AUTOMATIQUE ET COMMANDE NUMERIQUE

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Motivation

Why are we interested in feedback control systems ?

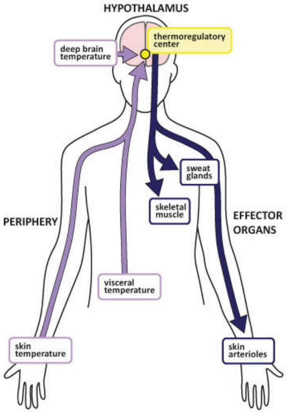
Feedback is everywhere : Biology, Economics and **ENGINEERING**

- Body temperature control
- Glucose control
- Inflation control
- Grasping by hand
- Shower temperature control
- Water level control
- Driving a car
- Robotics
- Electrical networks
- Communication networks

Body Temperature Control

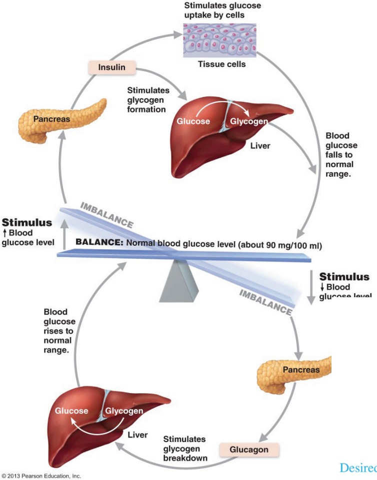
Objective : Keep the body temperature at 37°.

Process : The body balances its heat budget by metabolic activity, conduction and radiation.
Measurements : Thermo-receptors in the skin
Controller : Hypothalamus
Actuators : Sweating, Shivering, ...

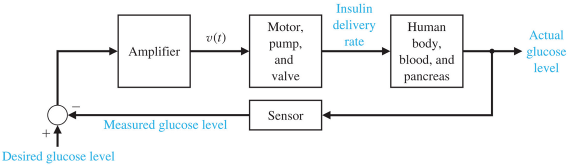


Glucose Control

Objective : Keep the blood glucose in an appropriate level.



Insulin Delivery System
(Artificial pancreas)



Inflation Rate Control

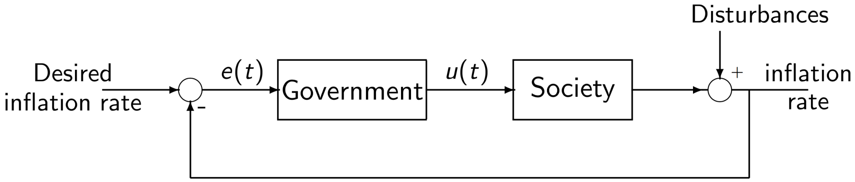
Objective : Keep the inflation rate at the desired value.

Process : The society (the relation between interest rate, direct taxes, government spending, etc and inflation rate)

Measurements : The general level of prices during a given period

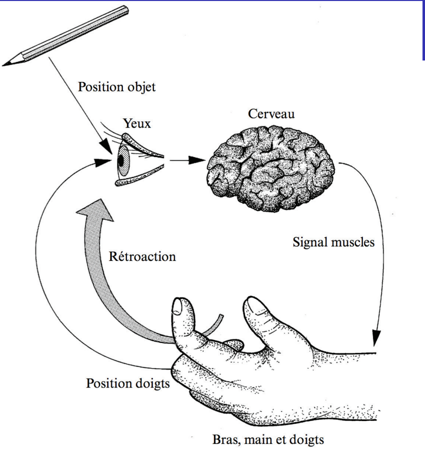
Controller : Government

Actuators : Interest rate, taxes, ...

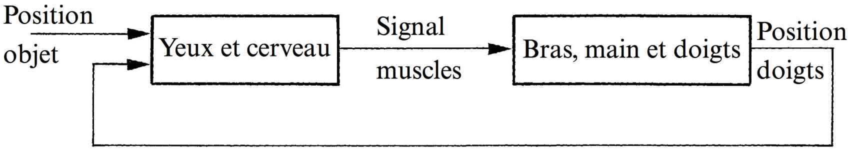


Grasping by Hand

Objective : Grasping a pencil.



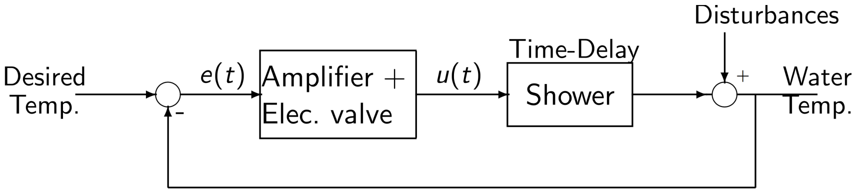
Process : Arm, hand and fingers
Measurements : By eyes (image processing)
Controller : Brain
Actuators : Muscles



Shower Temperature Control

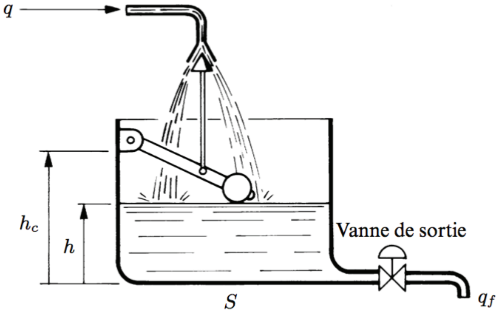
Objective : Taking shower with desired water temperature
Process : Shower
Measurements : By hand sensors
Controller : Brain
Actuators : Fingers, valve

Automatic Control :

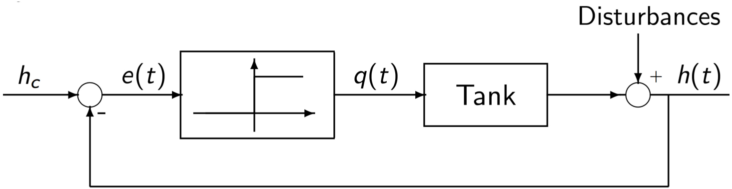


Water Level Control

Objective : Keeping the water level at a desired value
Process : Water tank
Measurements : By floater
Controller : on-off
Actuators : Valve

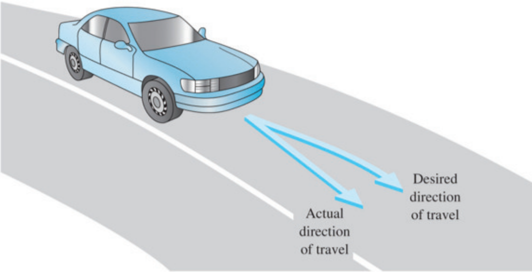


Block diagram :

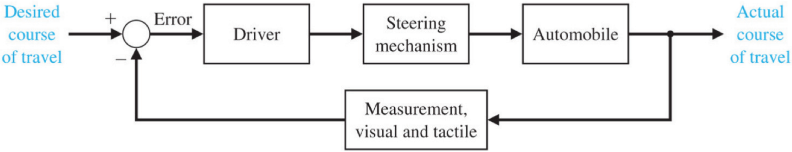


Driving a Car

Objective : Driving in a desired direction
Process : Automobile
Measurements : Visual
Controller : Driver
Actuators : Steering mechanism



Block diagram :



Driving a Car

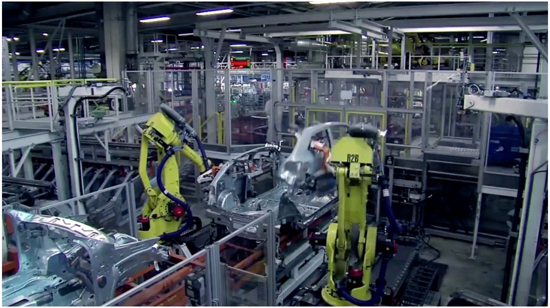
Automatic Driving

There are more than 500 feedback loops in a conventional car !

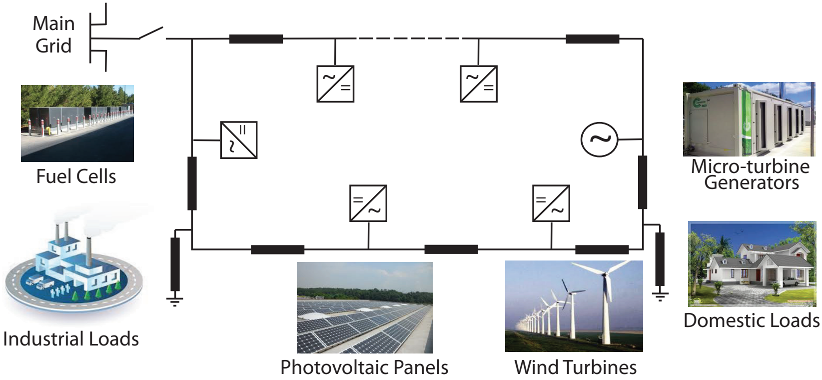
Robotics

Objective : Position control in a robotic arm
Process : Robotic arm
Measurements : Position sensors (encoders)
Controller : Computer
Actuators : Joint Servomotors

Robots in action :

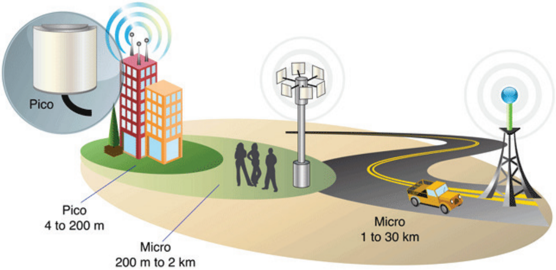


Objective : Voltage control of a microgrid in islanded mode
Process : Microgrid
Measurements : Voltage sensors
Controller : Computer
Actuators : Power electronic converters



Communication Networks

Objective : Signal quality control in mobile phones
Process : Mobile phones
Measurements : Signal quality (signal to noise ratio)
Controller : Computer
Actuators : Signal amplifier

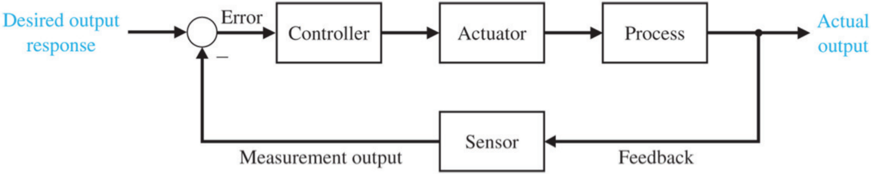


There are more than 10 feedback loops in each mobile phone
(Frequency control, gain control, transmission power control, etc.)

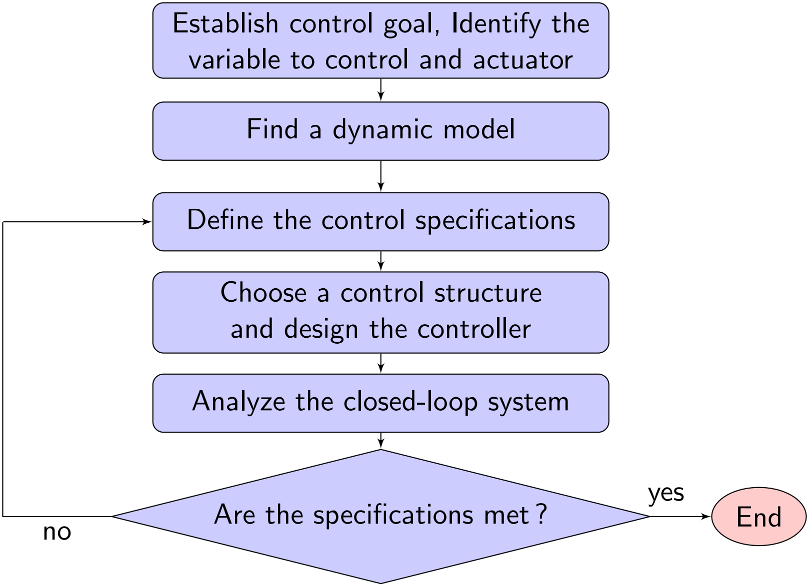
Components of Feedback Control Systems

All Feedback Control systems have four components :

- **Process** : The system to be controlled.
- **Sensor** : Measures the system output (the variable to be controlled).
- **Actuator** : Apply the command to the process.
- **Controller** : An algorithm that makes the closed-loop system to behave as we wish.



Control System Design Procedure



Course Objectives

Objective :

Analysis and Synthesis of Linear Feedback Control Systems

Learning Outcomes :

- Represent a linear dynamic system with a transfer function or a state-space model,
- Analyze a linear dynamical system (continuous- and discrete-time),
- Assess the stability, performance and robustness of a closed-loop system,
- Design PID or lead-lag controllers by loop-shaping method,
- Design optimal state-space controllers,
- Design digital RST controllers.

Teaching Method

Lectures : Question/Answer with Clickers and Written Exercises

www.echo360poll.eu

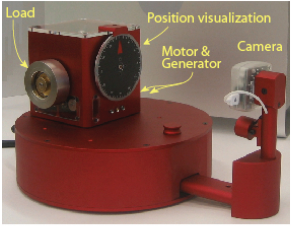
Written Exercises :
6 series of exercises with solutions. 6h of exercise sessions for answering the questions.

ed discussion

Computer Exercises :
Control of a flexible arm using different control strategies. It includes 5 Modules (10h).
The students will work in groups (three students) and their reports will be graded.

Using Jupyter Notebook

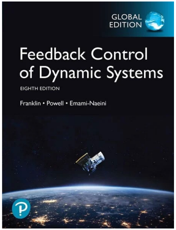
Hands-on Laboratory (Travaux Pratiques) :
5 Sessions (10h) in MED 21120 (MOOC available)



Responsible : Dr Christophe Salzmann

Objective : Control of a Servomechanism
TP sessions (1-4) can be done remotely
(5th session needs the presence of students).

Course Content



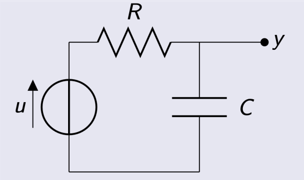
Strongly Recommended
Feedback Control of Dynamic Systems
by Franklin, Powell and Emami-Naeini,
Global Edition, 8th Edition, 2022

Chapter 1 : Introduction
Chapter 2 : Modeling of Dynamic Systems
Chapter 3 : Analysis of Dynamic Systems
Chapter 4 : Feedback Control Systems
Chapter 5 : The Root-Locus Design Methods
Chapter 6 : The Frequency-Response Methods
Chapter 7 : The State-Space Methods
Chapter 8 : Digital Control

Course Content

Chapter 2 : Modeling of Dynamic Systems

Physical reality



Model

- Variable of interest : y
- Independent variable : u
- Mathematical model :

$$y(t) = u(t) - RC\frac{dy}{dt}$$

Transfer Function : $Y(s) = U(s) - RCsY(s) \quad \Rightarrow \quad G(s) = \frac{Y(s)}{U(s)} = \frac{1}{RCs+1}$

Chapter 3 : Analysis of Dynamic Systems

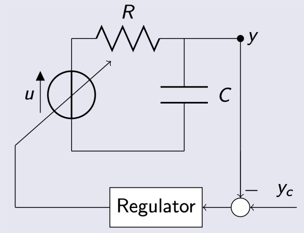
Analysis : Compute the output $y(t)$ for any input $u(t)$ (step response, impulse response, etc)

$$y(t) = \mathcal{L}^{-1}[Y(s)] = \mathcal{L}^{-1}[G(s)U(s)]$$

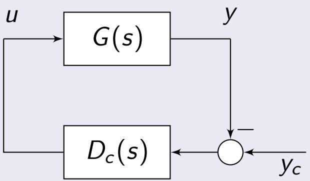
Stability **Performance**

Chapter 4 : Feedback Control Systems

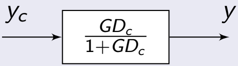
Physical reality (voltage regulator)



Closed-loop System



Simplifying block diagrams

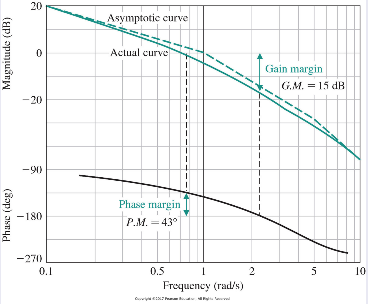


Analysis : Computing all closed-loop signals for any external input, closed-loop stability, closed-loop performance.

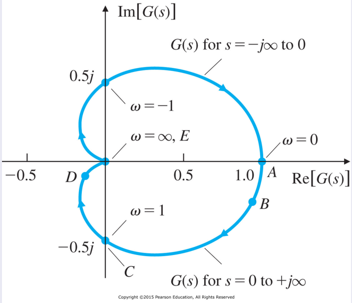
Synthesis : Design of the regulator, controller, $D_c(s)$ for the PID structure.

Chapter 6 : The Frequency Response Methods

Bode Plot



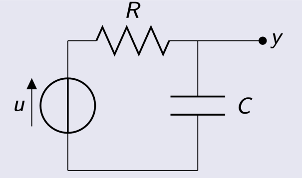
Nyquist Plot



- Sketching Bode and Nyquist plots ; Extracting information from the plots.
- Nyquist stability criterion, Gain, Phase and Modulus margins.
- Designing PID and Lead-Lag Controllers in the frequency domain (Loop Shaping Method).

Chapter 7 : The State-Space Methods

Transfer Function Model



$$y(t) = u(t) - RC\frac{dy}{dt}$$

$$G(s) = \frac{Y(s)}{U(s)} = \frac{1}{RCs + 1}$$

State-Space Model

- Variable of interest : y
- Independent variable : u
- State Variable : x

$$\dot{x}(t) = \frac{-1}{RC}x(t) + \frac{1}{RC}u(t)$$
$$y(t) = x(t)$$

General Representation

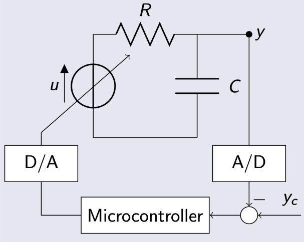
$$\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}u(t)$$
$$y(t) = \mathbf{C}\mathbf{x}(t)$$

Analysis : State-space modeling, converting TF to SS and vis-versa, Controllability, Observability.

Synthesis : Designing **optimal** state feedback controller $u(t) = \mathbf{K}\mathbf{x}(t)$ and state observer.

Chapter 8 : Digital Control

Discrete-time System



Digital Control System

- Controller is implemented on a computer (microcontroller).
- Controller sees the physical system as a digital system.
- The digital system is represented by a difference equation :
  $$y(k) = -ay(k-1) + bu(k)$$
- The z-transform is used instead of the Laplace transform.

Analysis : Analysis of discrete-time models using the z-transform and its inverse ; stability and performance of discrete-time systems.

Synthesis : Design of digital RST controller using the pole placement technique.

Course Schedule

	Wednesday		Thursday (CE12)		Friday (CE12)	
Date	13:15-15:00		10:15-12:00		10:15-12:00	
10-12 sep.	Chapter 1 (MEB 3 31)		Chapter 2		Chapter 2	
17-19 sep.	Chapter 3 (MEB 3 31)		Chapter 3		Chapter 3	
24-26 sep.	Written Ex 2-3		Chapter 4		Chapter 4	
1-3 oct.	TP1-A	CE1-B	Chapter 4		Chapter 4	
8-10 oct.	CE1-A	TP1-B	Chapter 6		Chapter 6	
15-17 oct.	TP2-A	CE2-B	Chapter 6		Chapter 6	
29-31 oct	CE2-A	TP2-B	Chapter 6		Chapter 6	
5-7 nov.	Written Ex 4-6		Chapter 7		Chapter 7	
12-14 nov.	Mid-term Exam		Chapter 7		Chapter 7	
19-21 nov.	TP3-A	CE3-B	Chapter 8		Chapter 8	
26-28 nov.	CE3-A	TP3-B	Chapter 8		Chapter 8	
3-5 dec.	TP4-A	CE4-B	Chapter 8		Chapter 8	
10-12 dec.	CE4-A	TP4-B	Chapter 8		Chapter 8	
17-19 dec.	Written Ex 7-8		CE5-A	TP5-B	TP5-A	CE5-B

TP in MED 21120 , CE in BC 07 and BC 08

Written Ex. Group A in MED 21120, Group B in BC 07 and BC 08

Exam and Grading

Report on computer exercises : Five Jupyter Notebook reports should be submitted in due times by each group of three students (1.75+1.75+2.5+3+3=12 points).

Written exam :

- Mid-term exam : Chapters 2, 3, 4 and 6 (48 points).
- Final exam : Only Chapter 7 and 8 (50 points),
  One question on TP (10 points).

Problems similar to the Written Exercises, One A4 Cheatsheet, nonprogrammable calculator

Grading :

Points	111-120	106-110	···	76-80	71-75	66-70	···	11-15	0-10
Grade	6.00	5.75	···	4.25	4.00	3.75	···	1.00	NA

Available on Moodle :

- Information about TP and Computer Exercises, Course slides
- Written Exercises with solutions (Ed discussion forum is available)

Exercise

Goto www.echo360poll.eu, Session ID : automatique

House Heating System

Provide a block diagram for the closed-loop temperature control of a house using a thermostat and a gas furnace.

Question

What is the process ? What is the actuator ?

A Gas furnace

B House

C Thermostat

D Heat

Exercise

Question

What is the output of the process ?

- A The heat generated by the furnace
- B The inside temperature of the house
- C The outside temperature
- D The back door of the house

Question

What is the reference signal ?

- A The front door of the house
- B The outside temperature of the house
- C Heat
- D Desired temperature

Exercise

Example (Household Temperature Control)