the first tank to the second tank then there will be differences in altitude. This difference is used to measure the flow of water with Arduino [1] that will be used to control the speed of the water pump motor.

This tool needs a tool that is able to measure the height of the water inside chambers. Therefore, the authors chose to use ultrasonic sensor as the measurement tool. It is used for the control process, i.e. as the feedback of the measurement, and give input data to controller to control the speed of the pump motor, where we use a PI control method. Because the dynamic system of twin tank is nonlinear, we use linearization to make the system linear, so that it may simplify the control system. To meet a certain response, we need to adjust the gain of proportional and integrative controller so that the rising time and the settling time will be shorter and the overshoot is considered small [2].

2. System Description

2.1 Basic Theory

The first theory used is the Bernoulli equation to calculate the flow rate of liquid coming out of the bottom of a container (see Fig. 1).

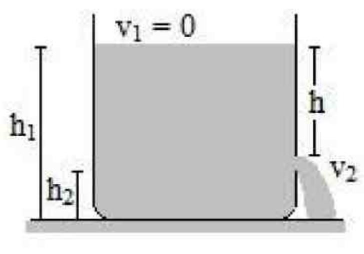

Fig. 1. Scheme of a Water Tank and Its Output Flow

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Bernoulli equation [3] is applied to the surface of the container and the surface of the hole. Because the diameter of the hole at the base of the container is smaller than the diameter of the container, then the flow velocity at the surface is considered zero ($v_1 = 0$). The surface of the container is an open pit so that the pressure is assumed to be equal to the atmospheric pressure ($P_1 = P_2$) and follow Bernoulli's equation [4]:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 \tag{1}$$

From equation (1), we get the equation speed of water flowing in a tank as follow:

$$v_2 = \sqrt{2gh} \tag{2}$$

where v_2 denotes the speed of water flow, g is gravitation, and h is height from above the hole to the water surface.

2.2 System

The realization of this idea is a system that can maintain its output water flow. This can be done by adjusting the desired amount of output discharge through a web browser on a PC. By pressing a button on a web browser the amount of output discharge can then be regulated. Whenever the button is pressed, there will be any commands to Arduino to regulate the amount of water flow.

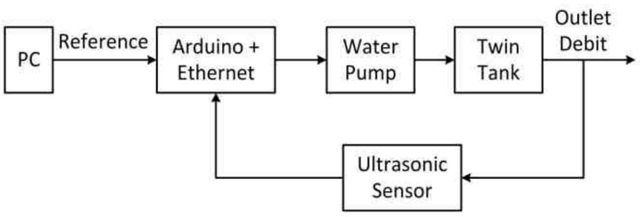

Fig. 2. Block Diagram of the System

From the block diagram of the system as shown in Fig.2, it can be seen that the data on the web browser/PC will be sent to Arduino via Ethernet shield using RJ-45 cable and set as input discharge. In Arduino the elevation of the data on water in tanks will be processed using ultrasonic sensors. The first ultrasonic sensor detects the water level in the tank. Then, the height of the water in the tank will be converted into effluent discharge, using the formula as in the previous chapter. Cross-sectional surface area of the output water flow must also be calculated in advance. After the cross-sectional area is known, we can make the system of the two chamber tank dynamic model as shown below (see Fig. 3)

$$\frac{\text{a1.dh}}{\text{2.dt}} = qo_0 - qo1 \tag{3}$$

$$\frac{a1.dh}{2.dt} = qo_0 - a2\sqrt{2gh} \tag{4}$$

By using Taylor's series expansion, we have a linearized model as shown in equation [5]

$$\frac{dh}{dt} + \frac{2.a2}{a1}\sqrt{2gh} = \frac{2.qo_0}{a1} \tag{5}$$

The solution of linear first-order differential equation above is as follow

$$h(t) = \frac{k_2}{k_1}(1 - e^{-k_1 t}) \tag{6}$$

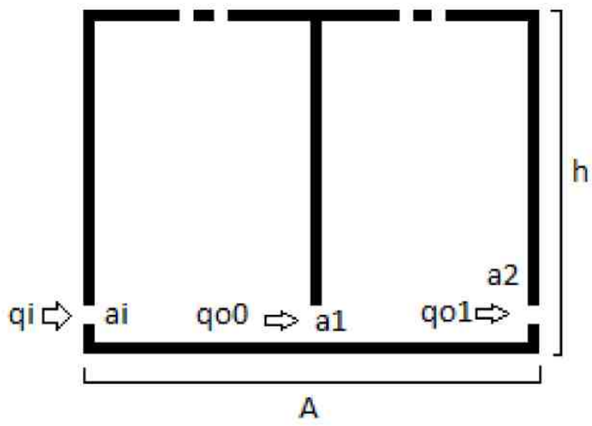

Fig. 3. Twin Tank Model

where

$$k_1 = \frac{2.a_2}{a1} \cdot \frac{\sqrt{2g}}{2h^{\frac{1}{2}}} h \tag{7}$$

$$k_2 = \frac{2.qo_0}{a1} \tag{8}$$

Table 1. Parameter of Twin Tank

qi	Input debit
qo0	Output debit first tank
qo1	Output debit second tank
ai	Circular area input
a1	Rectangular area for output debit qo0
a2	Circular area output
h	Tank's height
A	Bottom Tank's area

After feedback and output water flow is known, then we can go to the next process that is controlling the proportional integrative–method. The controlling process involves the calculation of error value, After that, the data will be processed again by using the proportional constant and integrative constant. Proportional constant is used to speed up rising time and output integrative constant is used to stabilize water flow.

After all the data is processed in Arduino, the water pump speed will then be obtained. To be able to control the speed of the water pump, it would require a DC motor driver. The driver will control the pump speed in accordance with the data that has been processed in the previous integrative proportional control. Accordingly, the water will turn the motor pump and will pump water from the storage tank to tank data processing or two chambers tank. The process will continue from this point until the desired output water flow is reached accordingly.

3. Result

Before we test the twin tank, we make a simulation to illustrate the response of the system, as shown in Fig. 3. It shows the time required for water to fill the second layer of the twin tank, represented by the height of the water. If the debit is bigger, the height will be higher, but it will take more time to reach the specific height.

3.1 Simulation

From equation (6) we can set a different height in simulation. From Fig. 4 we can see that every time height increases, the rising time will increase because the water must fill the tank on the first column, so it will take time to reach the reference height and the settling time will be longer than that of the lower height as reference.

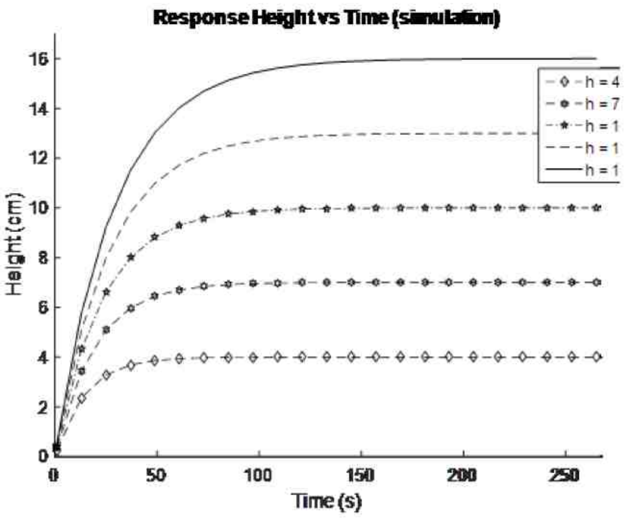

Fig. 4. Simulation of response height vs time

3.2 Simulator

Making the interface on the internet [6] is an important stage in this final project. A few keys will be given at the interface of this tool to adjust the flow of water we want. Once the button is pressed, it will send you the information [7] that will be read by the system so that the water will discharge in accordance with the desired water discharge, the water flow is regulated through the tool interface [8].

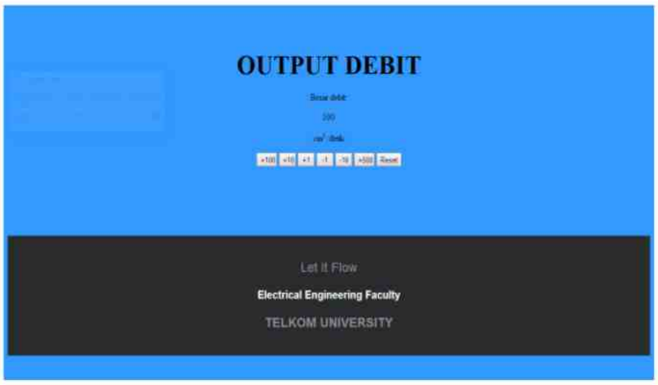

Fig. 5. Graphical user Interface

In accordance with the purpose of making this tool, which is making a powerful tank that can be used to store water without any leakage and secure for electronic components that will support the system, the water tank that can hold water without any leakage was then invented.

Fig. 5. Mechanical Twin Tank

The tool test used a measuring cup with a capacity of 2 liters with a resolution of 20 ml. To test how, we set the large debit in web browser and to test when the system was stable, we measured output water discharged per second from the system by using a measuring cup. How to test that, first set the timer for one second. When the timer starts counting, immediately place the measuring cup right at the end of the output water discharge. Once the timer goes off or hits one second, take a measuring cup and see how the volume of water. See and measure the volume of water then we can find out the flow of water per second output. After all the tools are available and installed, then do some tests on components of the distance measuring tools and finally test the system.

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Table 2. Ultrasonic Sensor Test

Height (cm)	Height in Sensor (cm)
5	5
10	10
15	15
20	20
25	25

After the experiment in measuring an object distance had been conducted and the results had also been obtained in accordance with the actual situation, then the experiment was continued to the next stage. The next stage was to measure the limits of experimental control of this water discharge. The data resulted from the experiment are as follows:

Table 3. Parameter Values

Input debit max	1051,50 mL/s
Output debit max	1051,43 mL/s
Height max	18 cm
Height min	3 cm
Gravitation	9,36 ms^2
P (proportional gain)	2
I (integral gain)	3
ai	5.72 cm^2
a1	90 cm^2
a2	5.72 cm^2
A	1800 cm^2
h	45 cm

Integrative and proportional constants were obtained by trying all proportional constants starting from zero to eventually obtain appropriate constant value which is able to provide better output water flow. We conducted some tuning of the PI controller, and examined the response of the system in order to choose the most suitable PI gain for our controller.

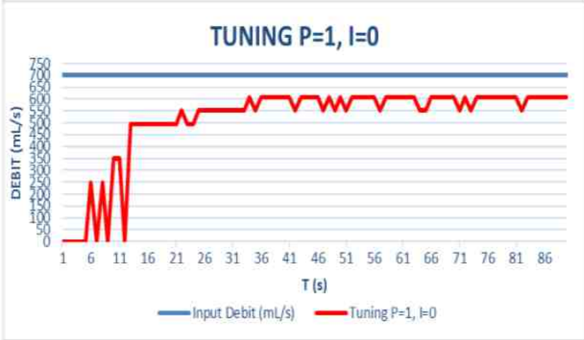

Fig. 6. Tuning P=1, I=0

The first step of this experiment is determined by proportional constant of one and integrative constant of zero. In Fig. 6 the blue line ~~is~~ refers to a discharge that we set in the web browser. While the red line shows the water discharge system with an output constant which had been determined previously. It can be seen that water effluent discharge in the system is still too small compared to the input discharge and rising time of the system is not big enough. That is because the proportional constant is too small. Accordingly, the output had not reached the water discharge desired.

The second trial is determined by proportional constant of two and integrative constant of zero. In Fig. 7, the blue line refers to a discharge that we set in the web browser. While the purple line shows the water discharge system with an output constant which had been determined previously.

Fig.7. Tuning P=2, I=0.

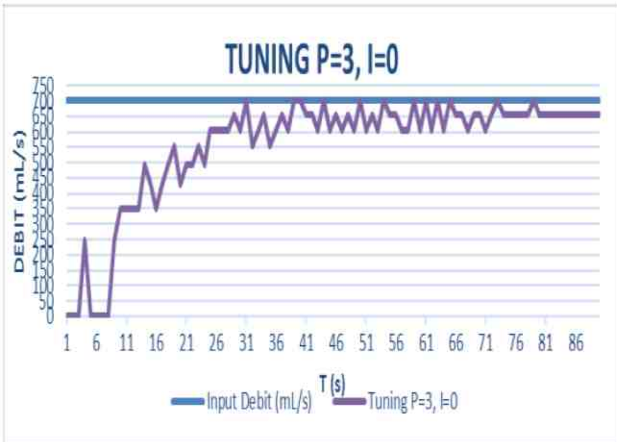

Fig. 8. Tuning P=3, I=0

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It can be seen that water effluent discharge in the system is still too small compared to the input discharge and rising time of the system is not big enough. That is because the integrative constant is still too small. Consequently, the output had not touched water discharge desired and was not yet stable.

The third trial is determined by the set of proportional constant of three and integrative constant of zero. In Fig. 8, the blue line refers to a discharge that we set in the web browser, while the purple line shows the water discharge system with an output constant which had been determined previously. It can be seen that water effluent discharge in the system had started to reach input discharge, but was still not stable. That is because the proportional constants had started to be appropriate, while the integrative constant was zero. Thus, the output water flow started to reach the water flow desired, but was not yet stable.

Fig. 9. Tuning P=2, I=1

The fourth one is determined by set of proportional constant of two and integrative constant of one. In Fig. 9, the blue line refers to a discharge that we set in the web browser, while the green line shows the water discharge system with an output constant which had been determined previously. It is seen that the water flow in the system output had reached a debit input, but was still not stable. That is because the proportional constants had started to be appropriate, while the integrative constant was still small. So, the output water flow started to reach the water flow desired, but was not yet stable.

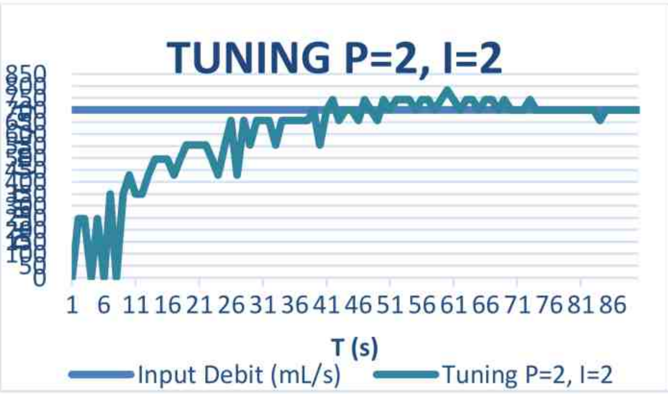

Fig. 10. Tuning P=2, I=2.

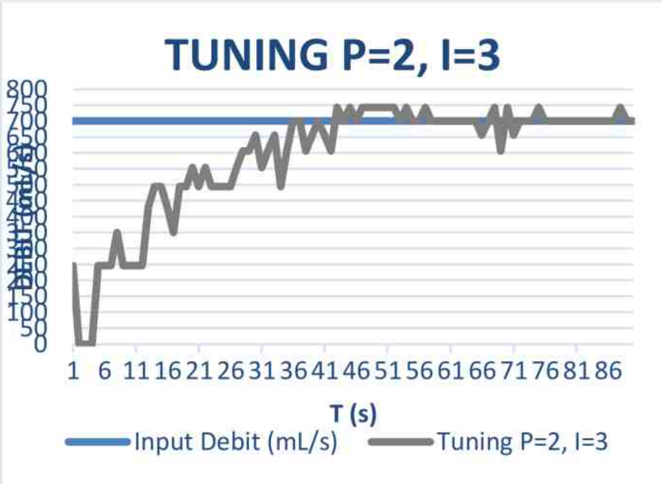

Fig. 11. Tuning P=2, I=3.

The fifth one, however, is determined by the set of proportional constant of two and integrative constant of two. In Fig. 10, the blue line refers to a discharge that we set in the web browser–while the dark blue line shows the water discharge system with an output constant which had been determined previously. It is seen that the water flow in the system output had touched a debit input, but was still not stable. That is because the proportional constants had started to be appropriate, while the integrative constant was still small. Accordingly, the output water flow began to reach the water flow desired, but was not yet stable.

The sixth experiment is determined by the set of two proportional constants and three integrative constants. In Fig. 11, the blue line refers to a discharge that we set in the web browser, while the gray line shows water discharge system with an output constant which had been determined previously. It is seen that the water flow in the system output had reached the input and stable discharge. That is because he proportional and integrative constants had been appropriate. Consequently, the output water flow reached the desired water flow and became stable.

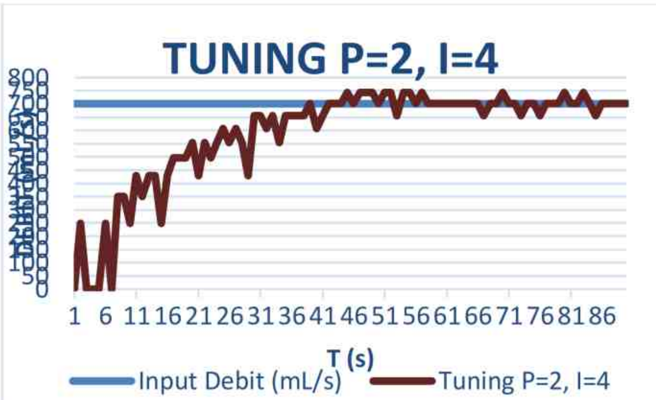

Fig. 12. Tuning P=2, I=4.

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The seventh trial is determined by proportional constant of two and integrative constant of four. In Fig. 12, the blue line refers to a discharge that we set in the web browser while the brown line shows the water discharge system with an output constant which had been determined previously. It is seen that the water flow in the system output had reached a debit input, but began unstable. That is because the proportional constants were appropriate, while the integrative constant had exceeded the limit. Accordingly, the output of the water discharge reached the unwanted amount and was not stable.

Therefore, having analyzed–the proportional constant of two and integrative constant of three, the right output water discharge that are in accordance with the desired output may then be reached, while the water flow also becomes stable.

When an experiment to measure the limits and determination of the constants have been met, then do the next experiment, i.e. an experiment in controlling the flow of water in the tank. The experiment will show the desired water flow, the water flow read by the system, the water level in the tank, the output speed of the water, and the water flow measured by a measuring cup. The results of the experiments are as follows:

Table 4. Debit measurement vs height

No	Height (cm)	Debit Output (mL/s)	Water Speed (cm/s)
1	0	0	0
2	1	247,82499	43,26662
3	2	350,47746	61,18823
4	3	429,24548	74,93997
5	4	495,64998	86,53323
6	5	554,15353	96,74709
7	6	607,04477	105,98113
8	7	655,68330	114,47270
9	8	700,95493	122,37647
10	9	743,47497	129,79985
11	10	783,69143	136,82105
12	11	821,94251	143,49913
13	12	858,49095	149,87995
14	13	893,54571	156,00000
15	14	927,27621	161,88885
16	15	959,82206	167,57088
17	16	991,29997	173,06646
18	17	1021,80862	178,39282
19	18	1051,43239	183,56470

Experiments were conducted by determining the desired discharge to be measured by the system and the measuring cup, the experiment is as shown in Table 5.

Table 5. Responses of Twin Tank vs Set Point

NO	Set Debit (mL/s)	Rise Time (s)	Steady State Time (s)	Output Debit in measuring cup (mL/s)
1	495,64	17	35	500
				480
				500
				510
				500
2	554,15	21	43	540
				600
				540
				540
				540
3	607,04	24	45	600
				620
				600
				610
				620
4	655,68	29	59	640
				640
				640
				660
				640
5	700,95	35	77	680
				700
				710
				700
				700
6	743,47	43	72	720
				740
				760
				740
				740
7	783,69	52	77	800
				800
				780
				780
				800
8	821,94	66	81	820
				820
				840

				820
				820
9	858,49	76	98	850
				860
				840
				850
				860
10	893,54	85	99	880
				910
				900
				900
				900
11	927,27	100	121	920
				940
				920
				930
				920
12	959,82	127	143	940
				960
				940
				940
				960
13	991,29	147	159	1000
				1010
				980
				980
				1000
14	1021,80	188	205	1020
				1040
				1040
				1020
				1000
15	1051,43	256	267	1040
				1050
				1060
				1040
				1040

Power consumption of these tools can be divided in advance by parts. There are 2 parts:

Microcontroller = 9 Watt

Pump = 96 Watt

4. Conclusions

The two chambers tank has been built and tested. From the result shown in Table 5, we conclude that the twin tank model can be used to control the debit of water that provides good response from several tuning of the PI controller (P=2 and I=3). The system meets the design specification. The larger the output water flow, the higher rising time will be. It is because the water should reach a certain height of the first layer tank before finally reach the set point of the debit. The experiment result is finally led to a linearization model as we can see from the chart. So, the linear model can be used to control debit in this model.

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