PROC 5071:
Process Dynamics and Control

Introduction, Examples and Terminology

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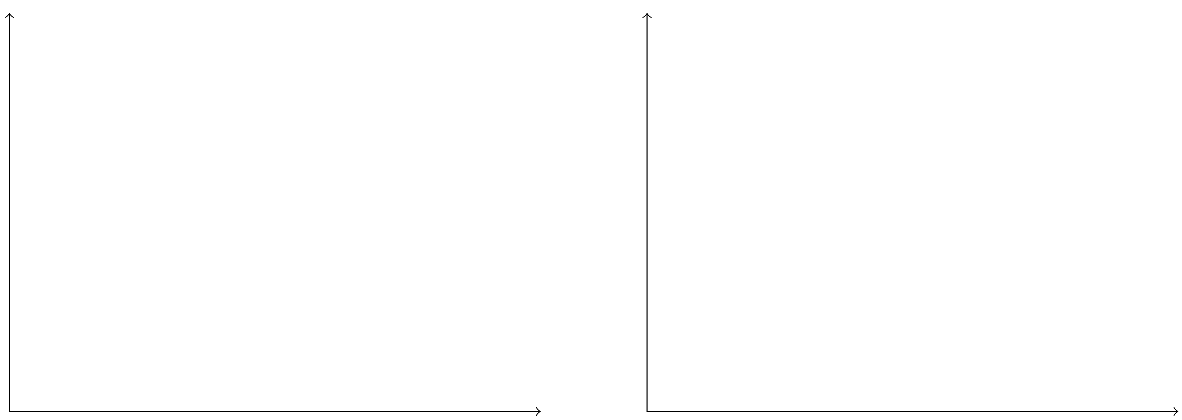
1 An introduction to the course

1.1 What is process dynamics

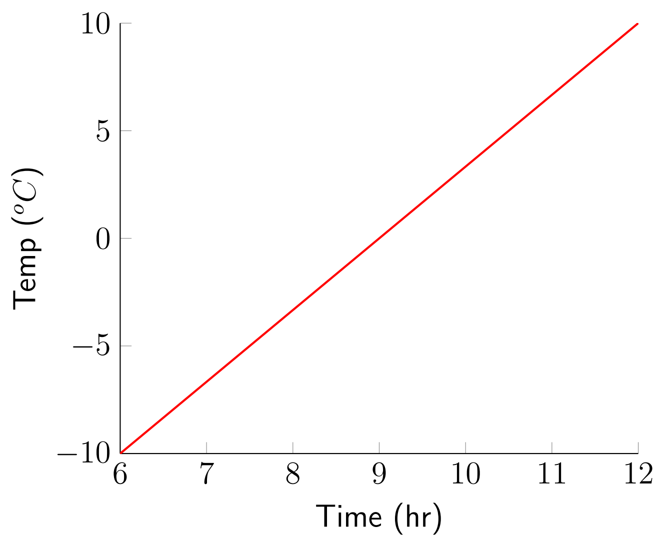
- Consider a furnace used for room heating; if you increase the fuel flow to the furnace what happens to the room temperature
  increase decrease
- A scenario: the fuel flow rate initially at 50% and changed to 60%. Draw the profiles of fuel flow rate and temperature



- Process dynamics is all about capturing, expressing and predicting the time-dependent behavior of process variables and their relations

1.2 What is process control

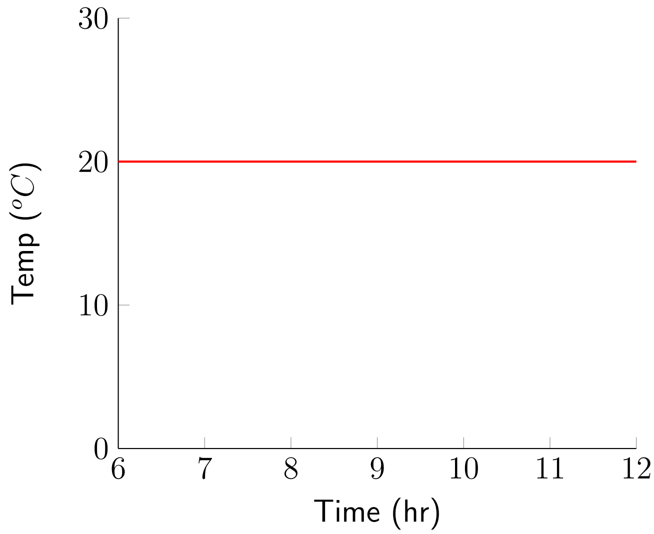
- Consider the same furnace heating system; how does it maintain room temperature although the outside temperature is changing
- A scenario: the outside temperature from 6 AM to 12PM is shown in the figure

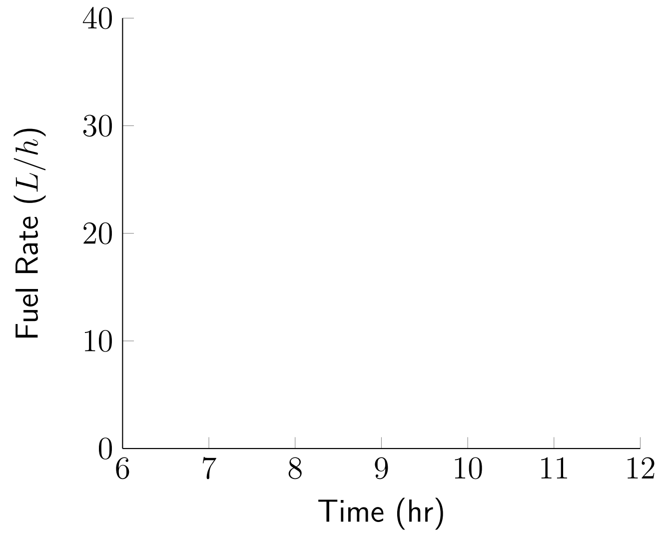


- If you want to maintain a room temperature constant at $20^O C$, how would you manipulate the fuel flow to the furnace
- Process control is all about systematically manipulating some variables to maintain some other variables at desired levels

1.3 Why do we need control

- Variables in a plant need to be maintained to
  - ensure safety





- maintain product quality
- optimize operation
- ....

1.4 Learning objectives

The learning goal of this course is to know the scientific and engineering principles of process dynamics and control. By the conclusion of the course, the student should

- Explain rationale behind different control strategies and role of control in plant operation
- Develop dynamic models of process systems from first principles and process data
- Use mathematical tools to represent dynamic models for control design and study the dynamic response of different systems to standard inputs
- Design classic PID controller systems and tune their parameters
- Analyse the stability and performance of feedback control systems
- Apply control to real as well as simulated process systems

1.5 Learning methods

- Abstract conceptualization - classroom lecture
- Implementation, observation and reflection
  - in real systems - laboratory experimentation
  - in simulation - project

1.6 Course content

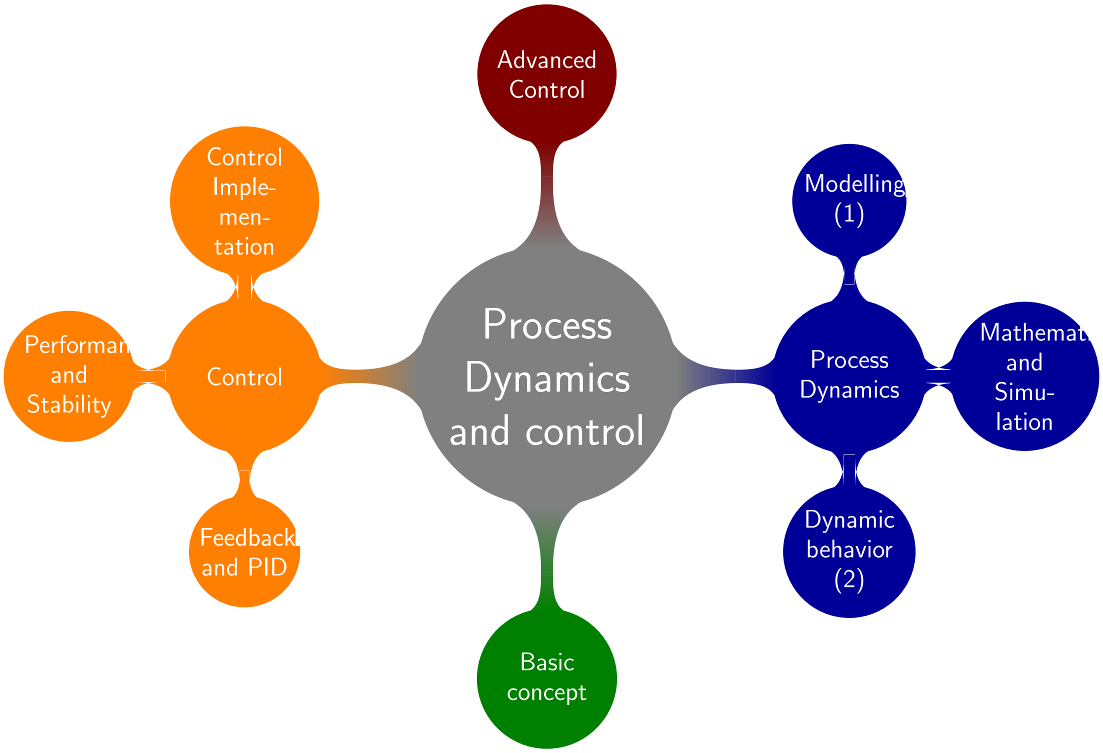
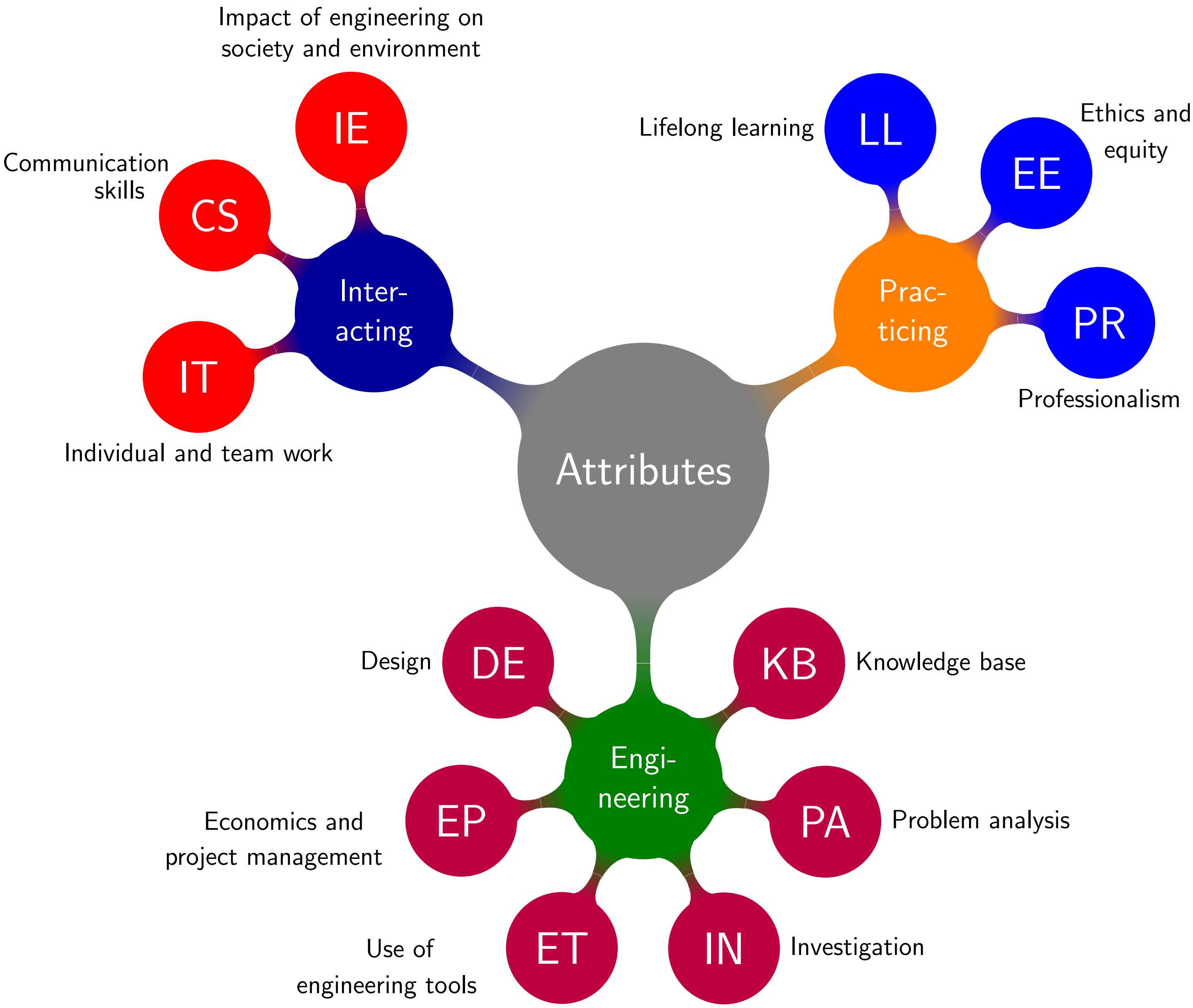


Figure 1: Course structure and contents.

1.7 Graduate attributes


Impact of engineering on society and environment
IE
Communication skills
CS
Inter-acting
IT
Individual and team work
Lifelong learning
LL
Ethics and equity
EE
Prac-ticing
PR
Professionalism
Attributes
Design
DE
KB
Knowledge base
Engi-neering
Economics and project management
EP
PA
Problem analysis
Use of engineering tools
ET
IN
Investigation

2 Example control problems

2.1 Will Sam drown?

Figure 5 shows the schematic of two pools. Water is pumped into Pool 1 and its inlet flow rate can be manipulated. Pool 1 has a constant hold up (the volume of water in the pool is constant) and the outlet from the pool is through the overflow line. The overflow from Pool 1 goes to Pool 2. There is also a second inlet flow to Pool 2. The outlet from Pool 2 is at its bottom and the output flow is due to gravitational force. Initially the entire system is at a steady state with all flow rates at constant values and the level of water in the second tank is below its maximum value (second tank is not overflowing).

Sam, a 2 year old boy, is standing in Pool 2. Suddenly

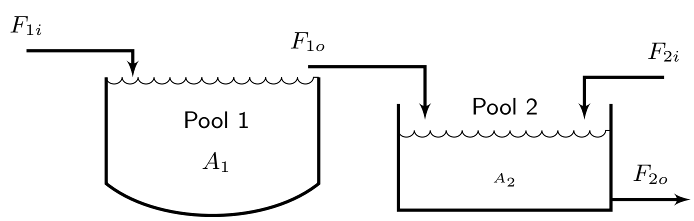


Figure 2: Schematic of the swimming pools.

someone increased opening of the inlet flow valve to Pool 1. Now the questions are:

1. Will Sam drown?
2. If yes, how much time is available to save Sam?

2.2 Boiler and shower system

Consider the day-to-day problem with shower and its associated boiler that supplies hot water. A comfortable shower requires a steady flow of water at a comfortable as well as steady temperature. However, as the boiler supplies water to different parts of the house, a certain opening of the shower water valve does not ensure constant flow. One needs to change the hot and cold water valve opening to maintain steady temperature and flow of water.

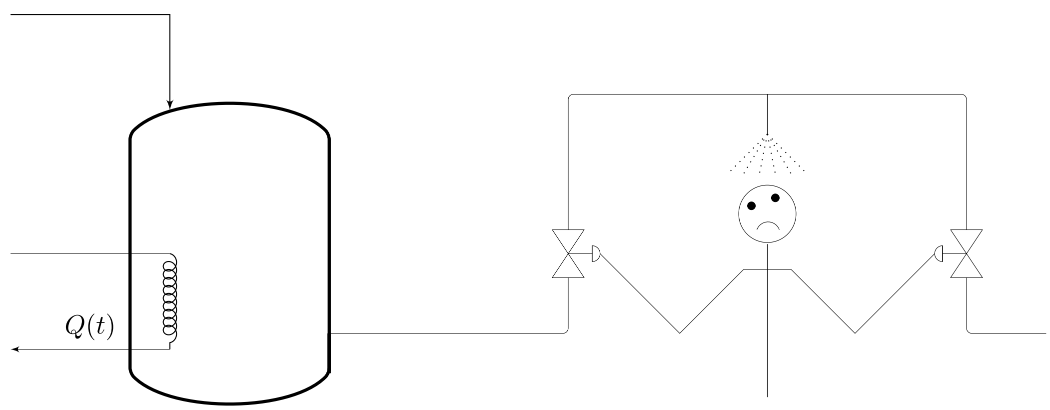


Figure 3: Schematic of the boiler and shower process.

Manipulating the shower water flow also affects the boiler operation. As outlet flow rate from the boiler varies, its heating load changes. Depending on flow change, the power input to the boiler needs manipulation. Also with changing demand of hot water the inlet flow to the boiler needs to be changed. All these require a set of controller for the boiler. However, as you can realize from this example, the boiler control does not involve human intervention. Some automated system is there in place does the job; same as the temperature controller in the lecture room. On the other hand, the shower control involves you. can you think a way to automate the shower system?

2.3 Runaway reactor

Consider the production of propylene glycol in a continuous stirred tank reactor (CSTR) and its subsequent separation in a distillation column. Such a system, reactor followed by a separation unit is quite common in the process industry. A schematic of the system is shown in Figure 4. A brief description of the process is given below.

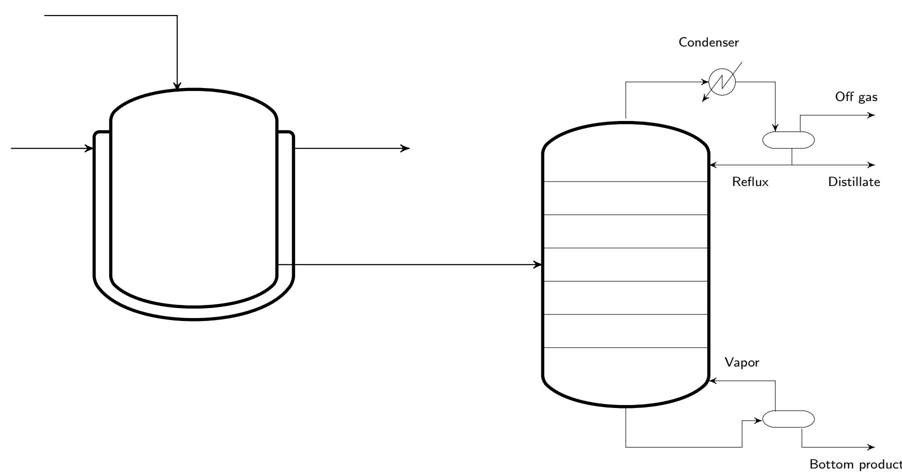


Figure 4: Schematic of the reactor along with the separator unit in propylene glycol production process.

2.3.1 Process description

Propylene oxide and water are fed to a CSTR where they react to produce propylene glycol. The following reaction takes place.

$$C_3H_6O + H_2O \rightarrow C_3H_8O_2 \tag{1}$$

The reaction is exothermic; so cooling is required to maintain the reactor temperature. At a temperature of 140^oF, 95% conversion of propylene oxide is achieved. To separate the glycol, product from the reactor is fed to a distillation column where most of the glycol is separated as the bottom product. A simple system like this can have a series of control problem and applying proper control strategies the process can be operated to achieve desired operational objectives.

2.4 Distillation product quality

The distillation column also needs a series of controller. The pressure in the column needs to be maintained; the reflux flow, liquid holdup, condenser temperature, all are required to be maintained.

3 Control Terminology

3.1 Revisit Will Sam drown?

For the "Will Sam drown" example, two questions were asked

1. Will Sam drown?
2. If yes, how much time is available to save Sam?

To get answers to the above questions, let us first formulate the problem from an engineering perspective. This will involve asking a set of analytical questions and figure out what additional data and information are required to get the answers.

- What does mean by whether Sam will drown or not?
  Well, drowning here can be referred to as the condition when the level of water in Pool 2 will exceed certain percent of the height of Sam. Do we know the height of Sam. The description includes that he is 2 years old. Is this a relevant information?
- Is the level of water in Pool 2 affected by the valve opening in line 1?
  Pool 1 is fed by line 1. If the flow through line 1 increases, the overflow of Pool 1 increases and this will affect the level in Pool 2.
- Exactly how line 1 flow rate affects Pool 2 level? From

basic science principles, it is understood that an increase in flow rate of 1 will increase the level of liquid in Pool 2. However, to know exactly what is the quantitative relation, it will require to develop the mathematical model between those two variable. To do so a set of data for the two pools will be required. Also we will require some relations among variables; these relations are governed by law of nature.

For the time being, we will not try to find the detail mathematical relation. Instead, assuming that Sam may drown, can we implement something in the system to ensure that Sam will not drown. Or in other word, cam we control the level of water in Pool 2? Well, it appears that we got a control problem. Let us try to find some solutions; here are some idea.

1. Ask someone to observe whether anyone is drowning (what to observe) and do something (what to do).
2. Well, ask someone to measure the water level and manipulate inlet flow to Pool 2 (which inlet).
3. Any other idea?

3.2 Workout: Control knowledge inventory

Here is what to do:

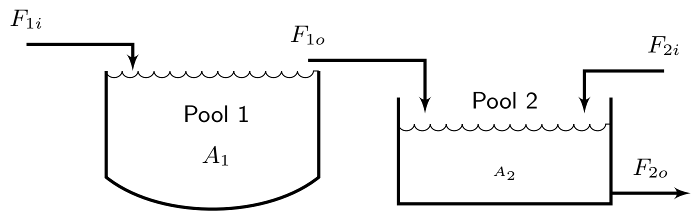


Figure 5: Schematic of the swimming pools. Standard notations for area (A) and flow rate (F) are used.

1. Using your knowledge about "control", just sketch on the following diagram, what control you may want to apply and how you want to do it.
2. Do you need to measure anything? What would you measure and how?

3. Do you plan to manipulate anything? What would you manipulate and how?

It appears that we are entering into technical domain and already using some jargons (e.g. manipulate). So let us first learn some technical jargons (or terminologies).

4 Terminologies

From the above solutions to the problem it appears that we were trying to keep the water level at a certain value. This is what is called control objective. Every control problem starts with defining an objective. So for this problem

4.1 Control objective

Maintain the level of water in Pool 2 at a certain value.

Every control objective focuses on to maintain a particular variable. For the drowning problem, the variable that we want to maintain is the level of water in Pool 2. So, the level of water in Pool 2 is the output for the control problem with the above objective.

4.2 Output

The variable that is controlled or maintained at a desired value is called the output. We see that there is a desired value associated with an output. For the drowning problem, if Sam is 2 ft tall and we want to maintain the level of water below 2 ft, say at 1.5ft; this is the set-point.

4.3 Set-point

The desired value of the output is called the set-point.

Now how do you maintain the level of water in Pool 2. You may want to manipulate the flow rate through inlet 2. For this problem, the flow rate of inlet 2 is called the input.

4.4 Input

The variable that is manipulated to maintain the output at its set-point is called the input.

The level of water in Pool 2 (output) is affected by the inlet 2 flow rate; however, it is also affected by the the inlet 1 flow rate. If we choose to manipulate only inlet 2 flow rate, then inlet 1 flow rate is considered as a disturbance for the level of water.

4.5 Disturbance

A variable that affects the output, however, is not manipulated or cannot be manipulated, is called disturbance.

The above terminologies are standard and understood by control professionals. However, there are other names for input and output that we will learn later.

5 Workbook: Identify input, output and disturbance

5.1 Workout 1

Think about the heating system in the lecture room. You can feel the hot air being circulated through the openings in the ceiling. Also there is a controller near the entrance of the room. For this control task define the followings:

Control objective :

Output :
Input :
Disturbance :

5.2 Workout 2

Now think about the driving problem. You are driving through the picturesque rocky mountains uphill and downhill; however, you want to maintain a certain speed. Identify the followings for speed control.

Control objective :

Output :
Input :
Disturbance :

5.3 Workout 3

Next, consider the shower problem. Based on what you need for a comfortable shower, are there more than one objective? Yes, indeed there are. For each control problem encountered during shower, identify the followings.

1. **Control objective** :

   Output :
   Input :
   Disturbance :
2. **Control objective** :

   Output :
   Input :
   Disturbance :