Chapter 1. Introduction to Intelligent Control System

Luis Miguel Bergasa

Introduction to ICS
General information

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- Degree in
  - Computer Science Engineering (Obligatory)
  - Computer Engineering, Engineering in Information Systems (Optional)
- Course Webpage: http://www.uah.es/aula_virtual/

Introduction to ICS
General information

Computer Science Engineering

HORA	LUNES	MARTES	MIÉRCOLES	JUEVES	VIERNES
8:00/8:55		*Lab.* Fundamentos de la Ciencia de Datos – *A1 (NL8)*			
9:00/ 9:55		*Lab.* Fundamentos de la Ciencia de Datos – *A1 (NL8)*		OPT: ARQ. Y DISENO DE SISTEMAS WEB Y C/S **(NA6)**	
10:00/10:55	SISTEMAS DE CONTROL INTELIGENTES **(NA6)**	FUNDAMENTOS DE LA CIENCIA DE DATOS (SA8) ***(EF)***	*Lab. Aplicaciones de Sotf Computing* **(SL7)** ***(EF)*** *Lab. Sistemas Audiovisualies y App. Mul.* **(SL7)** OPT: REDES DEFINIDAS POR SOFTWARE **(EA2)** ***(EF)***	*Lab. Arq. y Diseno de Sistemas Web y C/s –* A1 **(NL11)** OPT: SIST. CONTROL PARA ROBOTS **(NA6)**	*Lab. Sistemas Audiovisualies y App. Mul.* **(SL7)**
11:00/11:55	SISTEMAS DE CONTROL INTELIGENTES **(NA6)**	FUNDAMENTOS DE LA CIENCIA DE DATOS (SA8) ***(EF)***	*Lab. Aplicaciones de Sotf Computing* **(SL7)** ***(EF)*** *Lab. Sistemas Audiovisualies y App. Mul.* **(SL7)** OPT: REDES DEFINIDAS POR SOFTWARE **(EA2)** ***(EF)***	*Lab. Arq. y Diseno de Sistemas Web y C/s – A1* **(NL11)** OPT: SIST. CONTROL PARA ROBOTS **(NA6)**	*Lab. Sistemas Audiovisualies y App. Mul.* **(SL7)**
12:00/12:55	Lab. Sistemas de Control Inteligentes – A1 (OL1) -A2 (OL5)	*Lab.* Fundamentos de la Ciencia de Datos – *A2 (NL8)*	*Lab. Aplicaciones de Sotf Computing* **(SL7)** *Lab. Redes Definidas por Software* **(EL11)**	*Lab. Sist. Control Para Robots* **(PL21)** *Lab. Arq. y Diseno de Sistemas Web y C/s – A2* **(NL11)**	*Lab. Sistemas Audiovisualies y App. Mul.* **(SL7)**
13:00/13:55	Lab. Sistemas de Control Inteligentes – A1 (OL1) -A2 (OL5)	*Lab.* Fundamentos de la Ciencia de Datos – *A2 (NL8)*	*Lab. Aplicaciones de Sotf Computing* **(SL7)** *Lab. Redes Definidas por Software* **(EL11)**	*Lab. Sist. Control Para Robots* **(PL21)** *Lab. Arq. y Diseno de Sistemas Web y C/s – A2* **(NL11)**	*Lab. Sistemas Audiovisualies y App. Mul.* **(SL7)**
14:00/14:55					
15:00/15:55	Lab. Sistemas de Control Inteligente – A3 (OL5)	*Lab. Sistemas de Visión Artificial* **(OL11)** *Lab. Patrones Software –A1* **(NL11)**		*Lab. Sistemas de Visión Artificial* **(OL11)** *Lab. Arq. y Diseno de Sistemas Web y C/s – A3* **(NL10)**	
16:00/16:55	Lab. Sistemas de Control Inteligente – A3 (OL5)	*Lab. Sistemas de Visión Artificial* **(OL11)** *Lab. Patrones Software –A1* **(NL11)**		*Lab. Sistemas de Visión Artificial* **(OL11)** *Lab. Arq. y Diseno de Sistemas Web y C/s – A3* **(NL10)**	
17:00/17:55		OPT: PATRONES SOFTWARE **(OA3)** ***(EF)***			
18:00/18:55		OPT: PATRONES SOFTWARE **(OA3)** ***(EF)***			
19:00/19:55		*Lab. Patrones Software* **–A2 (NL9)**			
20:00/20:55		*Lab. Patrones Software* **–A2 (NL9)**			

Introduction to ICS
General information

Computer Engineering, Engineering in Information Systems

HORA	LUNES	MARTES	MIÉRCOLES	JUEVES	VIERNES
8:00/8:55					
9:00/ 9:55				OPT: ARQ. Y DISENO DE SISTEMAS WEB Y C/S **(NA6)**	
10:00/10:55		GESTION DE REDES Y SEGURIDAD **(NA6)** ***(EF)***	*Lab. Aplicaciones de Sotf Computing* **(SL7)** ***(EF)*** *Lab. Sistemas Audiovisualies y App. Mul.* **(SL7)** SISTEMAS DE CONTROL INTELIGENTES **(NA8)** OPT: REDES DEFINIDAS POR SOFTWARE **(EA2)** ***(EF)***	*Lab. Arq. y Diseno de Sistemas Web y C/s –* A1 **(NL11)** OPT: SIST. CONTROL PARA ROBOTS **(NA6)**	*Lab. Sistemas Audiovisualies y App. Mul.* **(SL7)** OPT: COMPUTACIÓN DE ALTAS PRESTACINES (SA5A)
11:00/11:55		GESTION DE REDES Y SEGURIDAD **(NA6)** ***(EF)***	*Lab. Aplicaciones de Sotf Computing* **(SL7)** ***(EF)*** *Lab. Sistemas Audiovisualies y App. Mul.* **(SL7)** SISTEMAS DE CONTROL INTELIGENTES **(NA8)** OPT: REDES DEFINIDAS POR SOFTWARE **(EA2)** ***(EF)***	*Lab. Arq. y Diseno de Sistemas Web y C/s – A1* **(NL11)** OPT: SIST. CONTROL PARA ROBOTS **(NA6)**	*Lab. Sistemas Audiovisualies y App. Mul.* **(SL7)** OPT: COMPUTACIÓN DE ALTAS PRESTACINES (SA5A)
12:00/12:55		*Lab. Gestion de Redes y Seguridad- A1 (NL5)* **-***A2 (EL11)*	*Lab. Aplicaciones de Sotf Computing* **(SL7)** *Lab. Sistemas de Control Inteligentes* **(OL1)** *Lab. Redes Definidas por Software* **(EL11)**	*Lab. Sist. Control Para Robots* **(PL21)** *Lab. Arq. y Diseno de Sistemas Web y C/s – A2* **(NL11)**	*Lab. Sistemas Audiovisualies y App. Mul.* **(SL7)** *Lab. Computación De Altas Prestacines (NL5)*
13:00/13:55		*Lab. Gestion de Redes y Seguridad- A1 (NL5)* **-***A2 (EL11)*	*Lab. Aplicaciones de Sotf Computing* **(SL7)** *Lab. Sistemas de Control Inteligentes* **(OL1)** *Lab. Redes Definidas por Software* **(EL11)**	*Lab. Sist. Control Para Robots* **(PL21)** *Lab. Arq. y Diseno de Sistemas Web y C/s – A2* **(NL11)**	*Lab. Sistemas Audiovisualies y App. Mul.* **(SL7)** *Lab. Computación De Altas Prestacines (NL5)*
14:00/14:55					
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16:00/16:55		*Lab. Sistemas de Visión Artificial* **(OL11)** *Lab. Patrones Software –A1* **(NL11) –**		*Lab. Sistemas de Vision Artificial* **(OL11)** *Lab. Arq. y Diseno de Sistemas Web y C/s – A3* **(NL10)**	
17:00/17:55		OPT: PATRONES SOFTWARE **(OA3)** ***(EF)***			
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19:00/19:55		*Lab. Patrones Software* **–A2 (NL9)**			
20:00/20:55		*Lab. Patrones Software* **–A2 (NL9)**			

Introduction to ICS
Chapters

- Theory
  - Chapter 1. Introduction to Intelligent Control Systems
  - Chapter 2. Basic concepts of discrete control
  - Chapter 3. Introduction of the Neural Networks
  - Chapter 4. Neural Control
  - Chapter 5. Introduction to the Fuzzy Logic
  - Chapter 6. Fuzzy Control
- Practices
  - Training 1. Introduction to MATLAB-SIMULINK
  - Training 2. Identification and neural control
  - Training 3. Fuzzy control
  - Final project. ICS for a mobile robot

Introduction to ICS
Calendar

Sesión	Fecha	Horas	Dur	Temario
S1	09-09	10-11	1h	Presentación
S2	09-09	11-12	1h	Tema 1 (T)
S3-S4	16-09	10-12	2h	Tema 2-1 (T) Tema 2-2 (T)
S5-S6	16-09	12-14	2h	Training MATLAB – 1 Training MATLAB - 2
S7-S8	23-09	10-12	2h	Tema 2-3 (P) Tema 2-4 (P)
S9-S10	23-09	12-14	2h	Training MATLAB – 3 Training MATLAB - 4
S11-S12	30-09	10-12	2h	Tema 3-1 (T) Tema 3-2 (T)
S13-S14	30-09	10-12	2h	Training CN – 1 Training CN – 2
S15-S16	07-10	10-12	2h	Tema 3-3 (T) Tema 3-4 (T)
S17-S18	07-10	12-14	2h	Training CN – 3 Training CN – 4
S19-S20	14-10	10-12	2h	Tema 4-1 (T) Tema 4-2 (T)
S21-S22	14-10	12-14	2h	Training CN – 5 Training CN – 6
S23-S24	21-10	12-14	2h	Tema 4-3 (T) Tema 4-4 (T)
S25-S26	21-10	12-14	2h	Problemas CN-1 Problemas CN-2
S27-S28	28-10	10-12	2h	Tema 5-1 (T) Tema 5-2 (T)
S29-S30	28-10	12-14	2h	Tema 5-3 (T) Tema 5-4 (T)
S31-S32	04-11	10-12	2h	Tema 6-1 (T) Tema 6-2 (T)
S33-S34	04-11	12-14	2h	Problemas CB-1 Problemas CB-2
S35-S36	11-11	10-12	2h	Tema 6-3 (T) Tema 6-4 (T)
S37-S38	11-11	12-14	2h	Training CB – 1 Training CB – 2
S39-S40	18-11	10-12	2h	Problemas CB-3 Problemas CB-4
S41-S42	18-11	12-14	2h	Training CB – 3 Training CB – 4
TCB	25-11	10-11	1h	Test de conceptos básicos
S44-S46	25-11	11-14	3h	Miniproyecto
S47-S50	02-12	10-14	4h	Miniproyecto
S51-54	16-12	10-14	4h	Miniproyecto

Introduction to ICS
Evaluation

➢ Writing test	40 points
➢ Research final project	40 points
➢ Report quality	20%
➢ Scientific method and results	60%
➢ Presentation	20%
➢ Lab Training	20 points

Introduction to ICS
Bibliography

- Basic
  - A First Course in Fuzzy and Neural Control. Hung T. Nguyen, Nadipuram R. Prasad, Carol L. Walker, Elbert A. Walker. Chapman and Hall/CRC. 2002
- Complementary
  - Neural Network Design. Martin T. Hagan, Howard. B. Demuth, Mark Beale. PWS Publishing Company, Thomson Learning. 2002
  - Application of Neural Networks to Adaptive Control of Nonlinear Systems. G. W. Ng. Research Studies Press Ltd. England. 2003
  - Neural Control Engineering: The Emerging Intersection between Control Theory and Neuroscience. Steven J. Schiff. The MIT Press. Firts edition 2012
  - Redes Neuronales y Sistemas Borrosos. Bonifacio Martín del Brío y Alfredo Sanz Molina. Ed. RAMA. 2001
  - Fuzzy Control. Kevin M. Passino, Stephen Yurkovich. Addison Wesley Publishing Company. First edition 1997
  - An Introduction to Fuzzy Control. D. Driankov, H. Hellendoorn and M. Reinfrank. Springer-Verlag. 1996
  - Adaptive Fuzzy Systems and Control Design and Stability Analysis. Li-Xin Wang. University of California at Berkeley. PTR Prentice Hall. 1994
  - Controladores en lógica borrosa. Javier Holgado Corrales. Servicio de Publicaciones de la Universidad de Cadiz. 1995

Introduction to ICS
Course Requirements

- Essential prerequisites
  - Classical Control
  - Linear algebra
  - Numeric methods
  - Basic knowledge of MATLAB
- Will not be covered
  - Review of all architectures and learning rules (only focused in control systems)
  - HW implementation
  - Biology

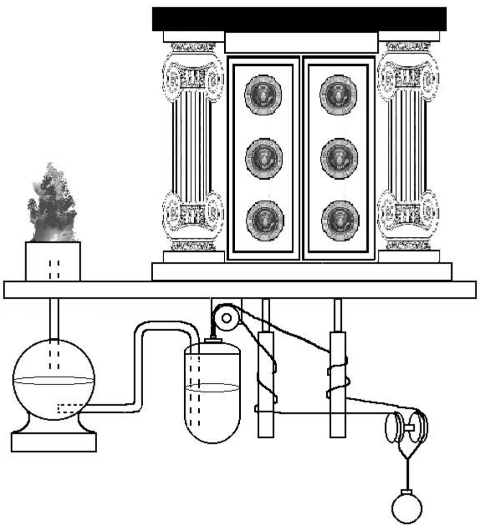
Introduction to ICS
General Goals

- This course gives an introduction to discrete control, neural network architectures and fuzzy logic principles
- Emphasis is placed on their application to control systems from a theoretical and practical point of view
- An implementation of a neural controller, fuzzy controller and neuro-fuzzy controller is done
- A review of the genetic algorithms and their application in control systems is then carried out

Introduction to ICS
General Overview

- Intelligent Control Systems
  - Neural Control Systems (NCS)
  - Fuzzy Control Systems (FCS)
  - Neuro-Fuzzy Control Systems
- Soft Computing
  - Neural Networks (NNs)
  - Fuzzy Logic (FL)
  - Genetic Algorithms (GA)

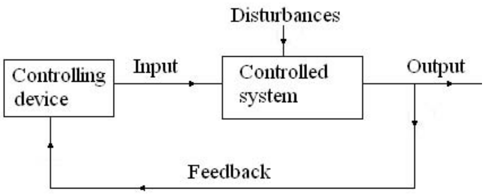
A Prelude to Control Theory
An Ancient Control System



- Amazing control system invented about 2000 years ago by Hero of Alexandria (c. I AD)

A Prelude to Control Theory
Examples of Control Problems

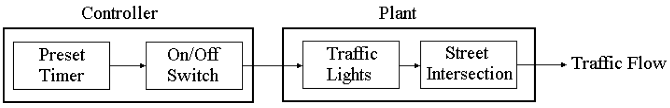
- The goal of **control theory** is to force a system to behave the way we want
- **Control system:**



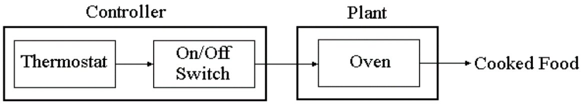
- Classification:
  - Open-loop control
  - Closed-loop control

A Prelude to Control Theory
Examples of Control Problems

- **Open-loop control**
  - Control systems operating without feedback regarding the system behavior
  - Example 1 (Traffic light)

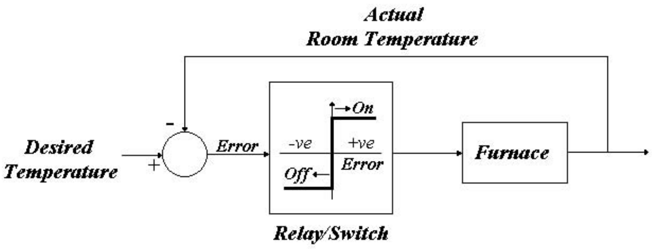


  - Example 2 (Conventional oven)



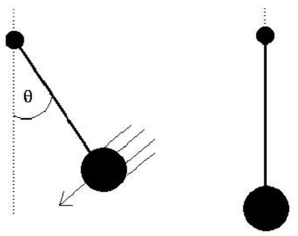
A Prelude to Control Theory
Examples of Control Problems

- **Closed-loop or feedback control**
  - The behavior of the system is observed by some sensory device, and the observations are fed back so that a comparison can be made about how well the system is behaving in relation to some desired performance.
  - Example 1 (Temperature control)



A Prelude to Control Theory
Stable and Unstable Systems

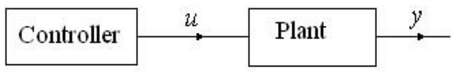
- **Stability of a system**
  - The ability of the system to maintain equilibrium or resume its original position after displacement.



- **Stable system**
- **Unstable system**

A Prelude to Control Theory
A look at controller design

- **Control law**
  - The engineering problem: How do you find the function u and how do you implement it?



- **Example: cruise control (open-loop case)**
  - We want to keep the speed of a car at y_0 = 65 mph for all $t > t_0$

$$y(t) = f(u(t))$$

Given y_0, the problem is to find the control function $u_0(t)$ such that

$$f(u_0(t)) = y_0 \quad for\ t > t_0$$

f -> mathematical model of the plant

A Prelude to Control Theory
A look at controller design

- **Classical approach: standard control theory**
  - Focuses on finding a **mathematical model of the plant**
    - **Analysis**, collecting information pertinent to the control problem
    - **Synthesis**, constructing a successful control law
  - **Problems**:
    - Requires detailed knowledge of the plant
    - The model is, at best, an approximate representation of the actual physical system

$$\frac{d^2x(t)}{dt^2} + \frac{a\,dx(t)}{dt} = b\,u(t) \qquad , x(t): car's\ \ position$$

$$y(t) = \frac{dx(t)}{dt} \qquad , y(t): car's\ velocity \longrightarrow \frac{dy(t)}{dt} + a\,y(t) = b\,u(t)$$

A Prelude to Control Theory
A look at controller design

- **Classical approach: standard control theory**
  - **Concrete solution**

$$y(t) = y_0, for\, t > t_0 \rightarrow \frac{dy(t)}{dt} = 0 \rightarrow u(t) = \left(\frac{a}{b}\right) y_0$$

  - **Second-order linear differential equation**: Laplace Transforms in the frequency domain

$$\frac{dy(t)}{dt} + a\, y(t) = b\, u(t)$$

$$\downarrow L\{\ \}$$

$$sY(s) + aY(s) = bU(s) \rightarrow U(s) = \frac{(s+a)}{b} Y(s)$$

$$\downarrow L^{-1}\{\ \}$$

$$u(t)$$

$$Y(s) = L\{y(t)\}$$
$$U(s) = L\{u(t)\}$$
$$y(t) = L^{-1}\{Y(s)\}$$
$$u(t) = L^{-1}\{U(s)\}$$

A Prelude to Control Theory
A look at controller design

- **Classical approach: standard control theory**
  - **Closed-loop control**

$$y(t) - y_0 = e(t) \rightarrow u(t) = g(e(t)) = h(y(t), y_0)$$

    - The problem is to find the function g or to approximate it from observable values of u(t) and y(t)
    - For LTI systems the so-called **proportional integral derivative (PID)** controllers work satisfactorily
    - There exist systematic ways to design successful PID controllers knowing the plant model.

Modern approach: intelligent control theory

- How can you control complicated systems whose plant dynamics are difficult to know?
- We can **approximate a plausible control law**, either from a collection of if .. . then. . . rules or from training data **without a mathematical model for the plant**
- This is the philosophy of the fuzzy and neural approaches to control (**weaker knowledge**)
- There are parameters in these controllers but they are adjusted by training samples or trial and error. There is no need for analytical mathematical models in this process.