Lab Week 5: Liquid Level Simulation Model

0. Objectives

- Create a simulation model from a block diagram

1. Overview

This multi-week lab consists of using MATLAB Simulink and Arduino microprocessors to control a liquid level system. The system operates by manipulating the outlet valve to maintain a desired water height regardless of inlet flowrate.

2. System Description

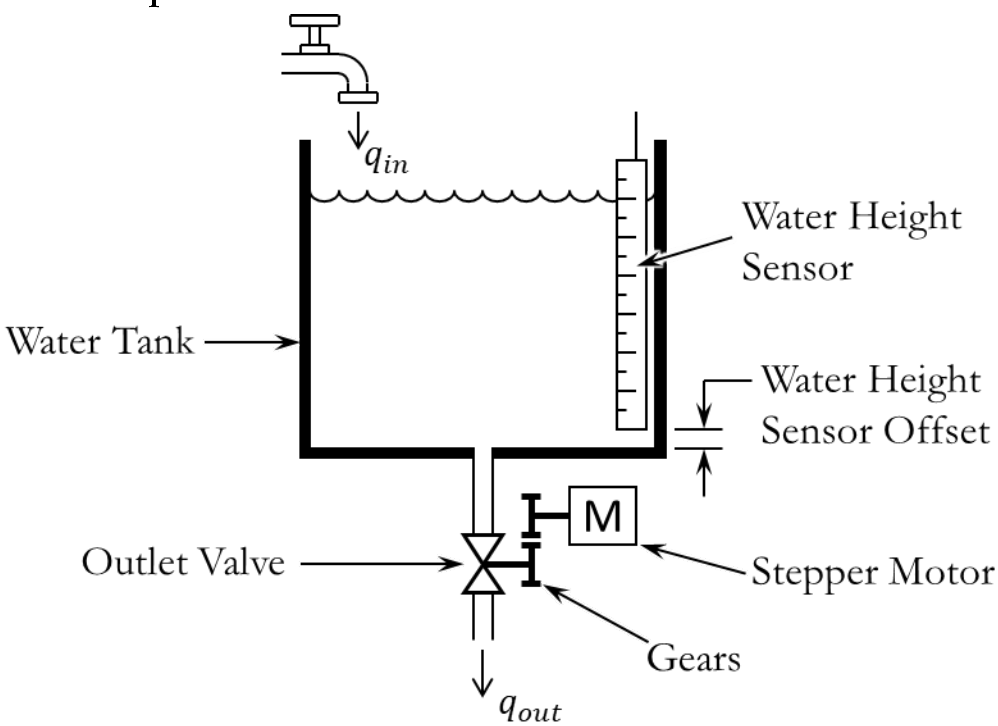

Figure 1: Mixing tank schematic

2.1 Main System Components:

- Outlet valve: controls outlet flowrate to maintain desired water height
- Stepper Motor
  - Opens and closes outlet valve via gears
  - When outlet valve is fully closed, the stepper motor position is 'steps = 0'
  - When outlet valve is fully open, the stepper motor position is 'steps = 1020'
- Water height sensor
  - Detects water height
  - Also referred to as an eTape sensor
- Water tank

2.2 Main system variables:

- Inlet flowrate (q_{in})
  - Inlet flowrate of water
  - Value of flowrate is unknown, uncontrollable, and can vary
  - Units: cm^3/s
- Outlet flowrate (q_{out})
  - Outlet flowrate of water
  - Flowrate will vary depending on outlet valve position **and** actual water height
  - Initial outlet flow rate is 0 cm^3/s
  - Units: cm^3/s
- Outlet valve position (X_{valve})
  - Fully closed position = 0 steps
  - Fully open position = 1020 steps
  - The valve position can be anywhere between 0 steps and 1020 steps
  - Initial valve position is 0 steps
  - Units: steps
- Water tank cross-sectional area (A_{tank})
  - Assume constant
  - 643 cm^2
  - Units: cm^2
- Setpoint water height ($h_{setpoint}$)
  - The desired water height
  - Units: cm
- Actual water height (h_{actual})
  - This is the output variable; the variable we want to control
  - The setpoint water height will be specified. By adjusting the outlet valve, the actual water height will change until it matches the setpoint water height
  - The initial actual water height is 0 cm
  - Units: cm
- Sensor water height (h_{sensor})
  - This is the output/reading of the water height sensor
  - Units: cm
- Water height sensor offset (h_{offset})
  - 3.5 cm
  - Units: cm

3. Objectives

Using MATLAB Simulink and Arduino microprocessors, a liquid level system will be controlled by manipulating the outlet valve to maintain a desired water level regardless of inlet flowrate. The basic steps for completing the multi-week lab are as follows:

1. Create a block diagram of the full system simulation model (completed Lab Week 4)
2. Characterize and model system components
3. Build simulation model of full system using Simulink
4. Run simulation model to optimize controllers and predict behavior
5. Build physical system control model
    - Create new block diagram that will be used for the physical control model
6. Compare simulated results and experimental results

4. Background: create simulation model from block diagram

In Lab Week 4, a block diagram was created for the liquid level control system. The next step is to create a Simulink simulation model that captures the dynamics of the system and can be used to fine-tune a controller in order to produce the desired system response.

4.1 Characterize and model system components

The block diagram created in Lab Week 4 will be used as a reference to create a Simulink simulation model. However, before a full model of the mixing tank system can be created, various system components need to be characterized (i.e., modeled and turned into transfer functions). Some components can be modeled using basic geometry and basic laws of physics (textbook Section 2.4). For example, based on the geometry of the water tank, the water volume can be found if the water height is known. The inverse of the tank cross sectional area is used as a transfer function to convert volume to height (see Figure 2 and Equation 1).

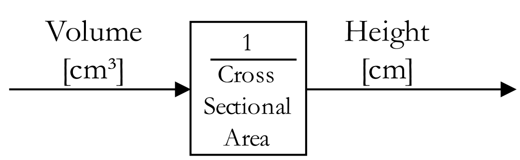

Figure 2: Volume changes to height

$$Height = \frac{Volume}{Area} \quad \Rightarrow \quad TF = \frac{Output}{Input} = \frac{Height}{Volume} = \frac{1}{Area} \qquad \text{(Eqn. 1)}$$

Another example of characterizing components can be seen from Lab Week 1 and was discussed in lecture on September 12th. A liquid tank system had a controllable inlet flow with a fixed valve resistance. The equation that was derived is seen below in Equation 2 and the transfer function in Equation 3. This transfer function was then placed into a Simulink simulation model.

$$RC\frac{dh}{dt} + h = Rq_{in} \quad \Rightarrow \quad 90\frac{dh}{dt} + h = 10q_{in} \qquad \text{(Eqn. 2)}$$

$$TF = \frac{Output}{Input} = \frac{H(s)}{Q_{in}(s)} = \frac{10}{90s+1} \qquad \text{(Eqn. 3)}$$

Other components can be modeled using empirical data collected during lab experiments. For example, Figure 3 shows the behavior of outlet flowrate vs. water height vs. valve position for the liquid level system from Figure 1. This data will be provided in the form of a Simulink 2-D lookup table and will be used in your model. If water height and valve position are sent to the lookup table, the output of the lookup table will be flowrate (note: negative flowrate indicates that the water is exiting the tank).

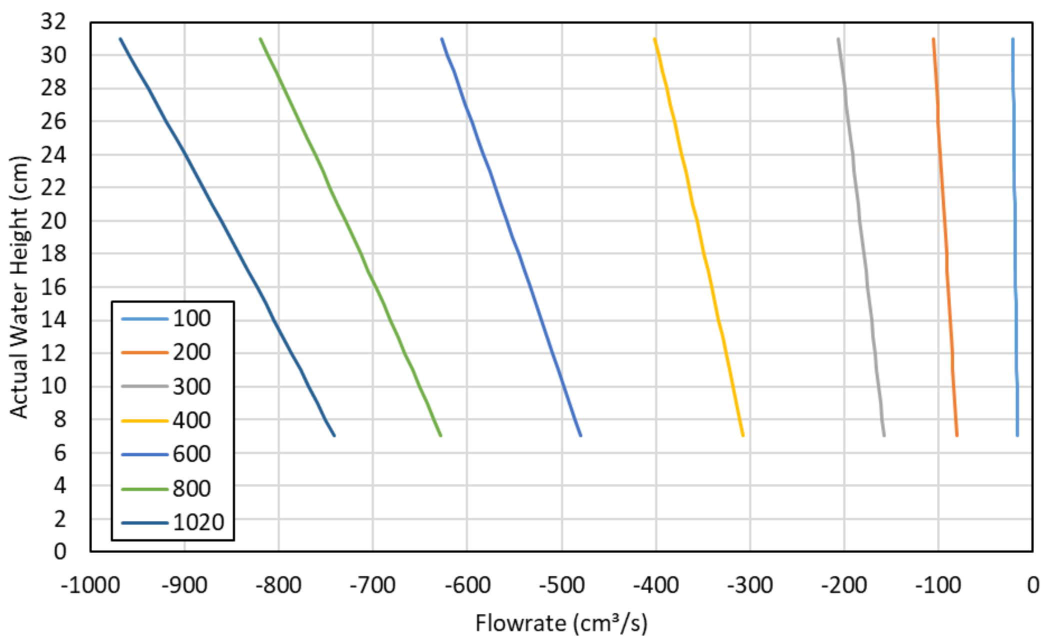

Figure 3: Outlet flowrate vs. water height vs. valve position

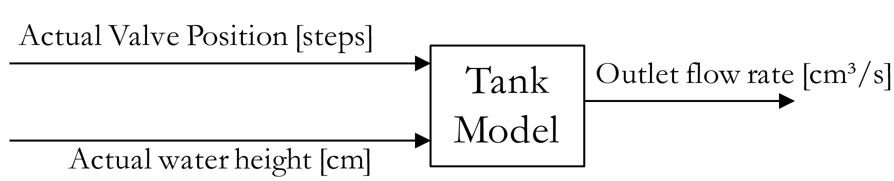

Figure 4: Tank model

The position response data of the valve is shown below in Figure 5. As seen in the plot, the valve does not instantly change from one position to another. This valve response characteristic needs to be included in your simulation model.

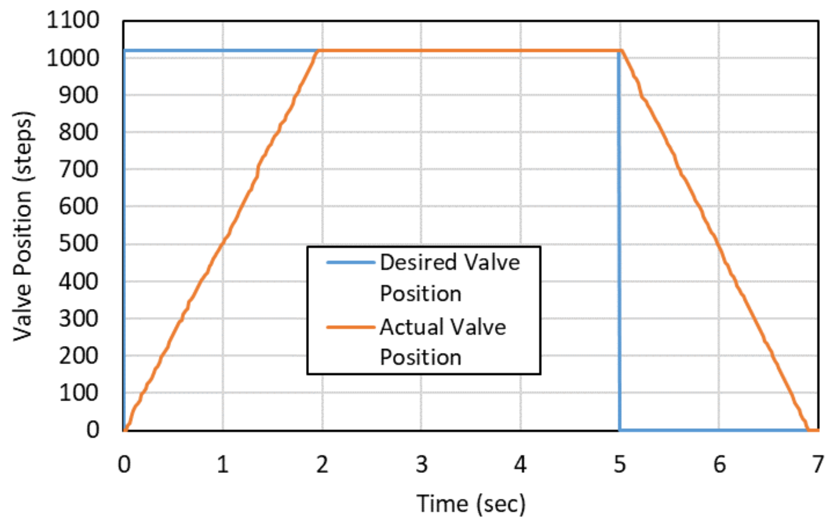

Figure 5: Valve position response

5. Assignment

Using the block diagram from Lab Week 4, create a Simulink simulation model of the liquid level system and run the model in order to predict performance. This model will account for all the important system components from the block diagram and will allow for tuning of the various controller parameters. **<u>Before building your model in Simulink, change the solver to be 'Fixed-step' with a step size of 0.1 seconds (see Figure 6).</u>**

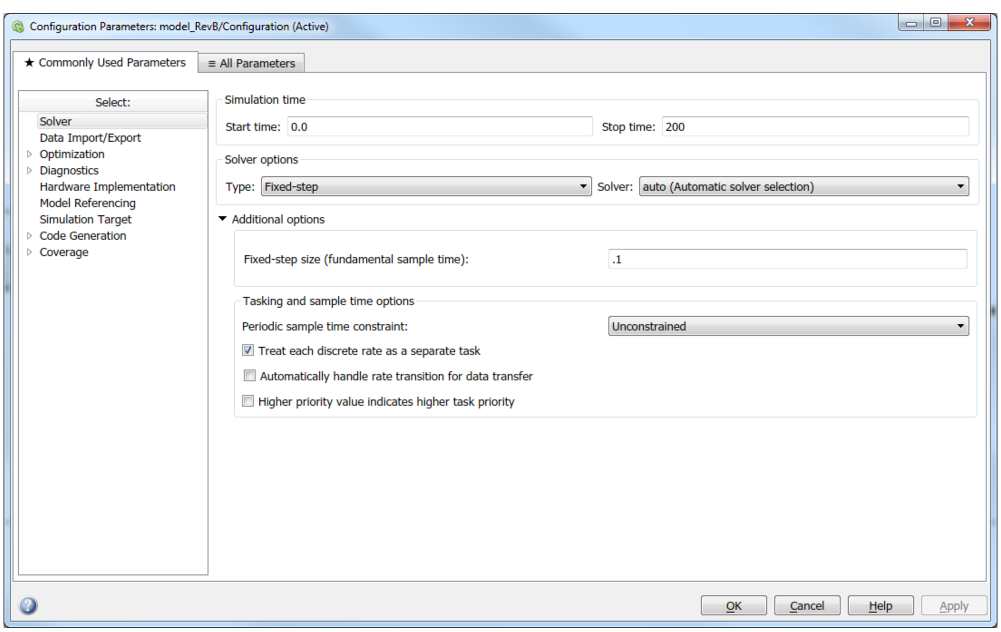

Figure 6: Solver settings

Below are specific requirements that your model <u>must</u> follow:

- Solver type = Fixed-step
- Solver time step = 0.1 seconds
- Use a 'PID Controller' block as your controller
- A 2-D lookup table for outlet flowrate vs. water height vs. valve position will be provided. The 2-D lookup table has two inputs and one output
  - Input 1: Actual water height [cm]: 0 cm to 40 cm
  - Input 2: Actual valve position [steps]: 0 steps to 1020 steps
  - Output: Outlet flow rate [cm^3/s]
- Model the water height sensor as a 1^{st} order transfer function with a time constant of 4 sec
- The minimum water height is 0 cm; maximum water height is 40 cm
- The minimum valve position is 0 steps; maximum position is 1020 steps

Below are additional parameters to use when building and running your model for this lab.

- Simulation time = 200 seconds
- Water tank will initially be empty
- Inlet flow rate is assumed to be a constant rate of 6.5 liter/min
- Water height setpoint = 10 cm
- PID gains (use the default settings for all options)
  - P = 1
  - I = 0
  - D = 0

6. Deliverables

- Completed Simulink simulation model
  - Include proper labels on all transfer functions and include units if necessary
  - Include proper labels and units on all signal flow arrows
- Plot of actual water height [cm] vs. time [sec]
  - Don't forget axis labels
  - Answer the following questions based on this plot:
    - What is the behavior of the graph?
    - Why does it look the way it does?
    - What is going on at the beginning?
    - What is going on later in time?
    - Are there oscillations?
    - What is the damping frequency (ω_d)?
    - What is the rise time?
    - What is the percent overshoot?
    - What is settling time?
- Plot of valve position [steps] vs. time [sec]
  - Don't forget axis labels
  - Answer the following questions based on this plot:
    - What is the behavior of the graph?
    - Why does it look the way it does?
    - What is going on at the beginning?
    - What is going on later in time?
    - Why are some portions of the plot flat?
    - What is the maximum opening position?
    - Why does the valve never fully open?
- Don't forget a cover sheet; coversheet guidelines are posted on Blackboard