PROC 5071: Process Dynamics and Control

Control Strategies and Benefits

Salim Ahmed

1 Control strategies

1.1 The concept of feedback

- In the pool level control problem, we suggested that the level of water in the pool be measured and the inlet flow be changed accordingly.
- In controlling the speed of a car, one needs to measure the speed, compare it with the desired speed (set-point) and increase or decrease fuel flow to maintain it at the set-point.
- In the reactor temperature control problem, the temperature (output) needs to be measured which is then compared with its set-point and the coolant flow (input) is changed accordingly.

In all of the examples above, we see that the output is measured and it is compared with the set-point and based on their difference, input is changed. This is one of the most common strategy for control and it is known as the feedback control.

1.2 A second strategy

- While approaching an uphill road, do you wait till the speed decreases before you increase the fuel flow?
- If the feed temperature of a distillation column decreases,

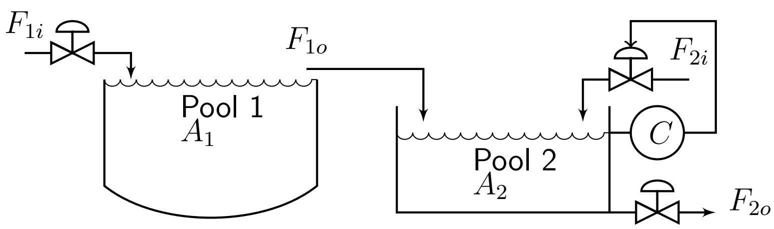
should one wait till the product quality changes and then manipulate the reflux?

The above examples indicate the feedback approach, i.e. to measure the output and manipulating the input when output deviates, may not be the only way to control.

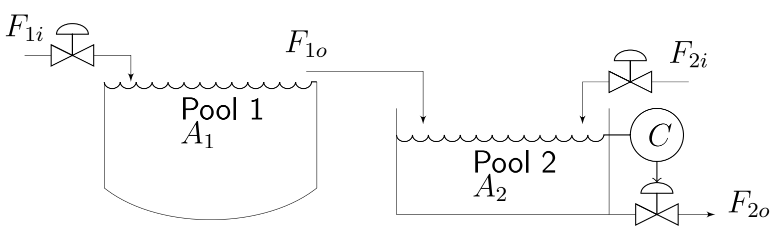
- A second way is to measure other variables that affect the output and manipulate the input by anticipating a change in the output
- This approach is called the feedforward control

1.3 Workout: Feedback vs. feedforward control

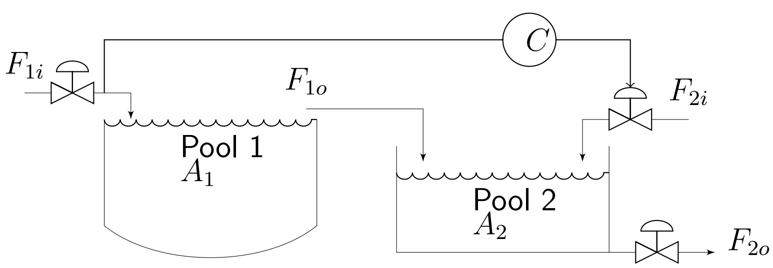
For the control configurations, classify which ones are feedback control and which are feedforward control.



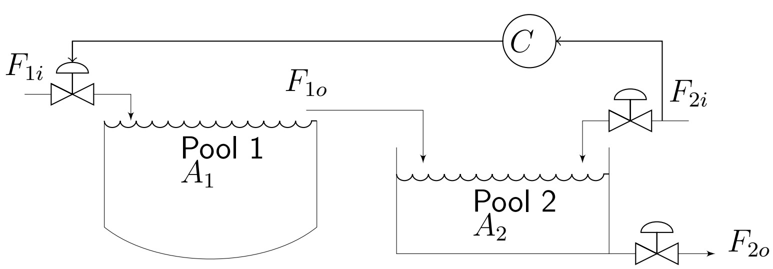
- What is the output? -
- What is being measured? -
- Is the control action based on the output or a disturbance? -
- Is it feedback or feedforward? -



- What is the output? -
- What is being measured? -
- Is the control action based on the output or a disturbance? -
- Is it feedback or feedforward? -



- What is the output? -
- What is being measured? -
- Is the control action based on the output or a disturbance? -
- Is it feedback or feedforward? -



- What is the output? -
- What is being measured? -
- Is the control action based on the output or a disturbance? -
- Is it feedback or feedforward? -

2 Benefits of control

2.1 Examples

Why did we applied control in the example problems?

- Will sam drwon problem - Safety
- Distillation column - Product quality
- Shower - Maintain quality
- Driving - Safety, Minimize time (optimization)
- Home heating - Comfort (quality), Energy saving (optimization)

The benefits of control can be categorized as follows:

2.2 Benefit categories

1. Ensure safety of people and process
2. Protect environment by preventing release of materials and energy
3. Prevent damage of equipment
4. Ensure un-interrupted operation and product quality
5. Allow optimization

In a nutshell, the objectives of control is to ensure safe and profitable operations; in other words, to minimize the risk and maximize profit associated with an operation.

3 Workbook: Control configuration of a flash column

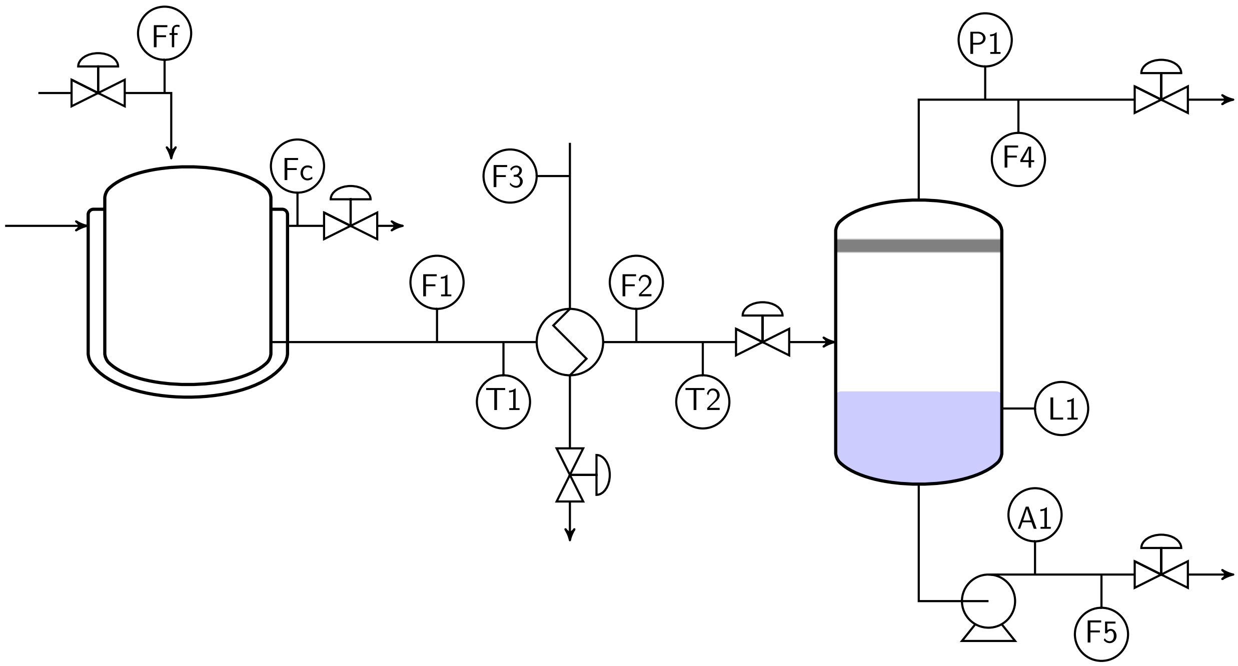


Figure 1: Schematic of a reactor and flash distillation system.

3.1 Workout 1: Controller for safety

Identify a variable that you would like to control in order to **ensure safe operation** of the process.

1. State the control objective for this case.
   Control objective: Maintain a certain pressure inside the column.
2. Identify the output.
   Output: Column pressure
3. Identify the input.

Input: Top flow rate

3.2 Workout 2: Controller for protecting environment

For this benefit, define a control objective and identify corresponding output and input.

Desired benefit:

1. Control objective:
2. Output:
3. Input:

3.3 Workout 3: Controller for preventing damage of equipment

Desired benefit:

1. Control objective:
2. Output:
3. Input:

3.4 Workout 4: Controller for quality assurance

Desired benefit:

1. Control objective:

2. Output:
3. Input:

3.5 Workout 5: Controller for optimization

Desired benefit:

1. Control objective:
2. Output:
3. Input:

4 How are the control benefits achieved?

4.1 Controller reacts to disturbance

In practice, how, say safety is ensured through control? To answer this question, think about the reactor example. To prevent the reactor from a runaway situation, the temperature in the reactor should be maintained below a certain value, say 1000^oC. Without control, the coolant flow can be set at a value that will keep the rector temperature at the desired value. However, if the temperature of the coolant rises, the reactor temperature will also rise and it can go beyond the limit. In other words, when any disturbance affects the output, without control the output cannot be maintained at its desired value. One of the task of a controller is to take action when disturbance enters into the process and cause the output to change from its desired value. In this case, if the coolant temperature changes, the controller will change the coolant flow accordingly to maintain the temperature.

4.2 Variabilities are inherent

However, is it really possible to maintain the temperature at the desired value using control. Think about driving your car under cruise control. Can its speed be maintained at the desired value without variation? In practice, it is not possible. Even if there is no other car on the road, the uphill and downhill will make the speed vary. The controller may get it back to the desired value. However, it is not possible to entirely avoid variation in speed. Every process has inertia and when something is changed, it takes some time to see its effects; by the time, the output may vary.

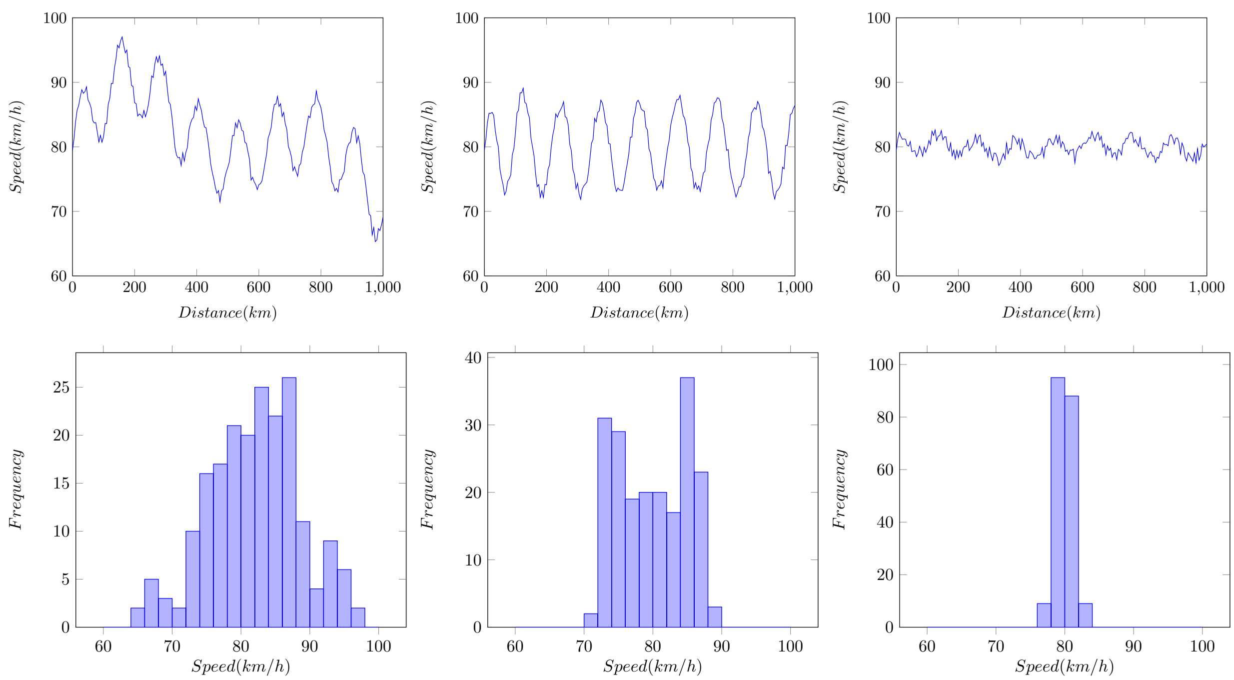


Figure 2: Car speed and histogram of speed for no control (left column), manual control (middle column) and cruise control (right column) while driving up and downhill.

4.3 Controller reduces variability in the output

Without control, the resulting variation is higher. For example, while driving, if no action is taken at uphill and downhill, i.e. fuel flow is not changed, the speed will vary over a wide range. Figure 2 shows the speed of a car and the histograms of speed for a car without any control (left column), with manual control (middle column) and with cruise control (right column) while being driven uphill and downhill. Obviously the speed varied over a wide range without control. With manual control (driver control) the variation decreased; however, with the cruise control, much less variation was achieved. The variation is important because as we see from the plots, although an average speed of approximately 80km/h was maintained for all three cases, if the limit was 80km/h, without control the car exceeded the limit for almost half of the drive and by a large margin. For manual control, the limit was exceeded by lower margin. However, for cruise control the speed was always within few km of the limit while the average speed was maintained at the limit.

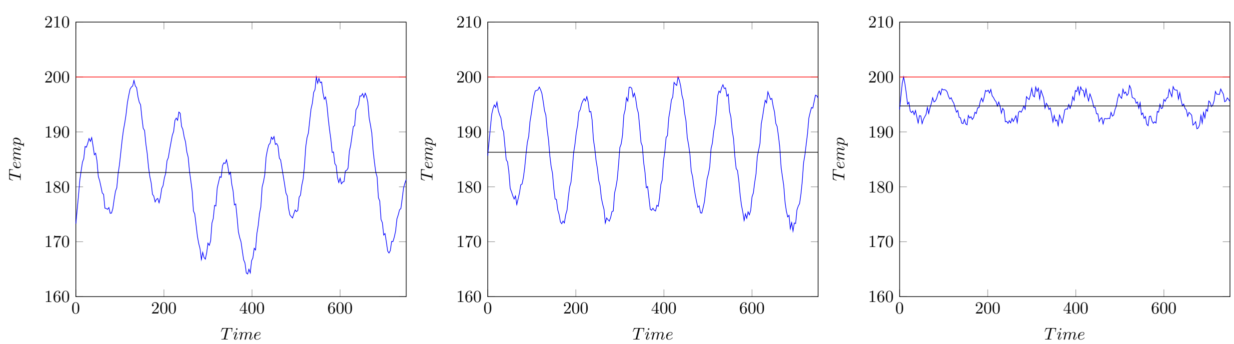


Figure 3: Temperature variation in a reactor with average operating and maximum temperature without control (left), with a poor controller (middle) and with a good controller (right).

4.4 Effects of variability

Variability play an important role in control. Because of inherent variability in process variables, desired values of outputs (set-points) are chosen in conservative ways. For example for the reactor temperature control problem, if runaway takes place at 200^oC and the temperature varies within 50^oC, the set-point should be chosen $\leq 150^oC$. Figure 3 shows the temperature inside a reactor without control (left). with poor control (middle) and with good control (right). It also shows the average temperature the reactor was operated and the maximum allowable temperature in the reactor.

The figure shows that due to high variability for the case without control, reactor was operated at low temperatures to avoid exceeding the limit. However, this resulted in low conversion. The poor controller resulted some improvement in terms of conversion. However, the good controller allowed operation close to the limit by reducing variability and thus improve conversion without exceeding the limit.

As mentioned earlier, variability may result from inertia of the process. However, under control, variability may also result from the action of the controller itself. If the controller is made too sensitive, it may result in a large control action even for a small change in the output.

The benefits of control are achieved through maintaining relevant variables within a bound and by minimizing their variability. the first three objectives require that the concerned variables are below their higher bounds and/or above their lower bounds. The last three objectives require that the variability of the variables are kept at minimum.

As an example of ensuring product quality, say the top product from a distillation column should contain at least 95% methanol. If top product composition varies within 2% methanol, the set-point should be $\geq 97\%$. However, this will require extra cost in terms of energy use. If the variability can be reduced to 1%, a set-point of 96% will ensure product quality; however, at a lower cost.