

AUTOMATIQUE ET COMMANDE NUMERIQUE

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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

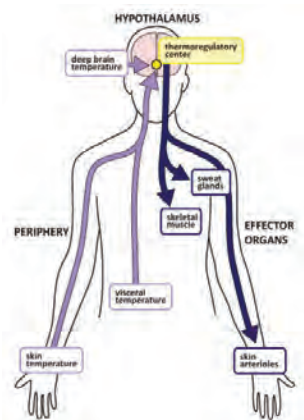
Objective : Keep the body temperature at 37° .

Process : The body balances its heat budget by metabolic activity, conduction and radiation.

Measurements : Thermo-receptors in the skin

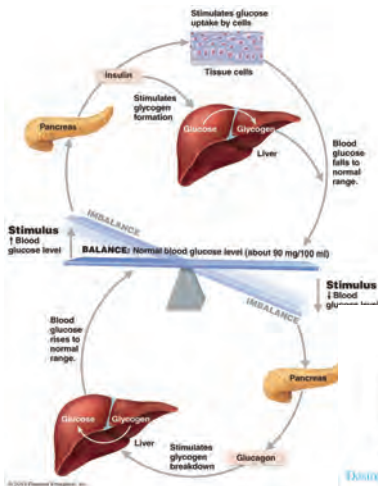
Controller : Hypothalamus

Actuators : Sweating, Shivering, ...

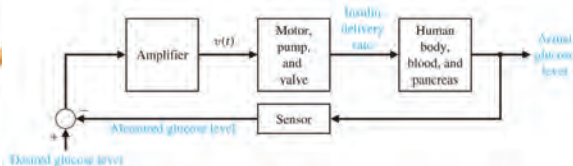


Glucose Control

Objective : Keep the blood glucose in an appropriate level.



Insulin Delivery System (Artificial pancreas)



Inflation Rate Control

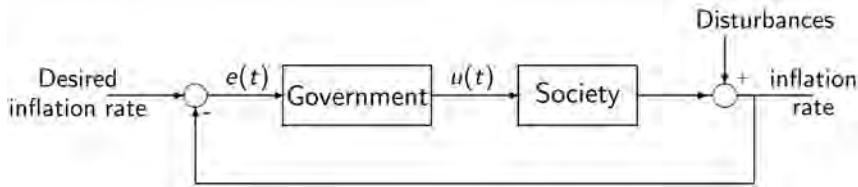
Objective : Keep the inflation rate at the desired value.

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

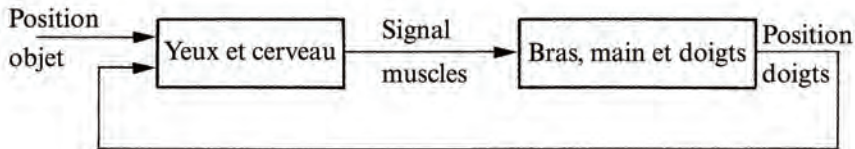
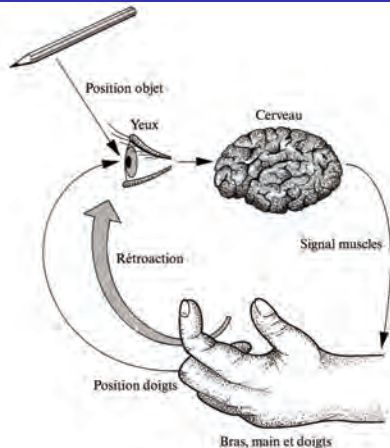
Objective : Grasping a pencil.

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

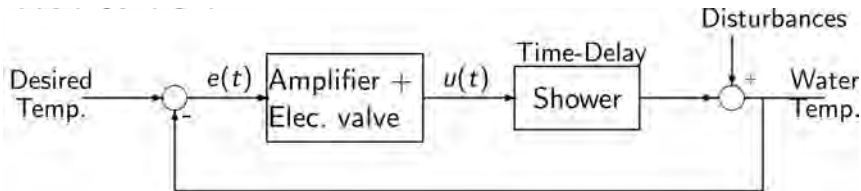
Measurements : By hand sensors

Controller : Brain

Actuators : Fingers, valve



Automatic Control :



Water Level Control

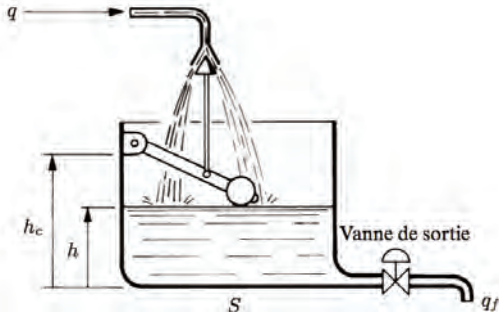
Objective : Keeping the water level at a desired value

Process : Water tank

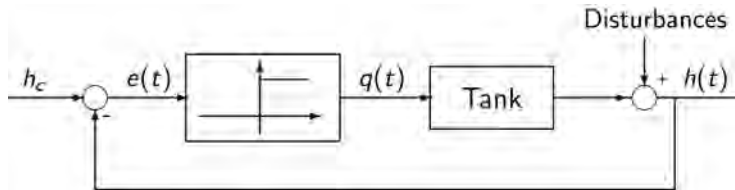
Measurements : By floater

Controller : on-off

Actuators : Valve



Block diagram :



Driving a Car

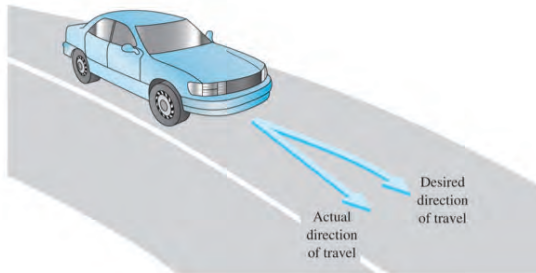
Objective : Driving in a desired direction

Process : Automobile

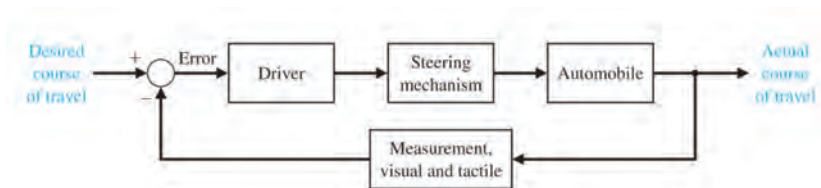
Measurements : Visual

Controller : Driver

Actuators : Steering mechanism



Block diagram :



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 :



Electrical Networks

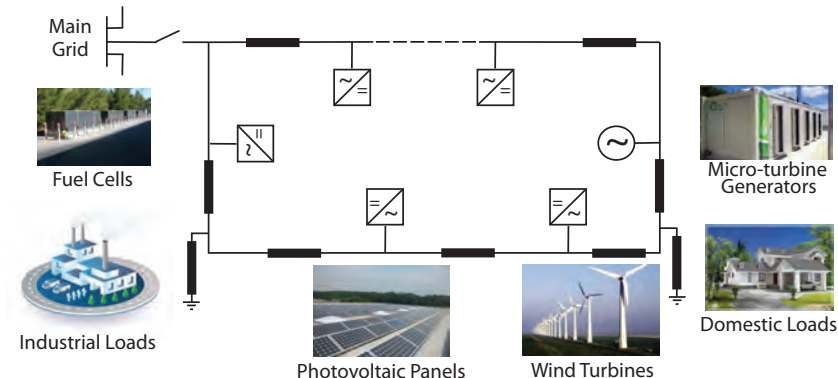
Objective : Voltage control of a microgrid in islanded mode

Process : Microgrid

Measurements : Voltage sensors

Controller : Computer

Actuators : Power electronic converters



Communication Networks

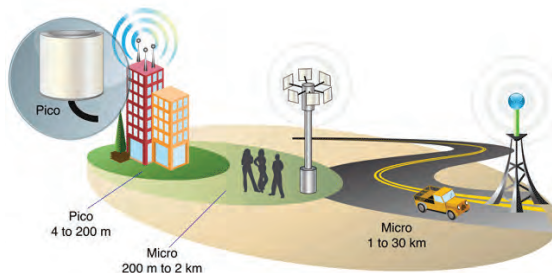
Objective : Signal quality control in mobile phones

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

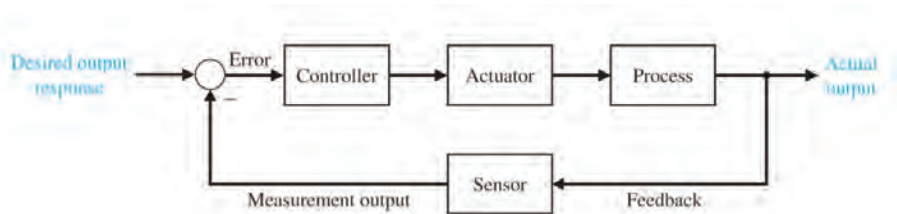
All Feedback Control systems have four components :

Process : The system to be controlled.

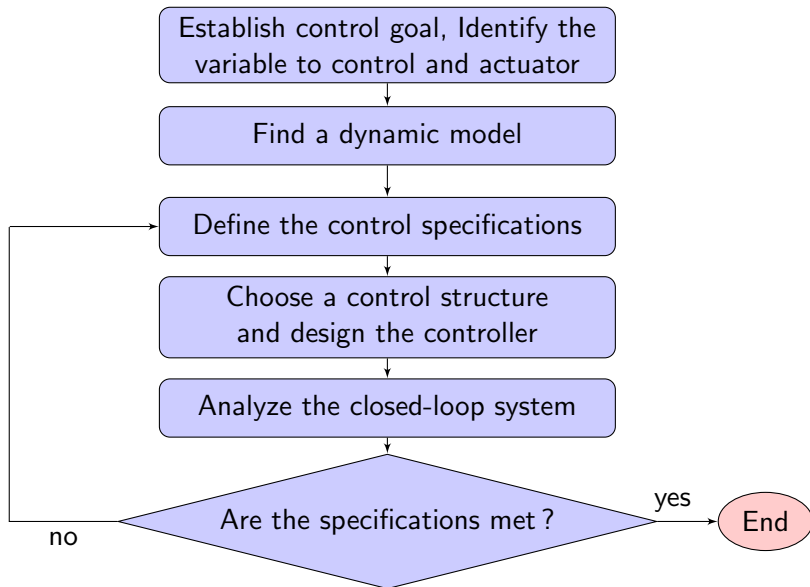
Sensor : Measures the system output (the variable to be controlled).

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



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.responseware.eu

Teaching Method

Written Exercises :

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



Computer Exercises :

Control of a flexible joint using different control strategies. It includes 5 Modules (10h).

The students will work in groups (three students) and their reports will be graded.

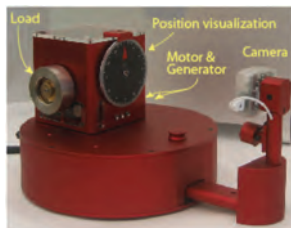


Using Jupyter Notebook

Teaching Method

Hands-on Laboratory (Travaux Pratiques) :

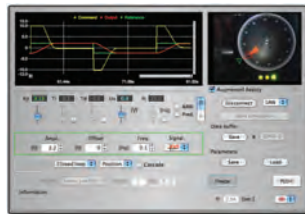
5 Sessions (10h) in MED 21120 (MOOC available)



Responsible : Dr Christophe Salzmann

Objective : Control of a Servomechanism

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





Strongly Recommended

Feedback Control of Dynamic Systems

by Franklin, Powell and Emami-Naeini,

Global Edition, 7th Edition, 2017.

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

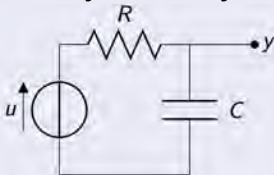
Chapter 7 : The State-Space Methods

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

Chapter 3 : Analysis of Dynamic Systems

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

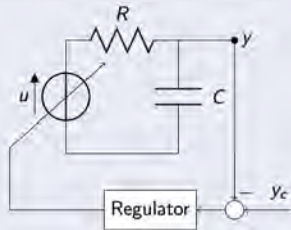
$$y(t) = \mathcal{L}^{-1}[Y(s)] = \mathcal{L}^{-1}[G(s)U(s)]$$

Stability

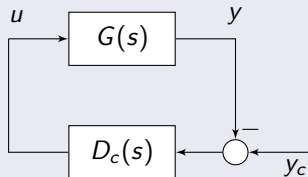
Performance

Chapter 4 : Feedback Control Systems

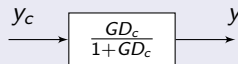
**Physical reality
(voltage regulator)**



Closed-loop System



Simplifying block diagrams

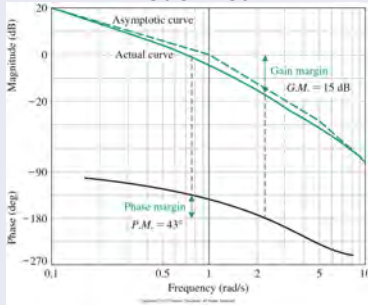


Analysis : Computing all closed-loop signals for any external input, closed-loop stability, closed-loop performance.

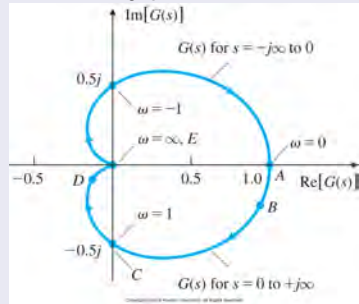
Synthesis : Design of the regulator, controller, $D_c(s)$ for the PID structure.

Chapter 6 : The Frequency Response Methods

Bode Plot



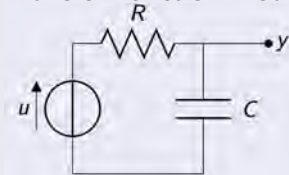
Nyquist Plot



- 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



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

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

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.

State-Space Model

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

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

$$y(t) = x(t)$$

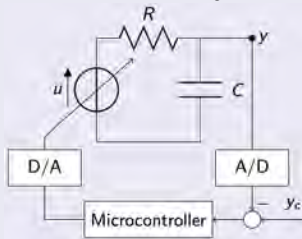
General Representation

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

$$y(t) = \mathbf{C}\mathbf{x}(t)$$

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 (CM4)	Friday (CM3)
Date	13:15-15:00	10:15-12:00	10:15-12:00
11-13 sep.	Introduction (SG 0211)	Chapter 2	Chapter 2
18-20 sep.	Chapter 3 (CE 1106)	Chapter 3	Chapter 3
25-27 sep.	Written Ex 2-3	Chapter 4	Chapter 4
2-4 oct.	TP1-A CE1-B	Chapter 4	Chapter 4
9-11 oct.	CE1-A TP1-B	Chapter 6	Chapter 6
16-18 oct.	TP2-A CE2-B	Chapter 6	Chapter 6
30 oct-1 nov.	CE2-A TP2-B	Chapter 6	Chapter 6
6-8 nov.	Written Ex 4-6	Chapter 7	Chapter 7
13-15 nov.	Mid-term Exam	Chapter 7	Chapter 7
20-22 nov.	TP3-A CE3-B	Chapter 8	Chapter 8
27-29 nov.	CE3-A TP3-B	Chapter 8	Chapter 8
4-6 dec.	TP4-A CE4-B	Chapter 8	Chapter 8
11-13 dec.	CE4-A TP4-B	Chapter 8	Chapter 8
18-20 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

Report on computer exercises : Five Jupyter Notebook reports should be submitted in due times by each group of three students ($1.5+1.5+2+2.5+2.5=10$ points).

Written exam :

- Mid-term exam : Chapters 2, 3, 4 and 6 (40 points).
- Final exam : Only Chapter 7 and 8 (40 points),
One question on TP (10 points).

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

Grading :

Points	96-100	91-95	...	56-60	51-55	...	6-10	1-5	0
Grade	6.00	5.75	...	4.00	3.75	...	1.50	1.25	1.00

Available on Moodle :

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

Goto www.echo360poll.eu, Session ID : [automatique](#)

House heating system

Provide a block diagram for closed-loop temperature control in 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

Question

What is the output of the process

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

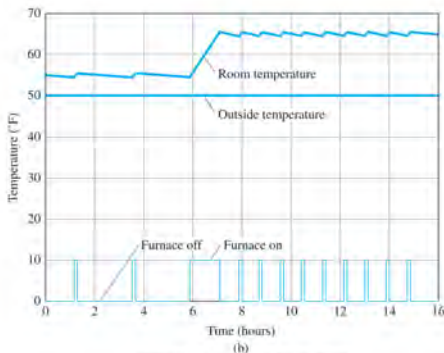
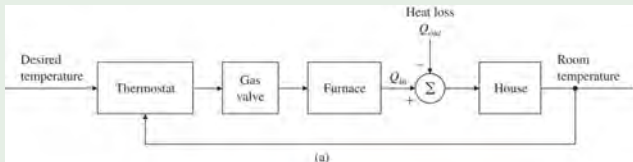
Question

What is the reference signal

- A the entrance door,
- B the outside temperature of the house
- C heat
- D desired temperature

Exercise

Example (Household Temperature Control)



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