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Technical Note

Studies on System Identification of Multiple Input Multiple Output (MIMO) Water Tank

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Abstract: In this study, the system identification of a multiple input multiple-output (MIMO) water tank has been investigated. The given experimental system is a first-order system. Its transfer function was evaluated and the time constant was predicted. Once the parameters of the transfer functions (delay, gain, and time constant) were determined for each step input. This model each of the step responses using MatLab's Simulink. These simulated responses were then compared to the observed experimental responses.

Keywords: MIMO, Time Constant, Delay and Gain

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1. Introduction

The objective of this experiment was to identify key system characteristics such as outlet flow, gain, delay, and time constants for multi-input multi-output (MIMO) water mixing tank apparatus. This was done by observing the relationships between cold water (CW)-to -level, hot water (HW)-to-level, CW-to-temperature, and HW-to-temperature. These relationships were examined with the LabVIEW program. The LabVIEW program is a graphical programming platform that is useful to scale from design to test and from small to large systems. It is ideal for the measurement of control systems (ni.com, 2013)[2]. The experimental data were recorded in Excel format with DataLogger.

The MIMO water mixing tank apparatus is illustrated in figures 1, 2, and 3. The controlled variables were two water supplies going into the tank; one hot and one cold. These were controlled with the LabVIEW program. The drain leaving the tank was left in the fully open position throughout the experiment. The measured variables (tank level and water temperature) were measured with le LabVIEW program. The disturbance variables for the system were the temperatures of the inlet streams, Th and Tc. Most industrial control applications involve MIMO. Modeling MIMO processes is no different conceptually than modeling SISO (single-input/single-output) processes (Seborg et al., 2011)[1].

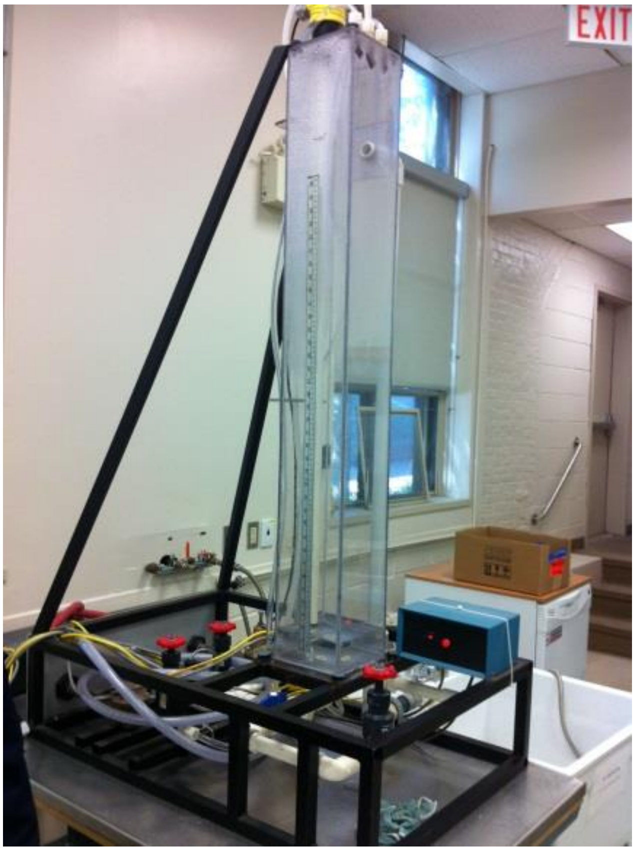

Figure 1. Tank

Figure 2. Hot and Cold Valves

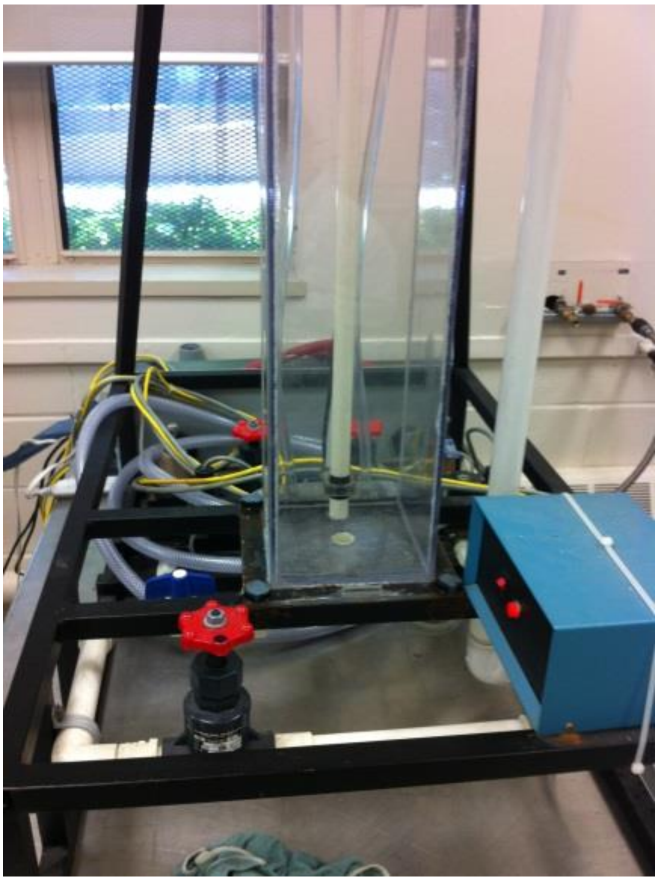

Figure 3. Drain Valve

Before starting the experiment, we waited for the system to stabilize and reach a steady state for both “Uc” and “Uh” (hot water flow and cold water flow) at 2V. We then added a step change to the system by changing the cold water feed to Uc = 3V. Once the new steady state was achieved, another step-change was introduced by changing Uc back to 2V. This procedure was repeated for Uh from 2V to 3V to 2V, Uc from 2V to 4V to 2V, and Uh from 2V to 4V to 2V. Measurements were continuously monitored with the LabVIEW program.

The delay (also known as dead time) is defined as the moment that lapses between input changes and process responses. For our system, the delay was the moment that elapsed between variations of the controlled variables (HW flow and CW flow) and the process response of the measured variables (tank level and water temperature). The processing time constant, T, is the time required to reach 63.2% of the steady-state value. Once the steady-state value is determined, the time constant can be found by locating 63.2% of this value on a process response curve. The time corresponding to this point is the time constant. For this experiment, time constants were calculated for each of the step inputs previously described.

The experimental system was a first-order system. First-order systems are systems whose dynamics are described by the following transfer function:

$$G(s) = \frac{output}{input} = \frac{K}{\tau s + 1}$$

Where K is the system’s steady-state gain and T is the time constant. The gain measures the magnitude of the change in steady-state from state 1 to state 2. In other words, it is the amplitude of the step response. The gain was determined for each of the step inputs from the step response curves.

Once the parameters of the transfer functions (delay, gain, and time constant) were determined for each step input that models each of the step responses using MatLab's Simulink. These simulated responses were then compared to the observed experimental responses.

2. Results

The graphs (Figures 4, 5, 6, 7, 8, 9, 10 and 11) were plotted using the data recorded from the lab. Each step was plotted from the time the valve was opened until the time the level and temp returned to a steady state at the original valve settings. This resulted in eight graphs (Figures 4, 5, 6, 7, 8, 9, 10 and 11) being produced. For every time a valve was opened and closed there is a graph of time versus level and time versus temperature. For each graph, the steady-state gain was calculated, which is just the overall change in either level or temperature, after the system returned to steady-state. With these values, it is possible to calculate the time constants by finding the time it took to reach 63.2 percent of the steady-state gain. There was no significant delay observed. Had there been a more noticeable delay this value would have been subtracted from the apparent time constant found from the gain. The overall system order of all models is first order. The time constants for the second temperature gain (the down step) were estimated from the graph because the data was too noisy.

Table 1. Gain and Time Constant Data

Height	Cw 2-3-2	Hw 2-3-2	Cw 2-4-2	Hw 2-4-2
Gain 1(cm)	5.088	3.933	4.679	6.061
Time Constant(s)	117	147	119	126
Gain 2(cm)	-3.8	-3.75	-4.5	-5.7
Time Constant(s)	108	110	156	73
Temperature				
Gain 1(cm)	-1.3	1.7	-1.25	3
Time Constant(s)	33.38	97.47	80.796	86.38
Gain 2(cm)	2	-1.5	1.25	-2.45
Time Constant(s)	120	155	190	210

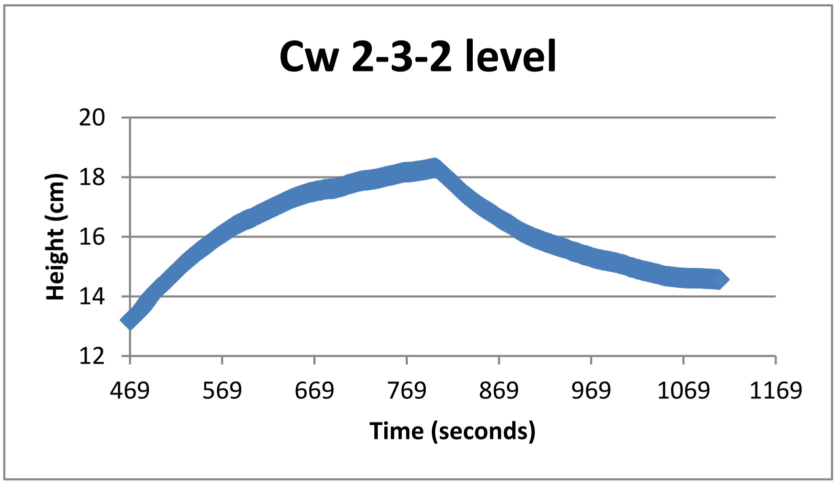

Figure 4. Tank Level vs. Time for Cold Water Valve 2V -> 3V -> 2V

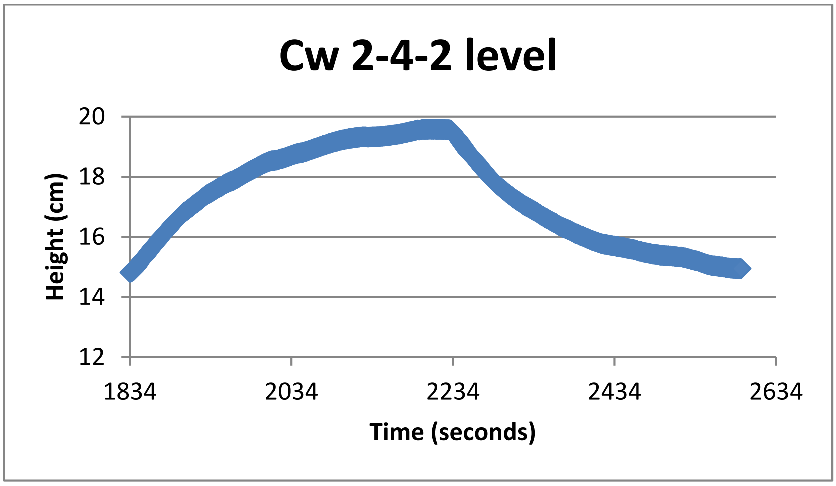

Figure 5. Tank Level vs. Time for Cold Water Valve 2V -> 4V -> 2V

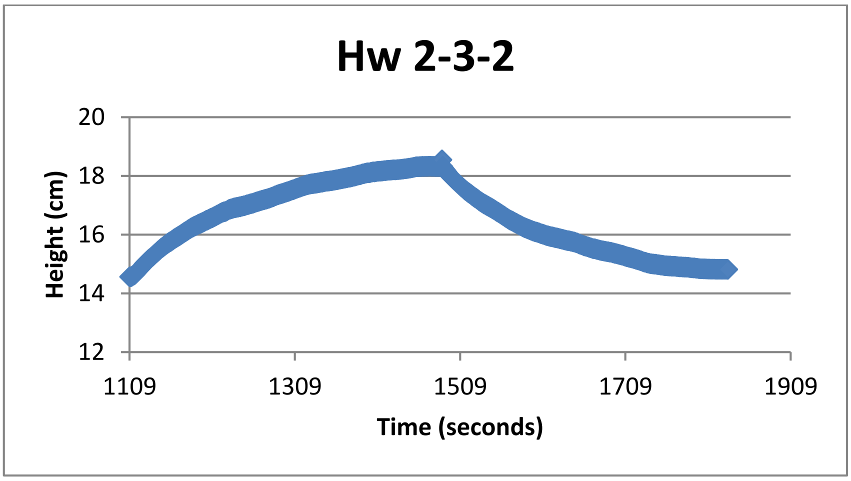

Figure 6. Tank Level vs. Time for Hot Water Valve 2V -> 3V -> 2V

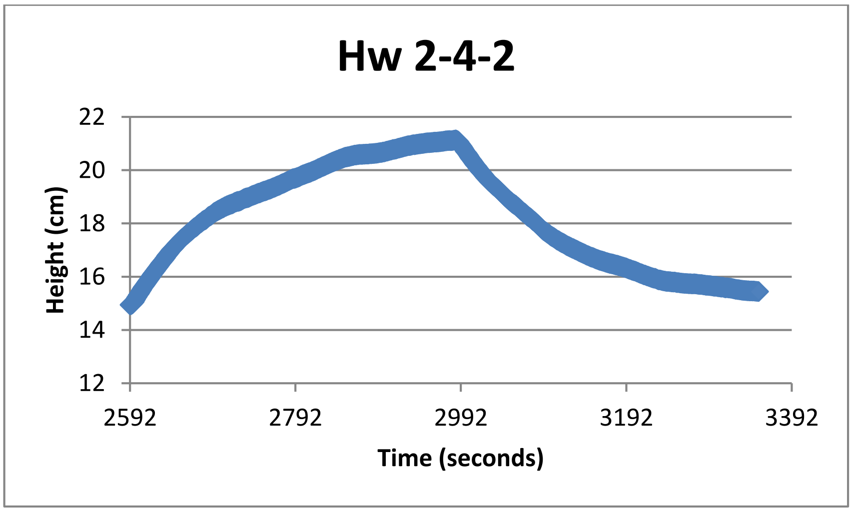

Figure 7. Tank Level vs. Time for Hot Water Valve 2V -> 4V -> 2V

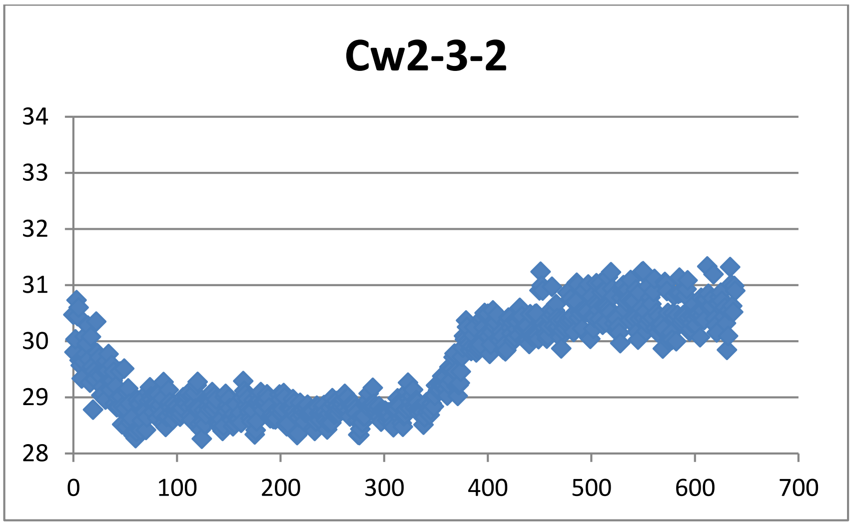

Figure 8. Tank Level vs. Temperature for Cold Water Valve 2V -> 3V -> 2V

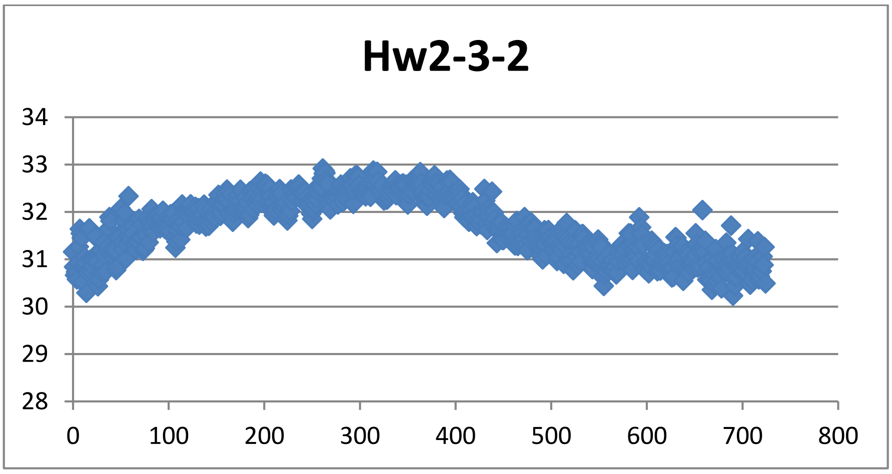

Figure 9. Tank Level vs. Temperature for Hot Water Valve 2V -> 3V -> 2V

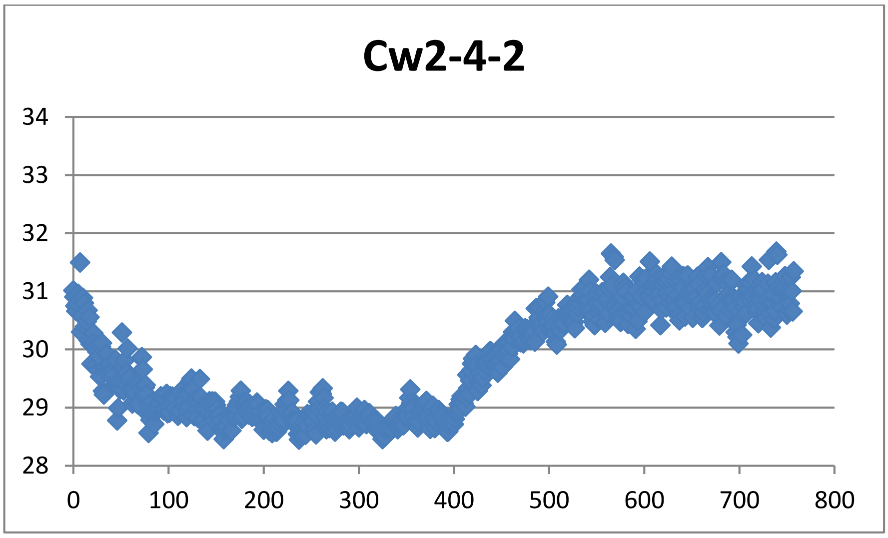

Figure 10. Tank Level vs. Temperature for Cold Water Valve 2V -> 4V -> 2V

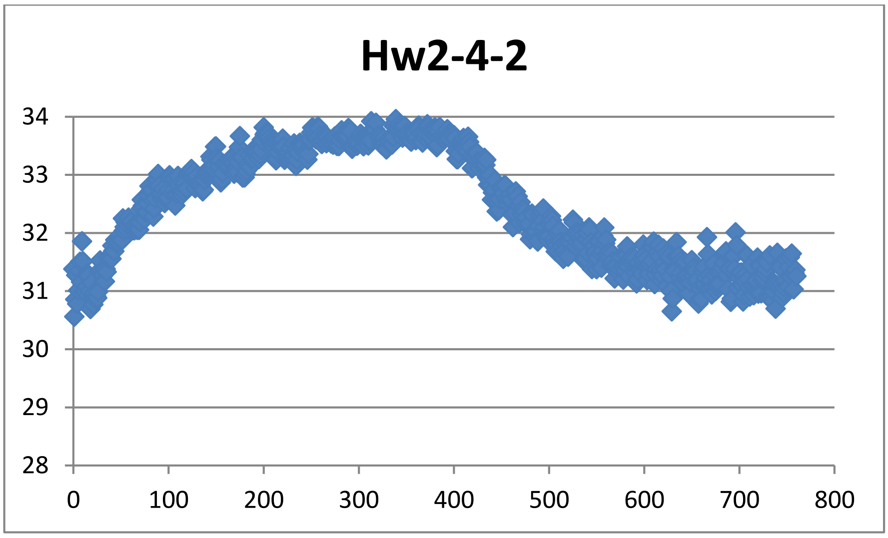

Figure 11. Tank Level vs. Temperature for Hot Water Valve 2V -> 4V -> 2V

3. Observations and Discussions

The level system gains are very close to equal in magnitude for both hot and cold water valves after being manipulated to 3V and equal but opposite when the valves were returned to 2V, the step to 4V and back to 2V has the same characteristics as the smaller step but a greater magnitude of steady-state gain. The temperature system gains are similar in magnitude for each step size but opposite in direction as the temperature is rising with the opening of the hot water valve and falling with the opening of the cold water valve and then returning to its original state when the valves are closed.

Using SIMULINK/MATLAB a step-change response of models was created using the identified delay, gain, and time constant. Because the system had no noticeable delay it was only necessary to input the gain and time constant obtained from the experiment. Below are the simulations of the different step inputs to either level or temperature.

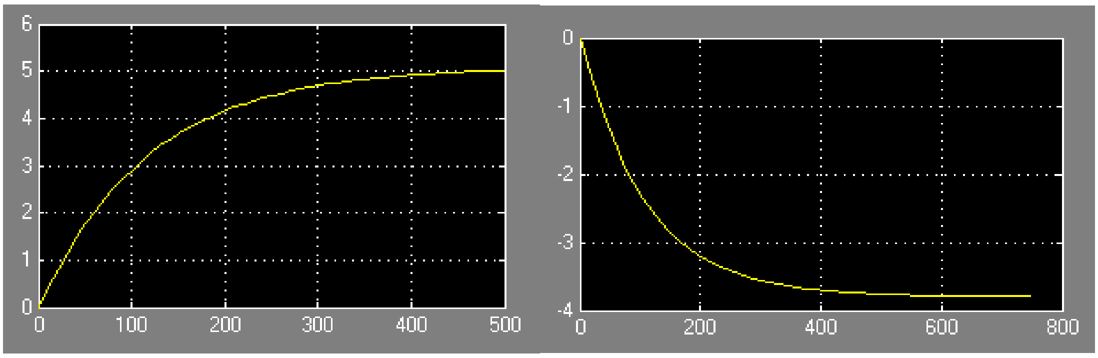

Figure 12. Cold water valve 2-3-2 (Time(s) vs. Level (cm))

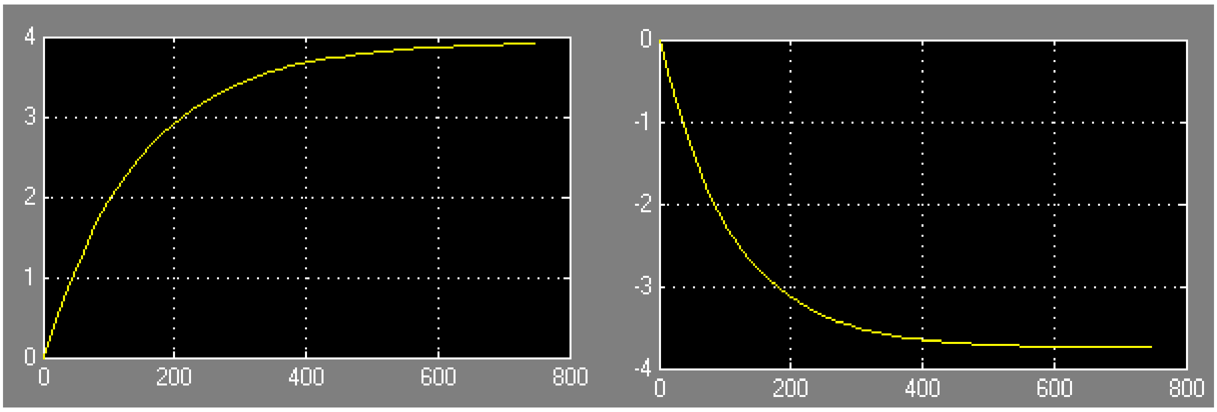

Figure 13. Hot water valve 2-3-2 (Time(s) vs. Level (cm))

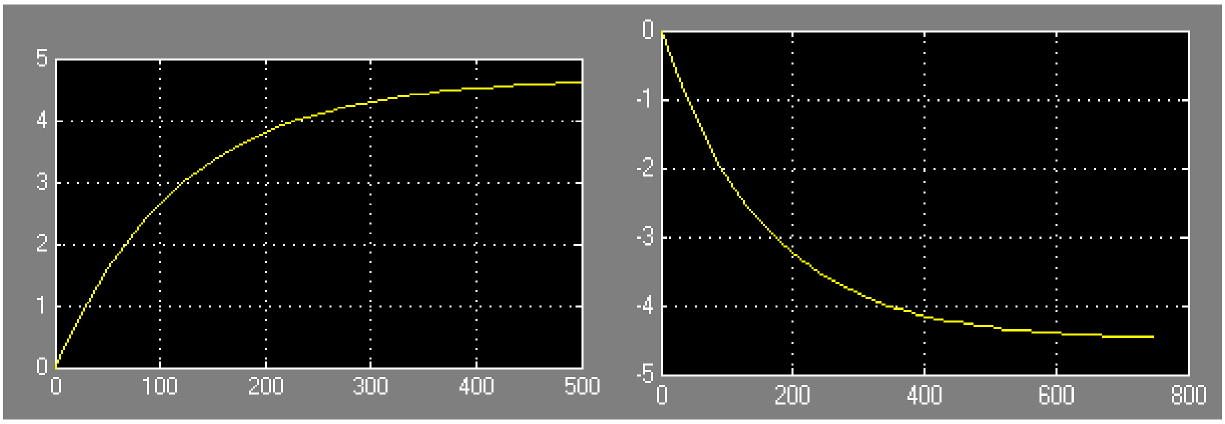

Figure 14. Cold water valve 2-4-2 (Time(s) vs. Level (cm))

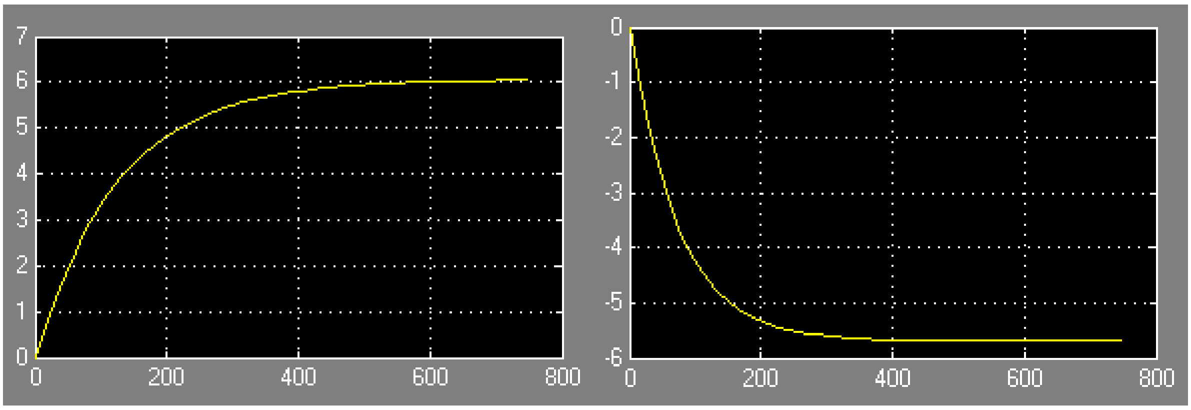

Figure 15. Hot water valve 2-4-2 (Time(s) vs. Level (cm))

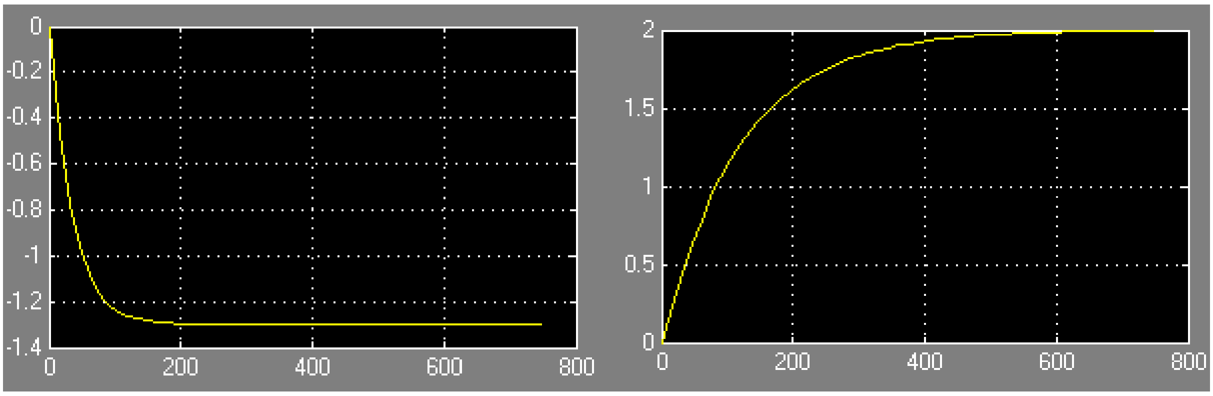

Figure 16. Cold water valve 2-3-2 (Time(s) vs. Temperature (°C))

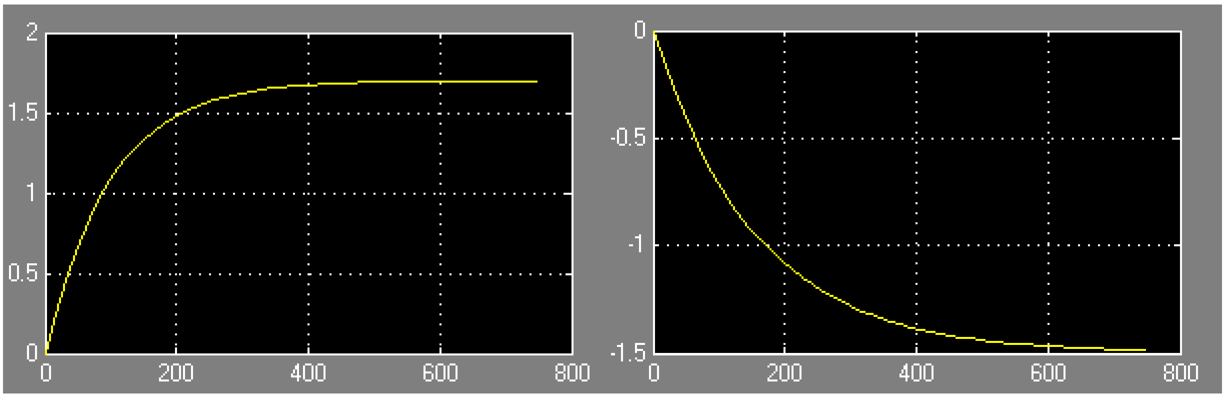

Figure 17. Hot water valve 2-3-2 (Time(s) vs. Temperature (°C))

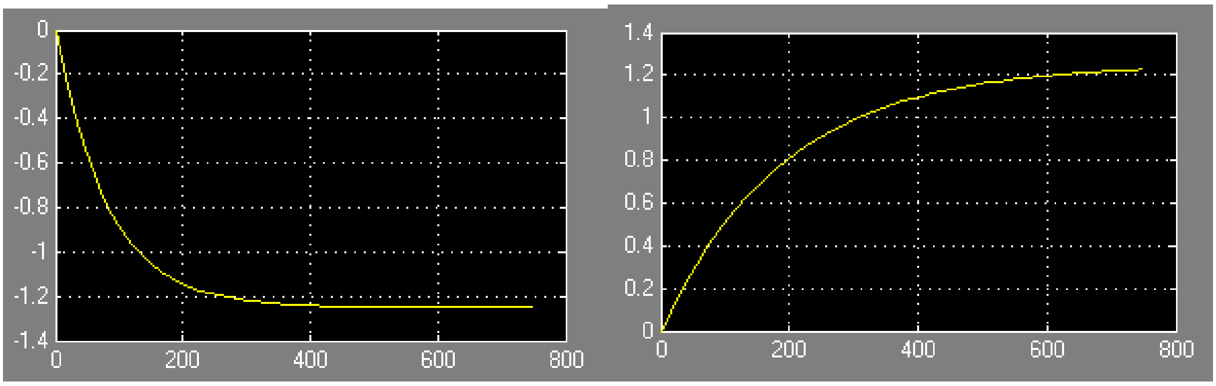

Figure 18. Cold water valve 2-4-2 (Time(s) vs. Temperature (°C))

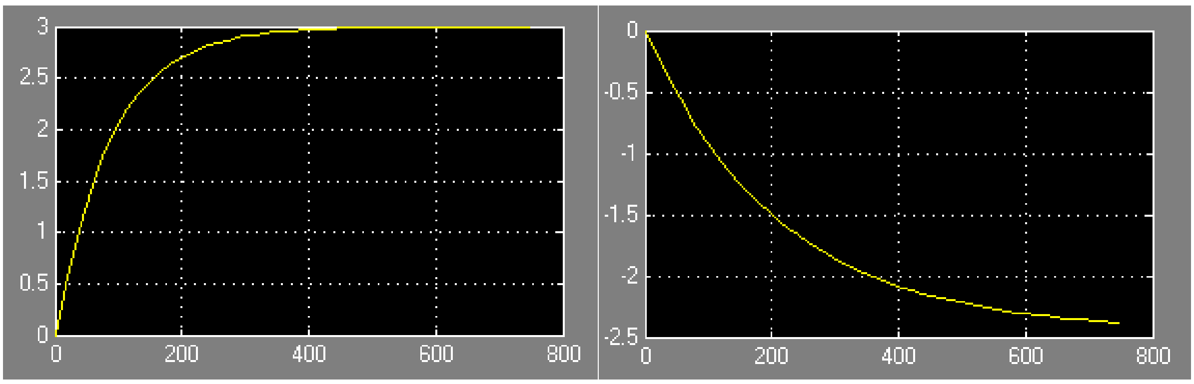

Figure 19. Hot water valve 2-4-2 (Time(s) vs. Temperature (°C))

The graphs (Figures 12, 13, 14, 15, 16, 17, 18 and 19) of these simulations are very similar to the experimental results obtained from the lab. They have roughly the same shape for both the increasing and decreasing functions. The steady-state gain and time constants are the same because these values were found from the experimental data and used to develop the transfer function which has the step input applied to it in SIMULINK/MATLAB. The experimental data is a lot noisier than the SIMULINK/MATLAB simulated step response, especially in the time vs. temperature data where the measured values fluctuate up and down a considerable amount and in a completely random fashion.

4. Conclusion and Recommendations

This experiment was successful in demonstrating the response of a first-order system to a step input of different magnitudes and showing how to identify the key system characteristics such as gain, delay, and time constants for these different step inputs to both temperature and level. It was also helpful in demonstrating how to simulate input to a known transfer function using SIMULINK/MATLAB which will be very useful in understanding the behavior of transfer functions when some input is applied.

Some recommendations to improve this experiment would be to have more time to complete the experiment because it felt rushed. Had there been more time the graphs of the data would have had a more noticeable steady-state area before manipulating the valve for the next step. Another recommendation would be to have a better-mixed tank making the temperature change more steady and allowing for an easier interpretation of the data. The new recommendation systems for the proposed model will be developed in the future using different recommendation models [3-5]. The evolutionary operators will be developed to optimize the proposed system performance in the future [6-12].

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