5ELEN018W - Robotic Principles
Lecture 6: Control - Part 1

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What is Robot Control?

- A robot needs to move its joints to achieve tasks
- A mobile robot moves to different locations

The movement of a robot (joints) is done using actuators.

In general, everything can be considered as **control**:

- Decisions we make affect (control) our future
- Decision while driving affect (control) the next position and the final location
- Control theory is a big area used not only in engineering and robotics, but in computer science
- Can be seen as what is <u>the best next action to take</u> (given a specific state) so as to <u>achieve (optimise) specific objectives!</u>

Actuators (Motors)

An actuator is a device that causes motion.

- Linear motion
- Rotary

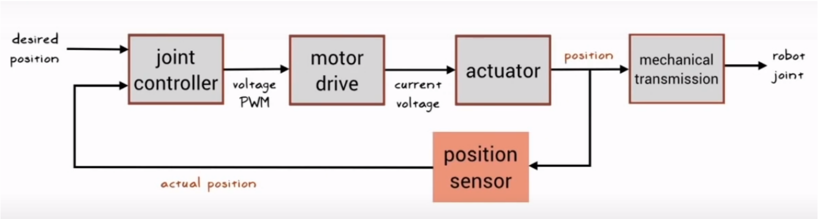
The output of an actuator can be:

- Speed
- Force (torque in the case of rotation)

Types of actuators:

- Hydraulic (using compressed oil)
- Pneumatic (using compressed air)
- Electric (using current)

Components of a Robot Joint Control System



The dynamic system that is to be controlled is called the **plant**.

Open-loop Control

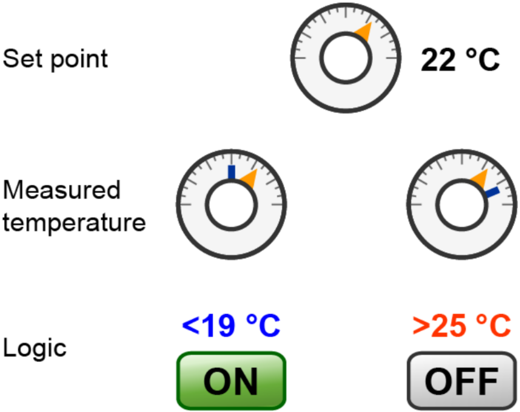
In open-loop (feedforward) control the control action from the controller is independent of the process (dynamic system or plant) output.

Example:

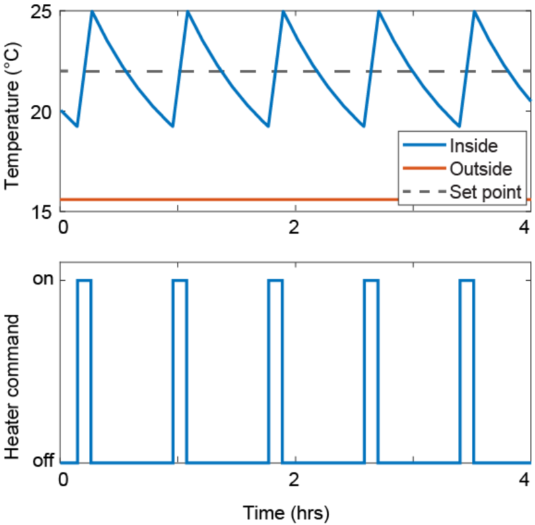
- Control of a boiler using a timer
- The controller (timer) switches the boiler on or off based on specific times and independent of the temperatures that the boiler has reached

There is no <u>feedback</u> from the plant output to the controller on what actual temperature the boiler reached.

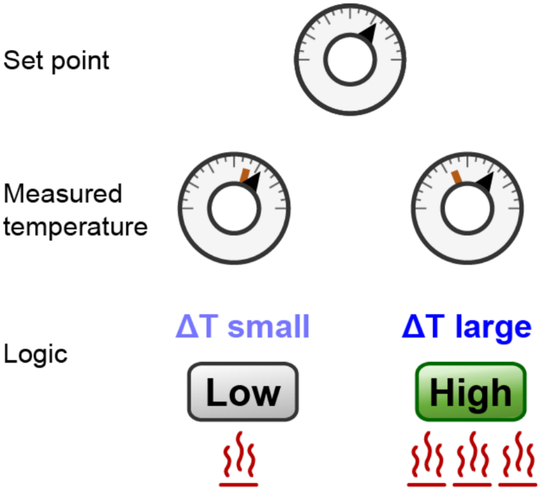
Closed-loop Control - Scenario 1



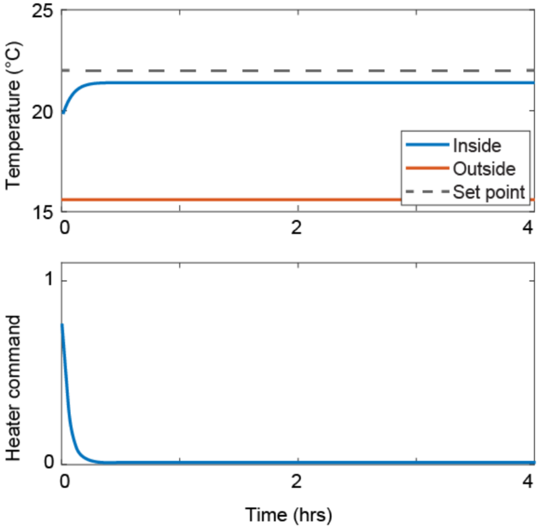
Closed-loop Control - Scenario 1 - System Responses



Closed-loop Control - Scenario 2

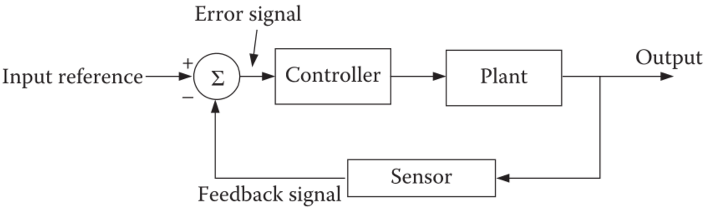


Closed-loop Control - Scenario 2 - System Responses



Closed-loop (Feedback) control

Block diagram of closed-loop control system:



Error Response

- How to measure the current error?

The desired behaviour (reference input) is compared with the current actual output value of the plant:

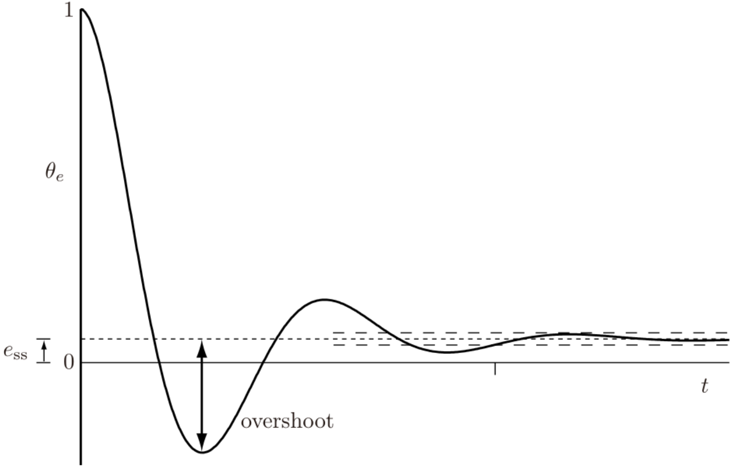
Example:
the desired joint position of a multi-joint robot is $\theta_d(t)$ and the actual joint position is $\theta(t)$, then the joint error is:

$$\theta_e = \theta_d(t) - \theta(t) \tag{1}$$

Error Response - Characteristics of a Good Controller

An ideal controller would drive the error to 0 instantly and keep it 0 forever.

- In practice, it takes time to reduce the error and a value of 0 might never be achieved.



Error Response - Characteristics of a good Controller (cont'd)

An error response $\theta_e(t)$ can be described by:

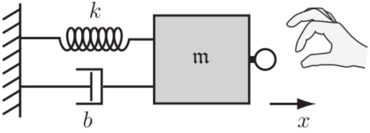
- A *steady-state response*: the error as time goes to infinity $t \to \infty$
- A *transient response*
  - $\rightarrow$ *overshoot*
  - $\rightarrow$ *settling time*

A good controller achieves an error response $\theta_e(t)$ with:

- small or no steady-state error
- little or no overshoot
- a short settling time
- stability: a steady state error is achieved (no oscillations)

A Surgical Robot - Impedance Control (Mass-Spring-Damper Example)

Simulation of a robot used as a haptic surgical simulator, mimicking the mass, stiffness and damping properties of a virtual surgical instrument in contact with virtual tissue.



- *surgical instrument* $\longrightarrow$ mass
- *tissue* $\longrightarrow$ spring

The Surgical Robot (cont'd)

The dynamics of a 1-degree of freedom robot rendering an impedance is described by:

$$m\ddot{x} + b\dot{x} + kx = f \tag{2}$$

where:

- x: is the position
- m: is the mass (surgical instrument)
- b: is the damping
- k: is the stiffness (of the tissue)
- f: is the force

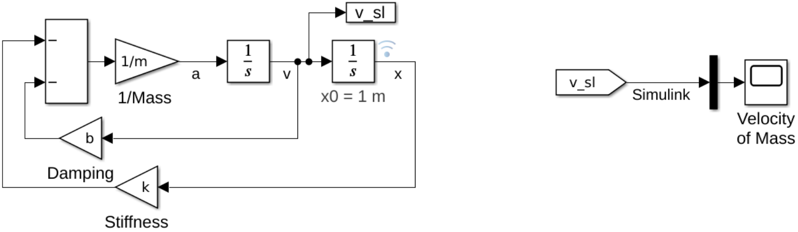
The Surgical Robot (cont'd)

To simplify, in the case that the robot force $f = 0$, the above second order differential equation can be written in the equivalent form of an algebraic equation:

$$ms^2 + bs + k = 0 \tag{3}$$

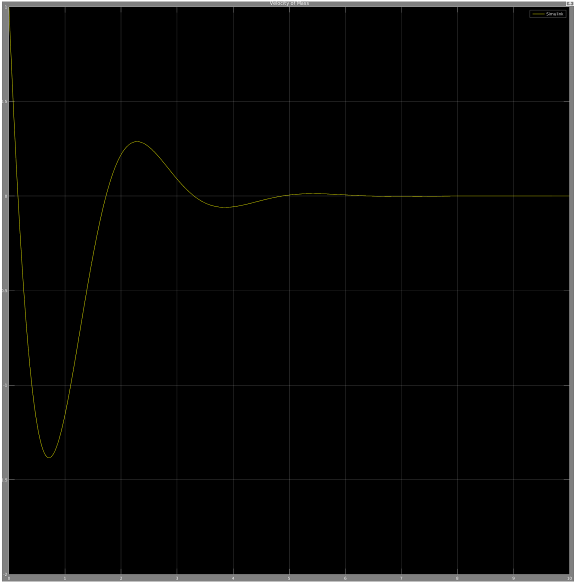
- One can solve for s, called the *poles* of the system
- The poles define the response (position) of the system as a function of time

Simulink Model of the Surgical Robot



- Experiment with different values... Start with: $b = 10,\ k = 400,\ m = 2, x_0 = 1, v_0 = 0.$

Running the Simulink Model



Multi-joint Manipulator Robot Control - Independent Joint Control

A common robot control strategy for manipulators:

- Each joint has its own controller
- Only a few parameters of the software controller need to be changed
- The parameters changed are done in a way so that they can control the different size motors attached to each joint.

Discrete vs Continuous Dynamic Systems

- Discrete dynamic systems are described by difference equations.

$$x(n) = 5 * x(n-1) + 6 * x(n-2) + 2$$

- Continuous dynamic systems are described by differential equations.

$$\ddot{x} = 5 * \dot{x} + 10 * x + 10$$

Linear vs Non-Linear Control

Although in practice many robotic systems follow non-linear dynamics:

- In many cases, a linear model can be developed
  - $\rightarrow$ It is much easier to develop controllers
  - $\rightarrow$ It is much easier to analyse mathematically
  - $\rightarrow$ It is much easier to prove mathematically the stability

Not possible to linearise complex dynamic systems!