Lab Week 1: Introduction to Process Control Systems and Simulink

1. Learning Objectives

- To introduce the fundamentals of automatic feedback control systems.
- To introduce the concepts of ON/OFF, proportional (P) and proportional-integral (PI) control modes.

2. Introduction

All manufacturing processes and dynamic systems are subject to disturbances that tend to change the operating conditions. Such disturbances have significant effects on the system performance. In order to minimize those effects, processes and systems are equipped with instrumentation and automatic controls. Several concepts of control methods have been developed. In this lab, we will briefly look at some of those concepts, develop a simple dynamic model, and learn to simulate the system using Matlab/Simulink.

3. Control block diagram

Control engineers often use block diagrams to illustrate the system. Each block in the diagram represents components within the system. Mathematical representations of the components are usually written in the blocks. Two principal control systems are open-loop and closed-loop systems. The block diagram in Figure 1 is an example of an open-loop control system, in which there is no measurement of the output and no subsequent use of that output to make the process conform to the desired output. The term "open loop" refers to the fact that there is no closed path or loop around which the signals can go back to the block diagram. In this case, we can notice that there is no way that the controller would adjust the manipulated variable according to changes of the output due to the disturbance.

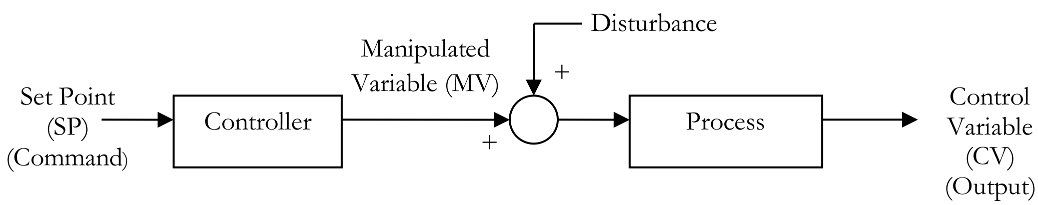


Figure 1: Open-loop control block diagram

In contrast to the open-loop control, the closed-loop control (Figure 2) makes use of the output signal. Sensors are used to read the output signal. The controller then adjusts the manipulated variable according to the deviation between the set point and the control variable.

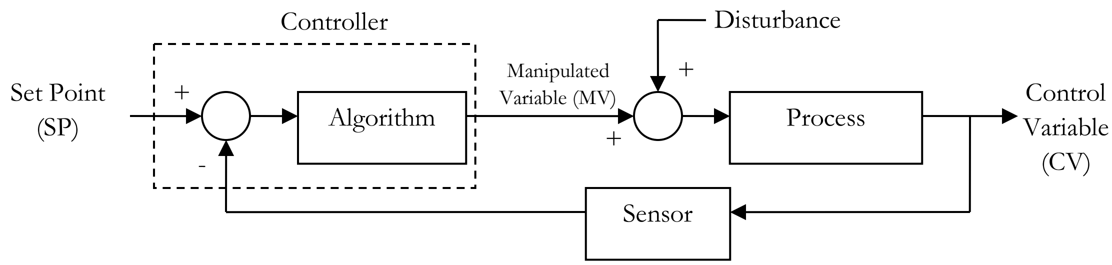


Figure 2: Closed-loop control block diagram

4. Example of feedback control system

Now, let's take a look at the system shown in Figure 3. The operator is trying to maintain constant temperature of the hot water exiting a heat exchanger. He measures the hot water temperature using his right hand and then decides to add more or less steam to the heat exchanger by adjusting the valve at their left hand. In this example, the operator acts as the controller in a closed-loop or feedback control manner. They use the hot water temperature, "feedback", to decide the steam valve setting.

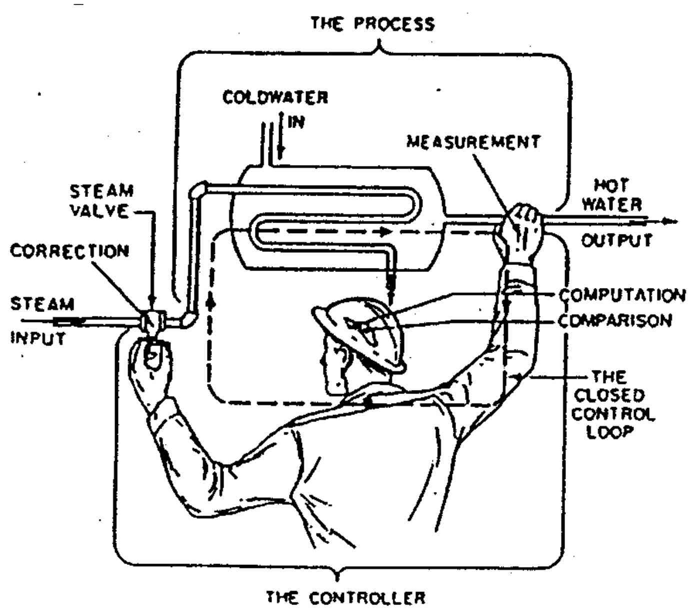


Figure 3: A water heating system operated by a human

5. Modes of feedback control

Several architectures of controllers are available for controlling the water heating presented in the previous section.

5.1 ON/OFF mode

If the valve is solely an ON/OFF valve, the operator would close the valve when the water temperature was too high and open the valve when the temperature was too low. This control manner generates fluctuation (Figure 4) in the control variable.

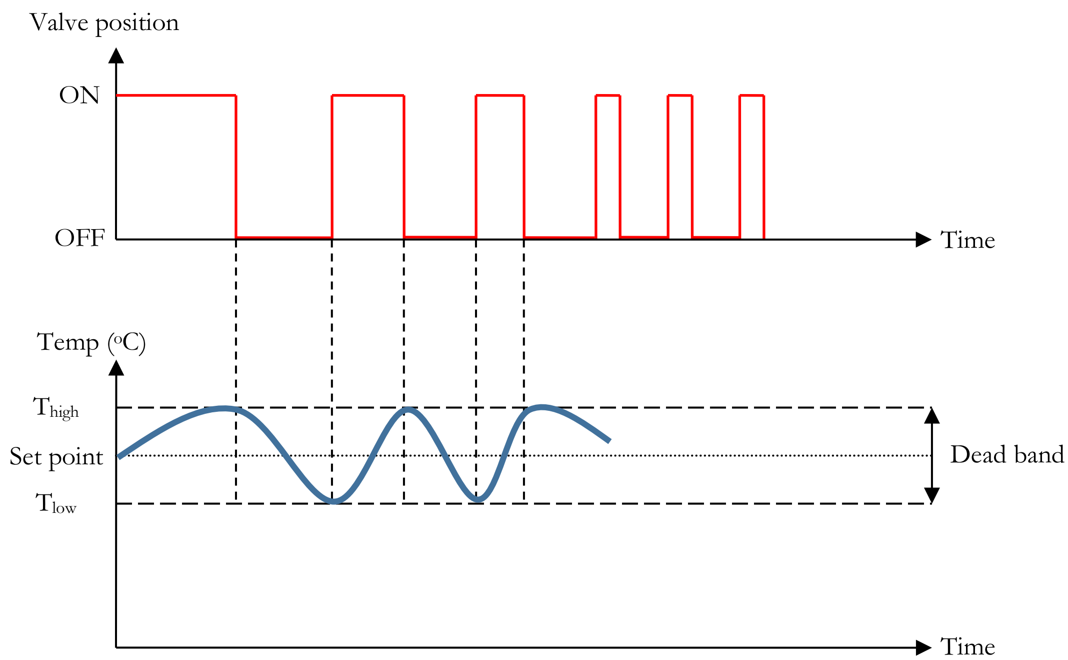


Figure 4: Fluctuation in the water temperature in response to the valve ON/OFF control

5.2 Proportional (P) mode

If the valve opening is adjustable (i.e. proportional), the operator can open and close the valve by different amounts. Then, if the temperature is only slightly low, they can open the valve by a small amount and vice versa. Adjusting the input variable proportional to the "deviation" of the output from the desired value (error) is the proportional control concept mathematically expressed in Equation 1 and Equation 2.

$$\text{Error} = \text{Set point} - \text{Output} \qquad \text{Equation 1}$$

$$\text{Valve position} = \begin{cases} 0, & Error < 0 \\ K_p \cdot Error, & Error \geq 0 \end{cases} \qquad \text{Equation 2}$$

where K_p is the proportional gain.

5.3 Proportional-Integral (PI) mode

In a real proportional control, the steady-state output would actually never reach the set point. For example, in Equation 2 for the valve to open there must be at least some error. At this point, heat lost by the heat exchanger equals the amount of heat added by the steam. This deviation at the steady-state of the system is called steady-state (ss) error or offset. In order to get rid of this "ss" error, the operator would "tweak" the steam valve until it disappeared. Mathematically, we can do this by integrating the error signal (Equation 3).

Equation 3 $$Valve\ position = K_p \cdot Error + K_i \int_0^t Error\ dt$$

where K_i is an integral gain.

6. Assignment

6.1 Referring to Figure 3, what will be the most appropriate type of steam valve for the system (fail-open or fail-closed)? And identify the following items.

a. Control objective
b. Process (the dynamic system)
c. Controller
d. Sensor
e. Actuator
f. Disturbance

6.2 Draw a block diagram representing the water heating system in Figure 3 (Use your answers in 6.1 to complete your diagram). Reminder: follow the general layout from Chapter 1. This is a generic block diagram that could be drawn in Word or PowerPoint (not a Simulink model).

6.3 For a liquid-level system, derive the mathematical model (differential equation) relating rate of change of "h" to the inputs. Reference section 2.4.6 in the text (pages 56-57):

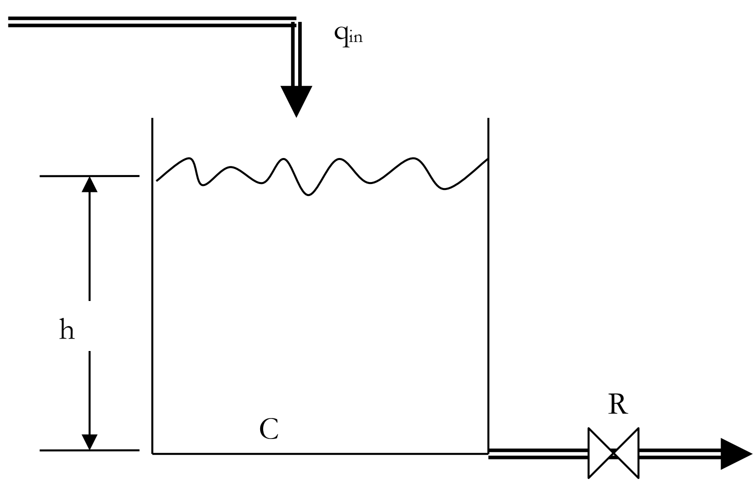


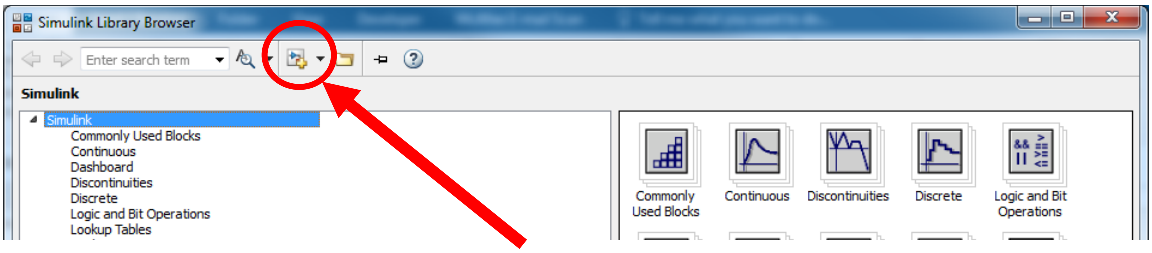
Figure 5: Liquid-Level System where R = 10 s / ft² and C = 9 ft²

6.4 Using the tutorial below, construct the block diagram in Simulink and simulate the response of the liquid level system equations developed in Part 6.3. The formal methodology (Laplace, etc.) will be presented in class in upcoming lectures, this is simply intended to be an introduction to how Matlab/Simulink utilizes block diagrams and Laplace transforms, so that as they are covered in class the connection is easier to make. Note: at the end of the instructions is a description of what is due at the completion of the lab.

Liquid Level Simulation using Simulink

6.4.1 Login and start Matlab. Type **`simulink`** at the >> prompt, and hit ENTER.

6.4.2 When the Simulink Library Browser appears, click the "New model" button and a new Simulink model window will open. Save this file with an appropriate file name.



6.4.3 Build the model in Figure 6. You can browse the library menu to find the blocks or use the search. The vertical black bar is a "mux" (short for multiplexer). To make a branch off of a line, hold CTRL while clicking and dragging the line. Note: yours might look different, just make sure connections and blocks are correct.

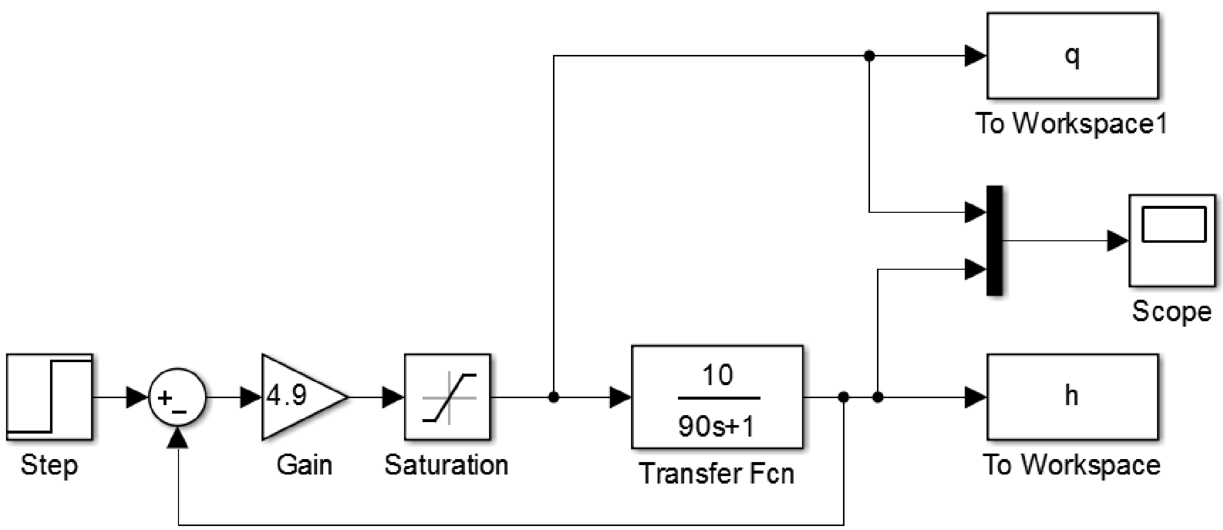


Figure 6: Simulink model

6.4.4 Set the following blocks and parameters (right click on block and click parameters):

- Step function: Step Time = 0
- Sum: |+-
- Gain: 4.9
- Saturation: Upper Limit = 500, Lower Limit=0
- Transfer Function: Numerator: [10], Denominator: [90 1]
- To workspaces
  - Variable name: 'q' or 'h'
  - Save format: Timeseries
- Simulation → Model Configuration Parameters
  - Solver → Stop Time: 15 (seconds)
  - Solver → Solver: ode23t

6.4.5 Run the simulation (green arrow). Double click the scope and click Autoscale. If everything is set up correctly, you should see something similar to Figure 7 (minus the title, labels, and legend).

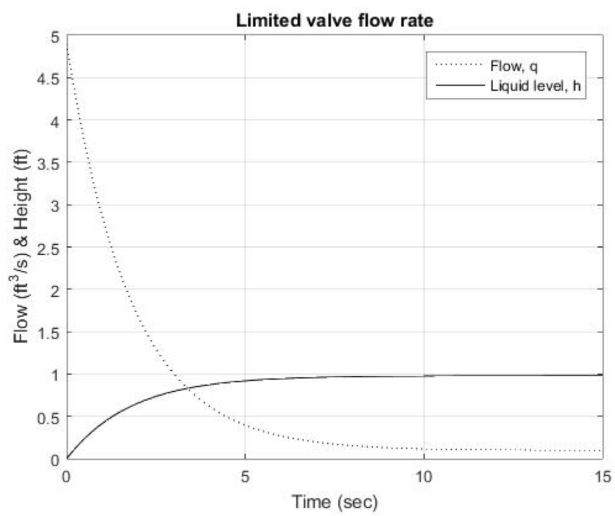


Figure 7: Plot of Simulink Model Output

6.4.6 The scope block in Simulink has many limitations, so make an "m-file" to generate a clear/legible graph of your data. Within the main Matlab window, Home Tab → New → Script. Save the m-file in the same folder as your Simulink model and give it an appropriate file name. Place the following code in your m-file:

```
figure(1)
plot(q.Time, q.Data, ':k')
hold on
plot(h.Time, h.Data, '-k')
hold off
title('Limited valve flow rate')
xlabel('Time (sec)')
ylabel('Flow (ft^3/s) & Height (ft)')
legend('Flow, q', 'Liquid level, h')
grid on
```

6.4.7 The model simulated unlimited available flow by setting the saturation upper limit at 500 ft^3/s (more than the error·K_p would ever be). Now run the simulation again, but first set the saturation upper limit to 1 ft^3/s, simulating a flow-limited system.

6.4.8 For this portion of the lab (in addition to the earlier assignment section), turn in:

a. Completed Simulink block diagram.
b. Completed graph when the maximum valve flow rate is 500 ft^3/s. Be sure to choose an appropriate time duration in order to completely show the system's response.
c. Completed graph when the maximum valve flow rate is 1 ft^3/s. Be sure to choose an appropriate time duration in order to completely show the system's response.
d. One paragraph describing the differences between the two graphs from parts b and c, and the trade-offs that might occur when choosing between to two if you were required to purchase and install such a system.

7. Deliverables

7.1 An executive summary that provides a concise introduction to the lab, the procedures, results, and conclusions (synthesize the data and draw conclusions). Maximum length of one page. Can be single, 1.5, or double spaced.

7.2 Following the executive summary, include answers to the questions in Part 6 (written text, drawings, and computer printouts).