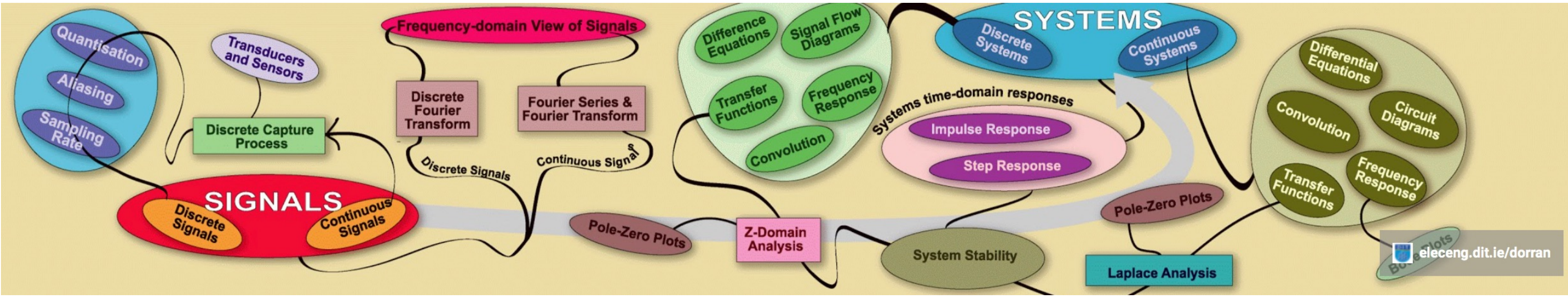
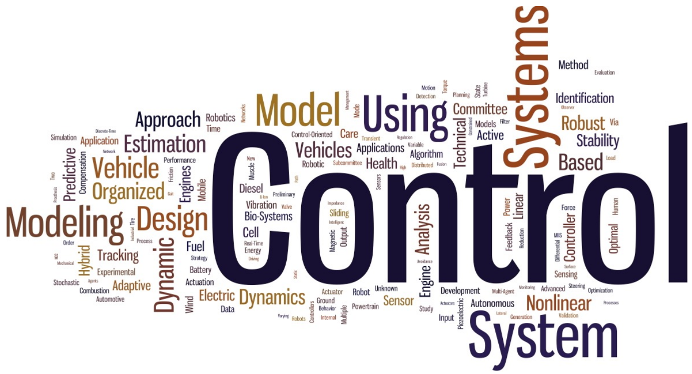


From David Dorran's youtube channel



Hugues GARNIER

hugues.garnier@univ-lorraine.fr

Version of February 10, 2024

Timeline in Automatic Control

First computer
End of 1940

Prehistoric **1868** ***Primitive*** **1910** ***Classical*** **1960** ***Modern***

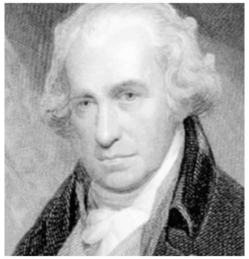
Classical:

- **Control**
- **Laplace transform**
- **Transfer function**
- **Feedback loop**
- …

Modern:

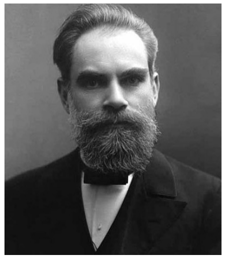
Space Program

- **Digital control**
- **Z- transform**
- **State-space model**
- …



James **Watt**
1736-1819

James **Maxwell**
1831-1879

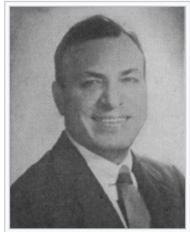


Alexandre **Lyapounov**
1857-1918

Harold **Black**
1898-1983

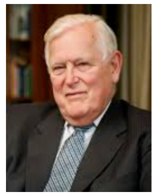
Harry **Nyquist**
1889-1976

Henrik **Bode**
1905-1982



John **Ragazzini**
1912-1988
(involved in the Manhattan project)

Gene **Franklin**
1927-2012

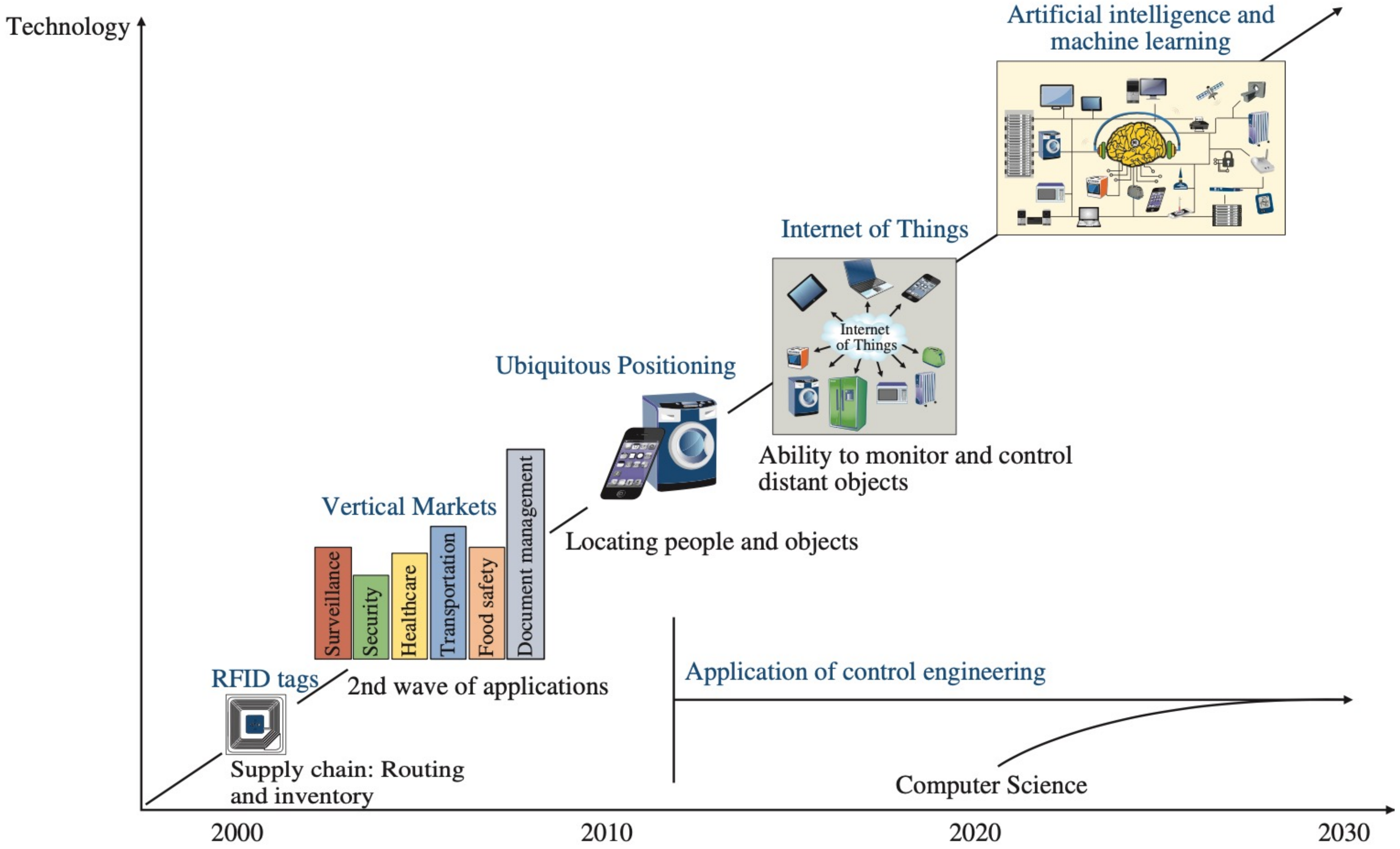


Rudolf **Kalman**
1930-2016

Eliahu **Jury**
1923-2020

They all have been PhD student of John **Ragazzini**

Technology roadmap to the IoT enhanced with IA with applications to control engineering (Source: SRI Business Intelligence)



Two separate parts for a total of 36 hours

- ***Digital control***
  - 6h of lecture
  - 8 h of tutorials
  - 4h of Labs
- ***State-space control***
  - 5h of lecture
  - 6h of tutorials
  - 4h of Labs

Course materials in English

- Lectures
  - Hugues Garnier
- Tutorials/Labs
  - Hugues Garnier
  - Floriane Collin
- Lectures/tutorials
  - Gilles Millérioux
- Labs
  - Hugues Garnier
  - Floriane Collin

Examination

- Exam 1 (2h00) *– Digital control*
  - In March
- Exam 2 (1h00) *– State-space model & control*
  - June 12, 16h30-17h30
- 1 Homework (HW)
  - In pairs
- 1 Lab report
  - In pairs

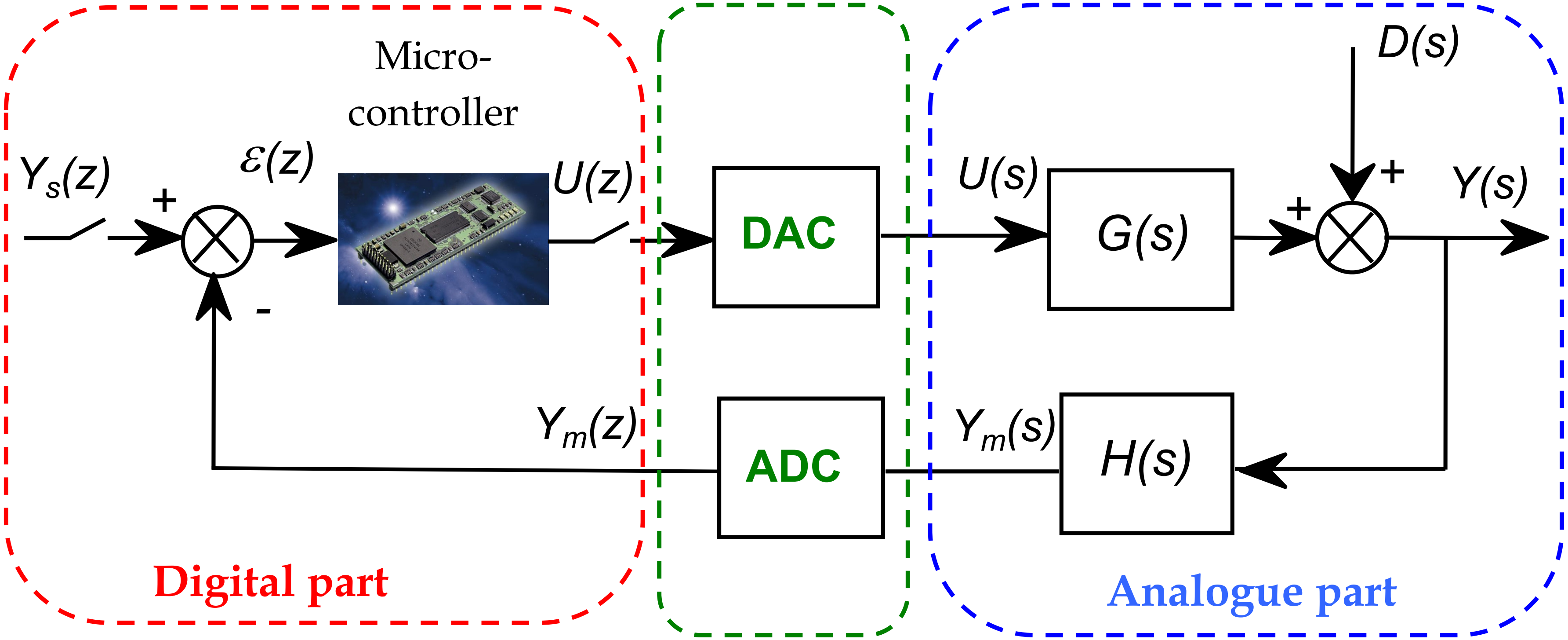
- Calculation of the final grade for the course

Final grade = 0,1 HW+ 0,4 Exam 1 + 0.25 Lab report + 0.25 Exam 2

Rule for the lectures

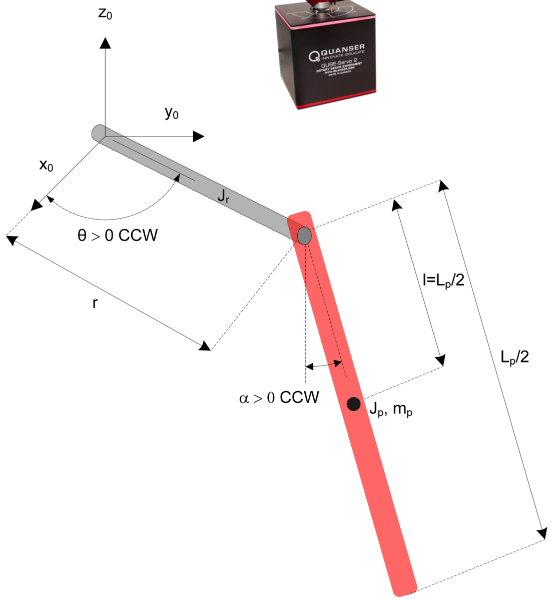
- It is forbidden to use your PC, tablet or cell phone during the course

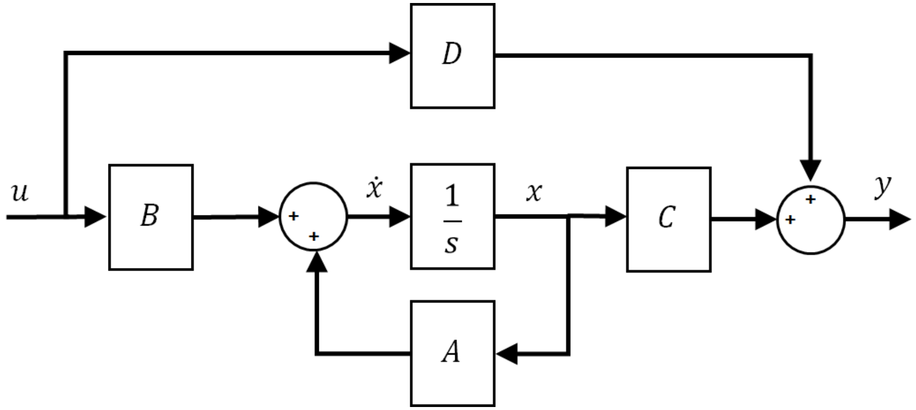
First part of the course: digital control
more appropriate to the current controller implementation



- Need for blocks to enable analogue and digital parts to interact : Digital to Analogue Converter (DAC) and ADC
- New mathematical tool to ease the analysis: the Z-transform
- PID controllers implemented digitally: discretization methods

Second part: State-space models and control more appropriate for the control of complex systems





$$\ddot{\theta} = \frac{1}{J_t}\left(m_p^2 l^2 r g\alpha - J_p b_r \dot{\theta} + m_p l r b_p \dot{\alpha} + J_p \tau\right)$$

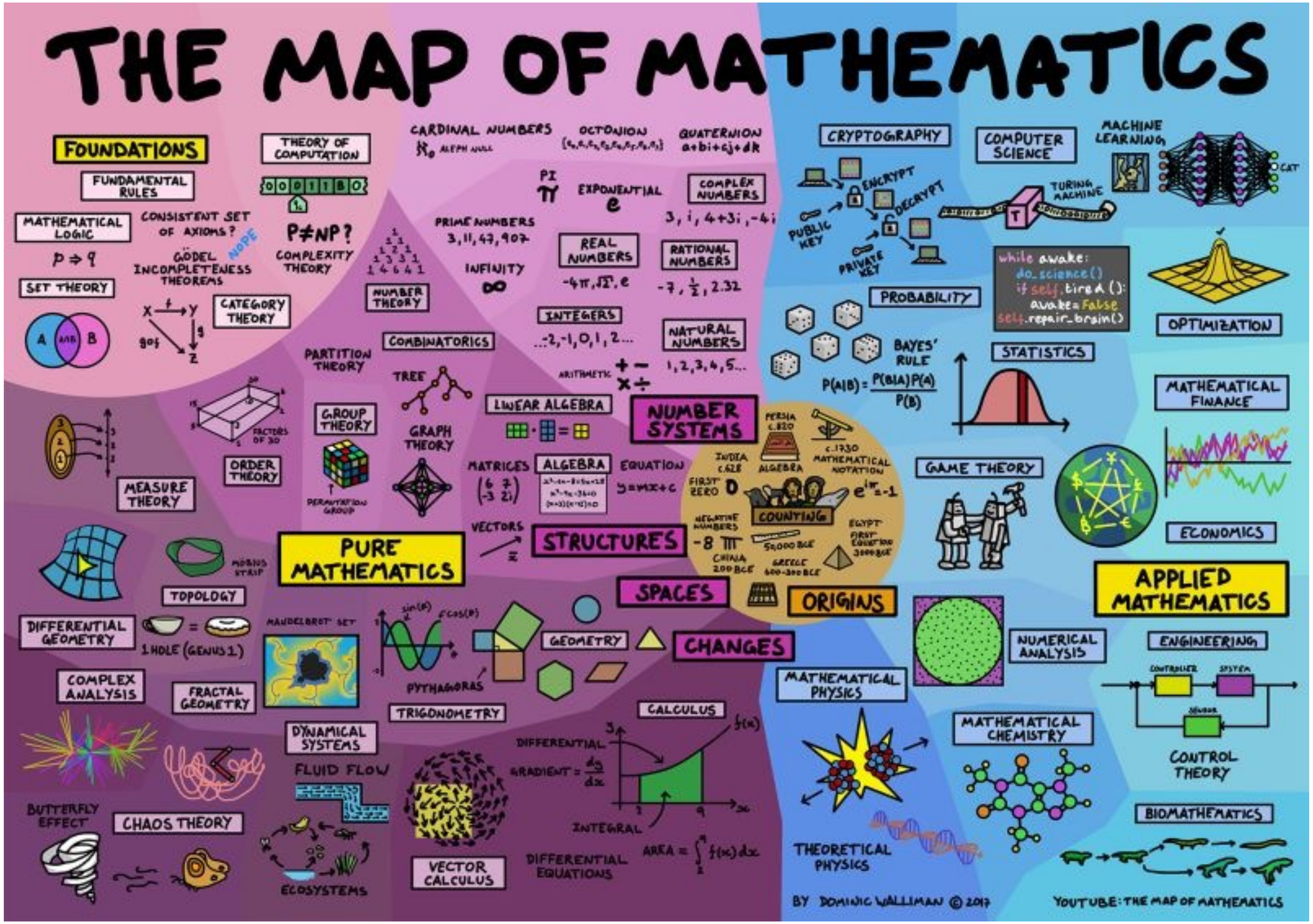
$$\ddot{\alpha} = \frac{1}{J_t}\left(-m_p g l J_r \alpha + m_p l r b_r \dot{\theta} - J_p b_p \dot{\alpha} - m_p r l \tau\right).$$

$$\begin{cases} \dot{x}(t) = Ax(t) + Bu(t) \\ y(t) = Cx(t) + Du(t) \end{cases}$$

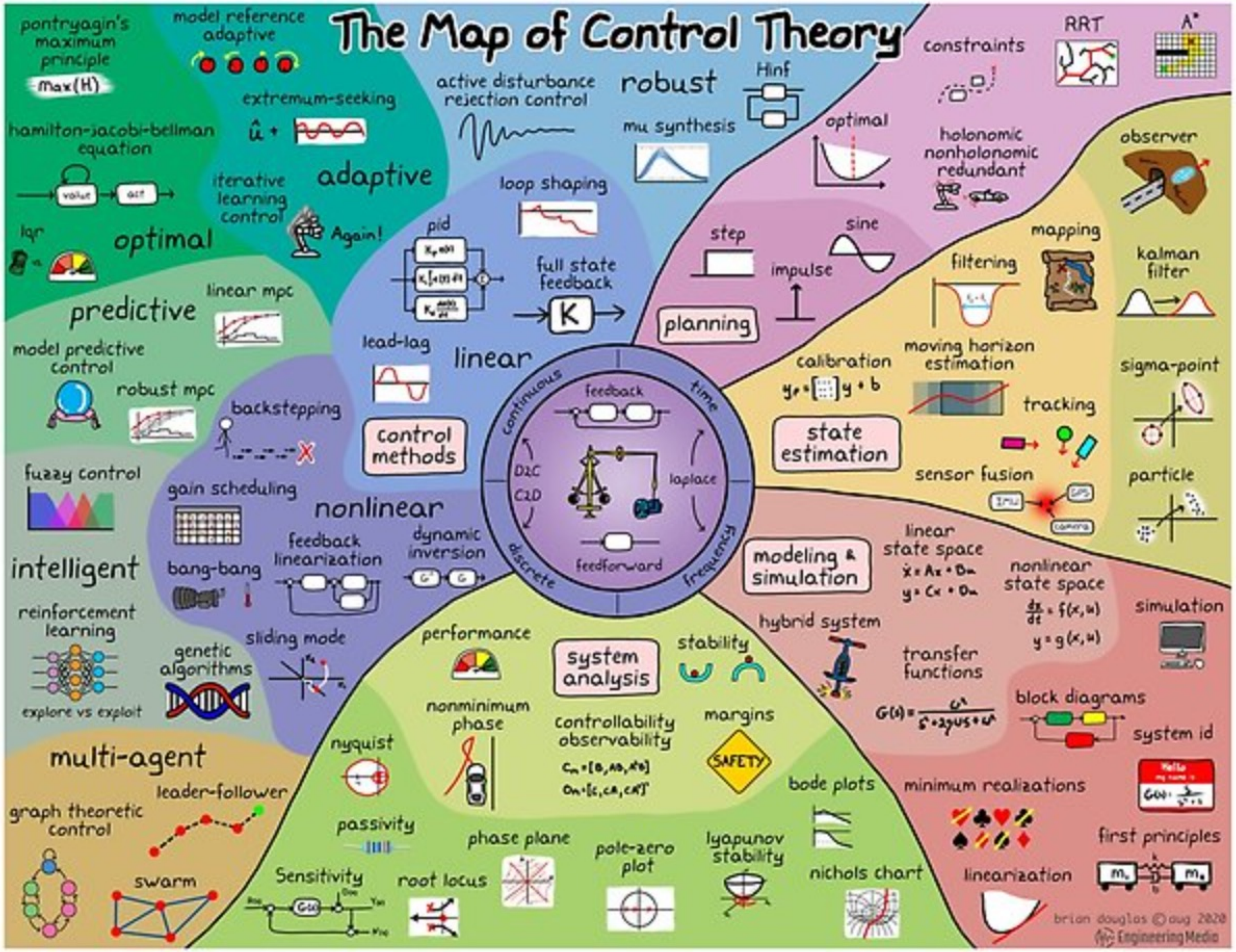
The state vector $x = \begin{bmatrix}\theta & \alpha & \dot{\theta} & \dot{\alpha}\end{bmatrix}^T$

The two outputs to be controlled $y = \begin{bmatrix}\theta & \alpha\end{bmatrix}^T$

Where is *Charlie* ? euh… Where is *Control theory?*



From Brian Douglas



Website for the course

- w3.cran.univ-lorraine.fr/hugues.garnier/?q=content/teaching

Search

Hugues Garnier

Navigation

Add content

Add file

33232

Teaching

Basic page *Teaching* has been updated. ×

View | Edit

Teaching activities

Since 2018, I have been head of the 3-year engineering programme (see pdf) in *Computer Science, Control Engineering, Robotics, IT Networks (IA2R)* at Polytech Nancy.

where I teach the following courses:

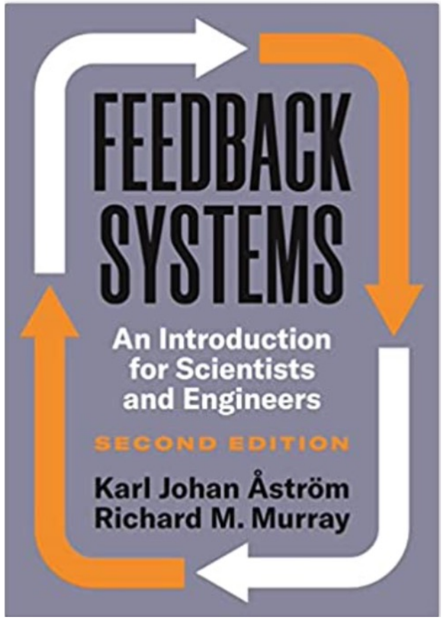
Digital control S6 (3A IA2R FISE)

- Slides for the course
  - Digital control - Intro
  - The z-trransform
    - Table of z-transforms
  - Converters & Holds
  - Sampled data systems
  - Discrete-time systems
  - Synthesis of digital controllers
  - Digital PID controllers
- Tutorials
- Labs
  - Files for Lab 1
  - Files for Lab 2
- Exams

Recommended books

Feedback Systems

An Introduction for Scientists and Engineers, *K.J. Åstrom & R. Murray 2021*



➡ pdf version of the book available

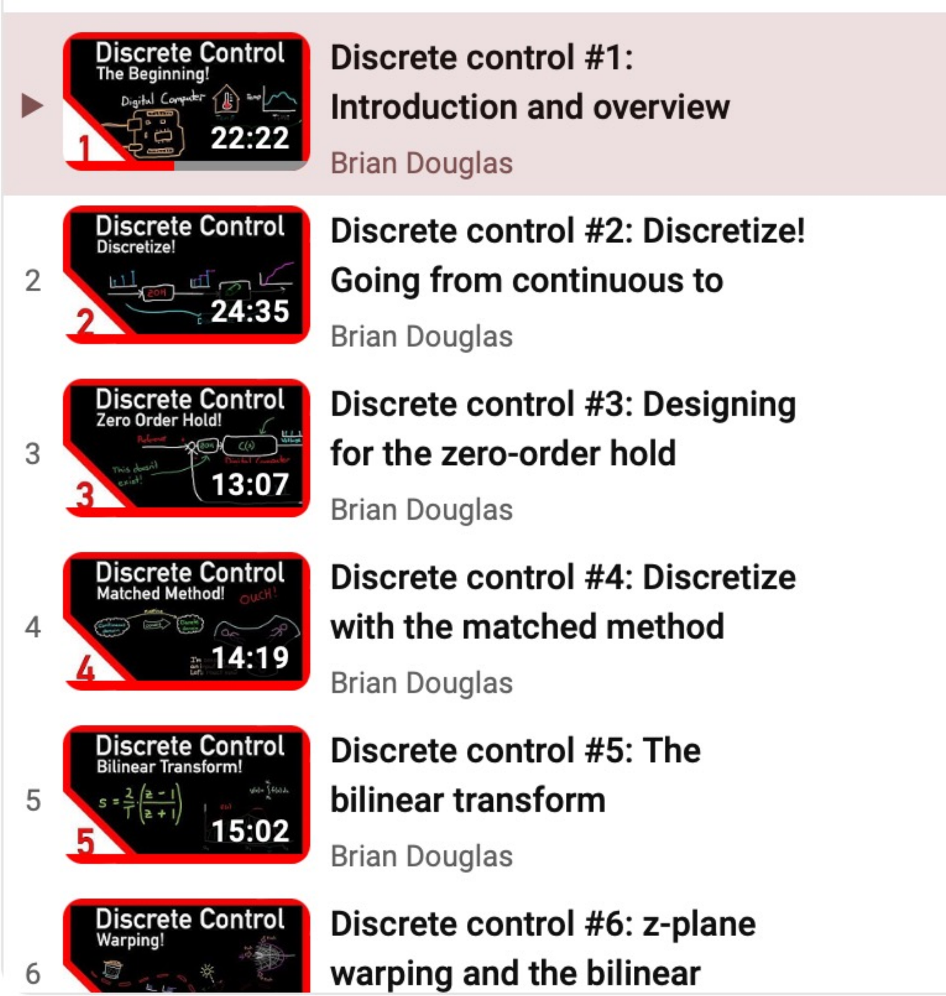
www.cds.caltech.edu/~murray/books/AM08/pdf/fbs-public_24Jul2020.pdf

See also

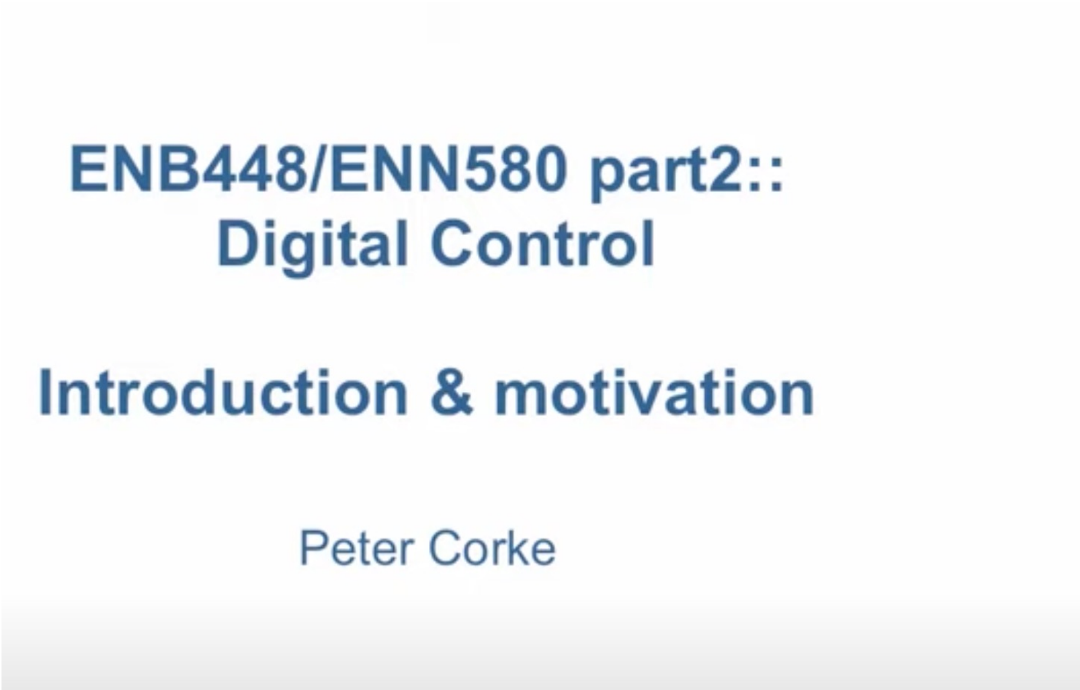
– K.J. Åström, B. Wittenmark, *Computer-controlled systems: theory and design* (3rd Ed.), Dover Publications, 2011

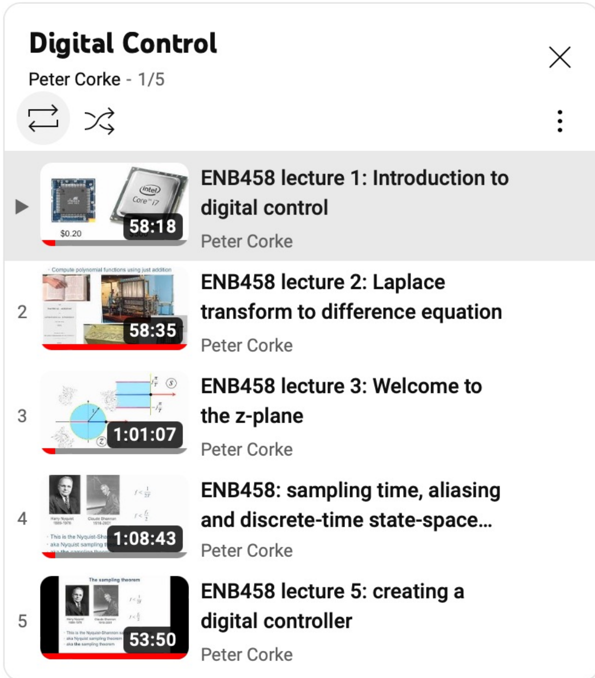
Videos available on Youtube

Discrete control by *Brian Douglas*



Some other resommended videos on Youtube
Digital control by *Peter Corke*

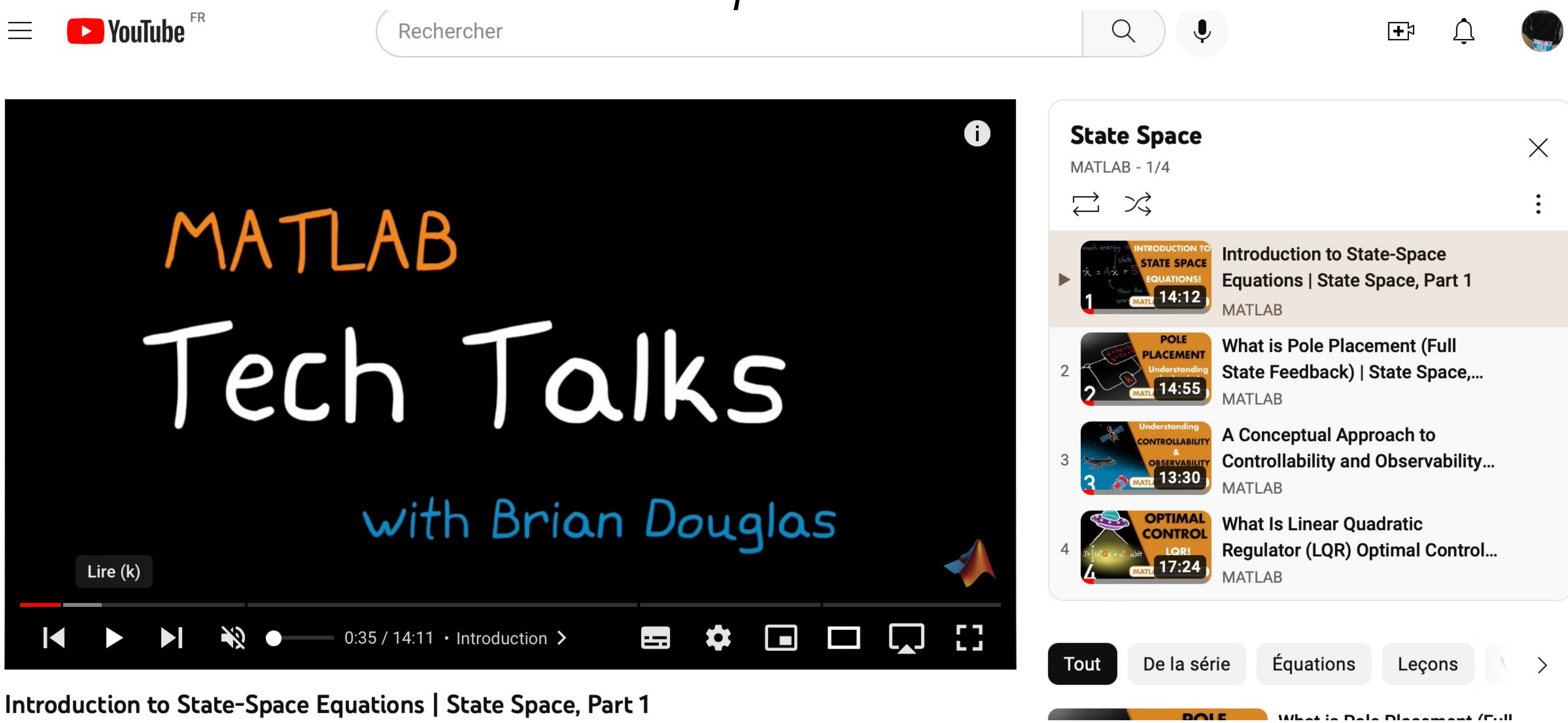




Youtube videos recommended for the course on State-space models and control

Matlab Tech Talks with *Brian Douglas*

State Space Models



Others resources in automatic control
Mobile textbook available from *Quanser*

Experience Controls by Quanser

Experience Controls is a free mobile textbook designed to give you real design intuition and relevant skills in a hands-on way in the control systems engineering space.

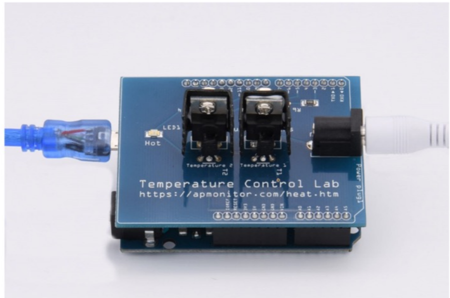
The textbook app includes:

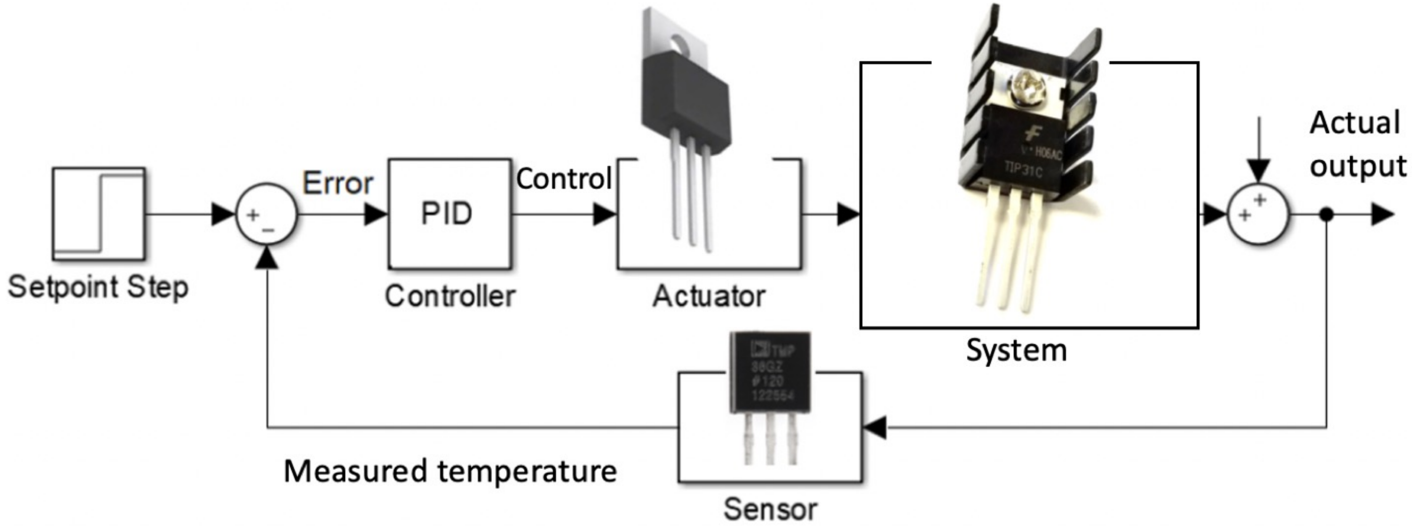
- 50+ lesson modules covering introductory to advanced concepts
- Interactive simulations of industrial-level controls problems
- Mini-lecture podcasts that summarize key takeaways for each chapter, available in-app or in your preferred podcast player
- End-of-chapter review questions to check your understanding

Download on the App Store

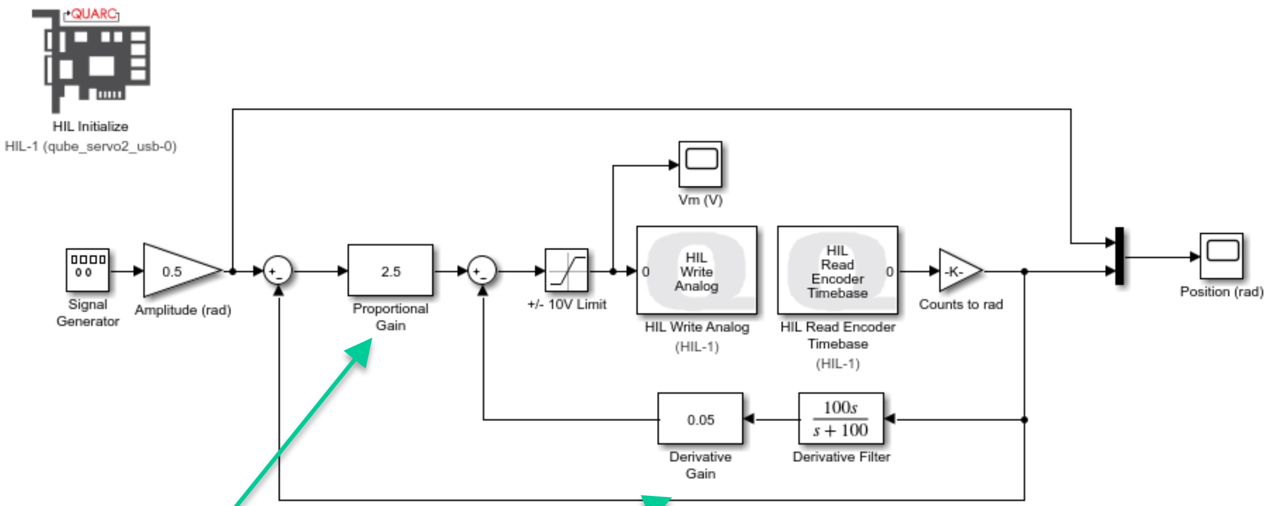
GET IT ON Google Play

Reminder - Control Lab 1 S5
On-off and PID temperature control of the TCLab kit



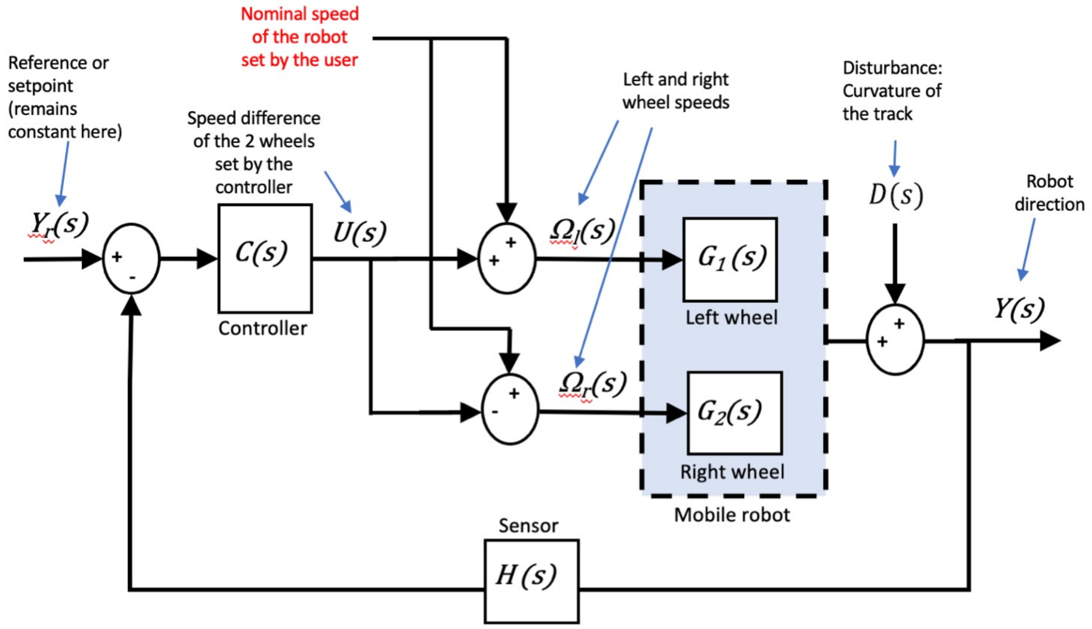


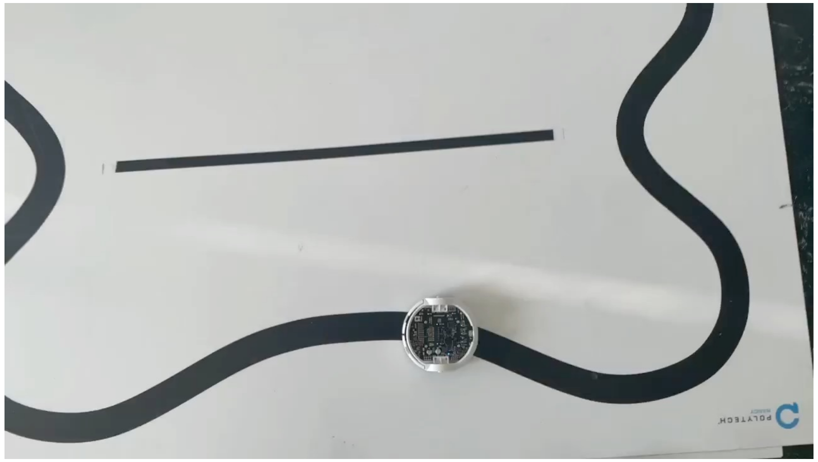
Reminder - Control Lab 1 S5
PID control of the angular position for the QUBE-servo 2



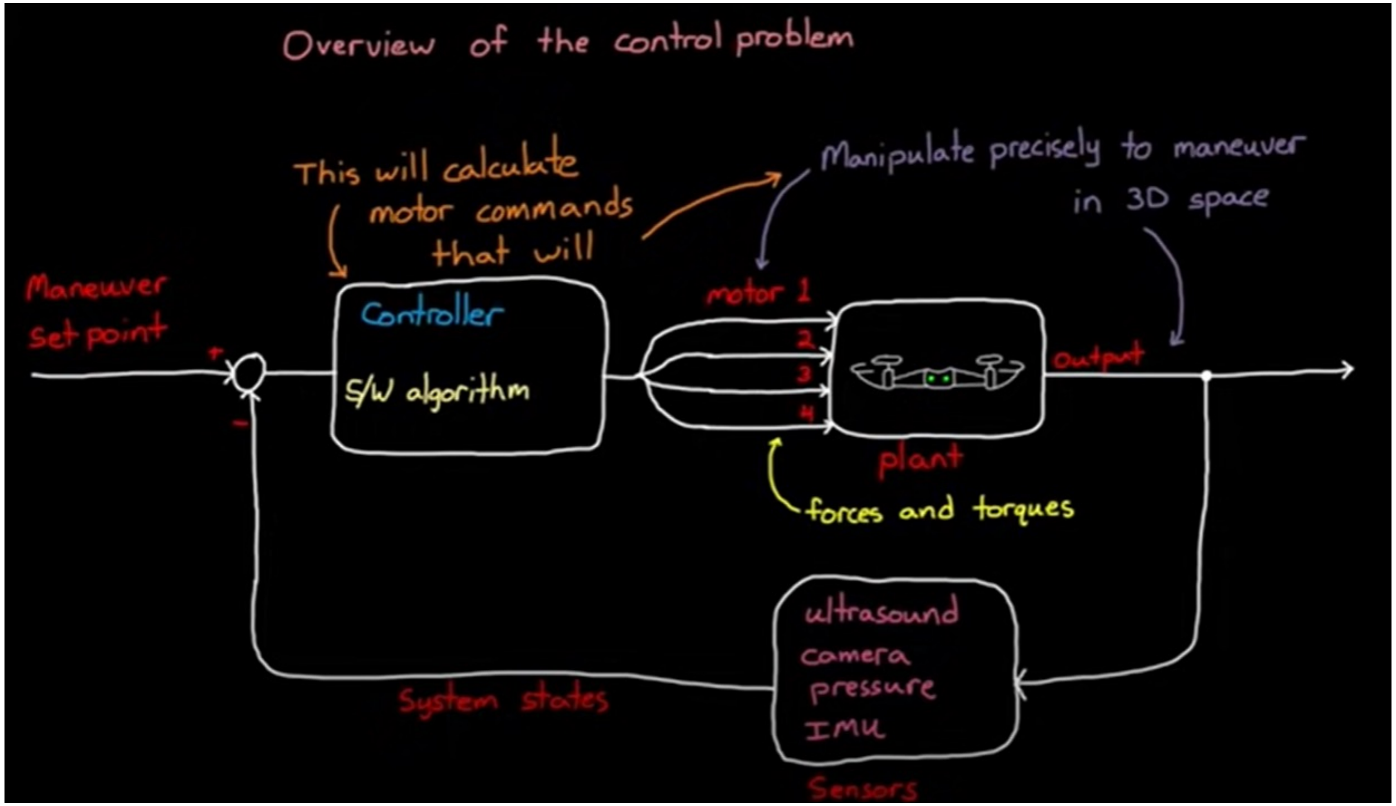
PD controller

Reminder - Control Lab 3 S5
Line tracking control for the 3pi+ mobile robot



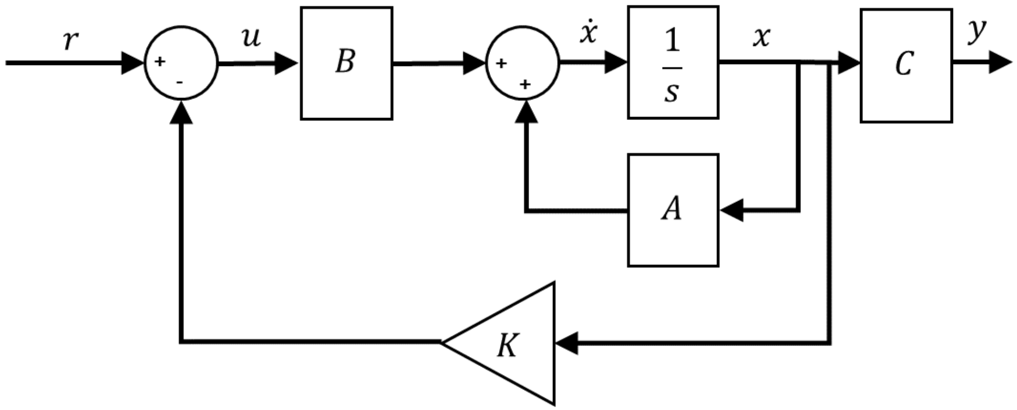


Lab 1 S6 – Altitude control for the Tello mini-drone



Lab 1 S6 – Altitude control for the Tello mini-drone

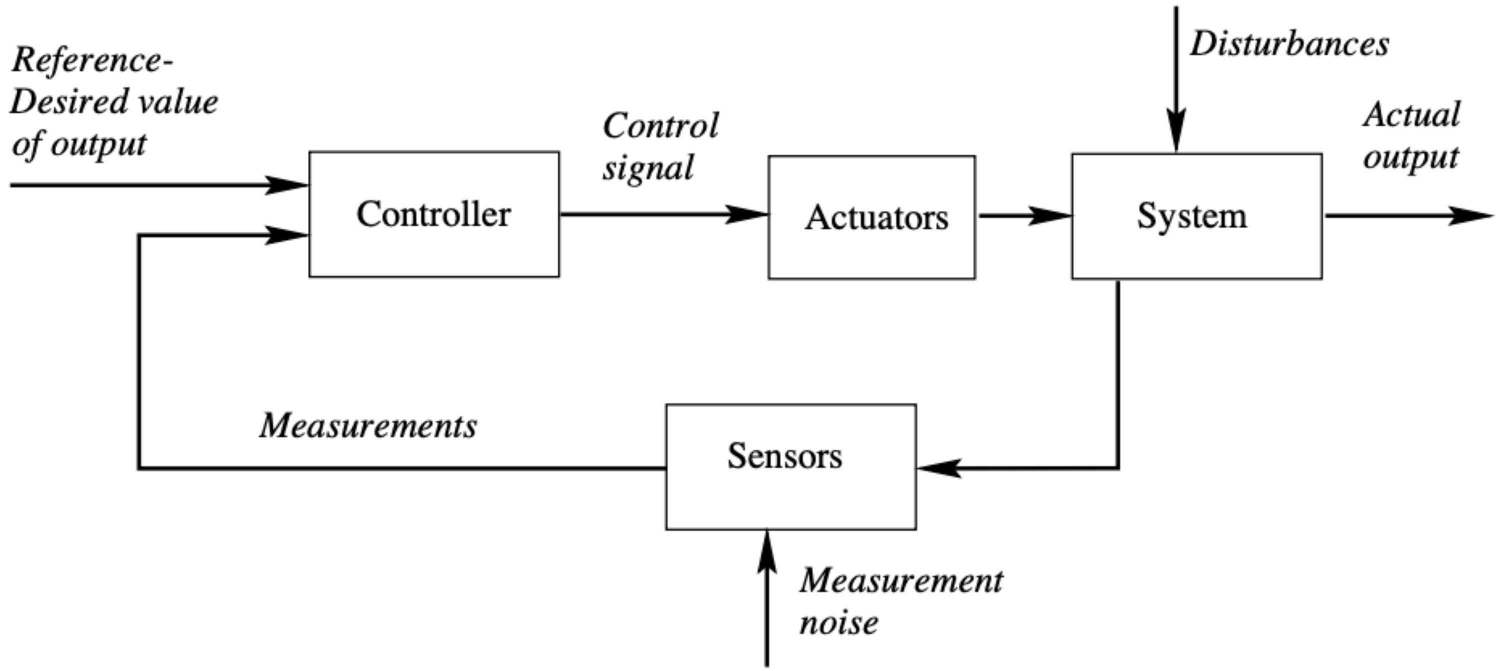
Lab 2 S6 – State feedback control of the rotary inverted pendulum



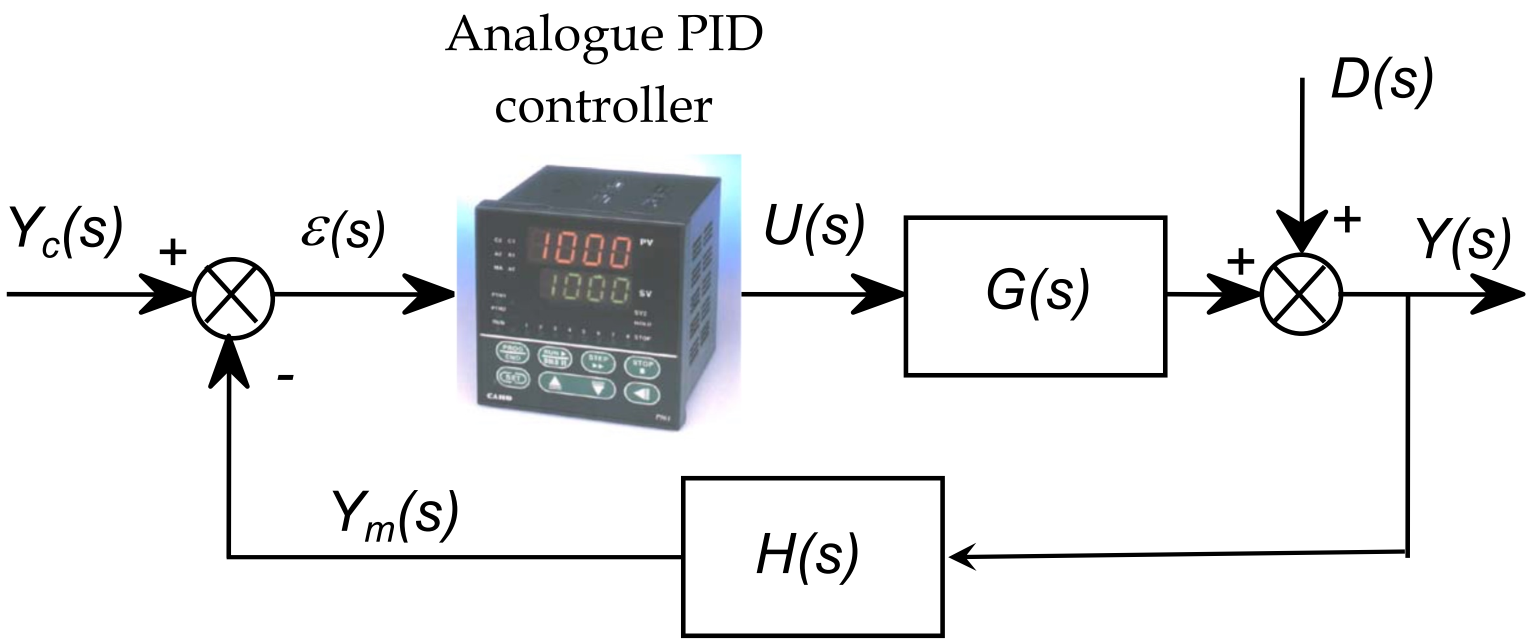
Synthesis of the controller gain by the pole placement method

Reminder - Principle of feedback control

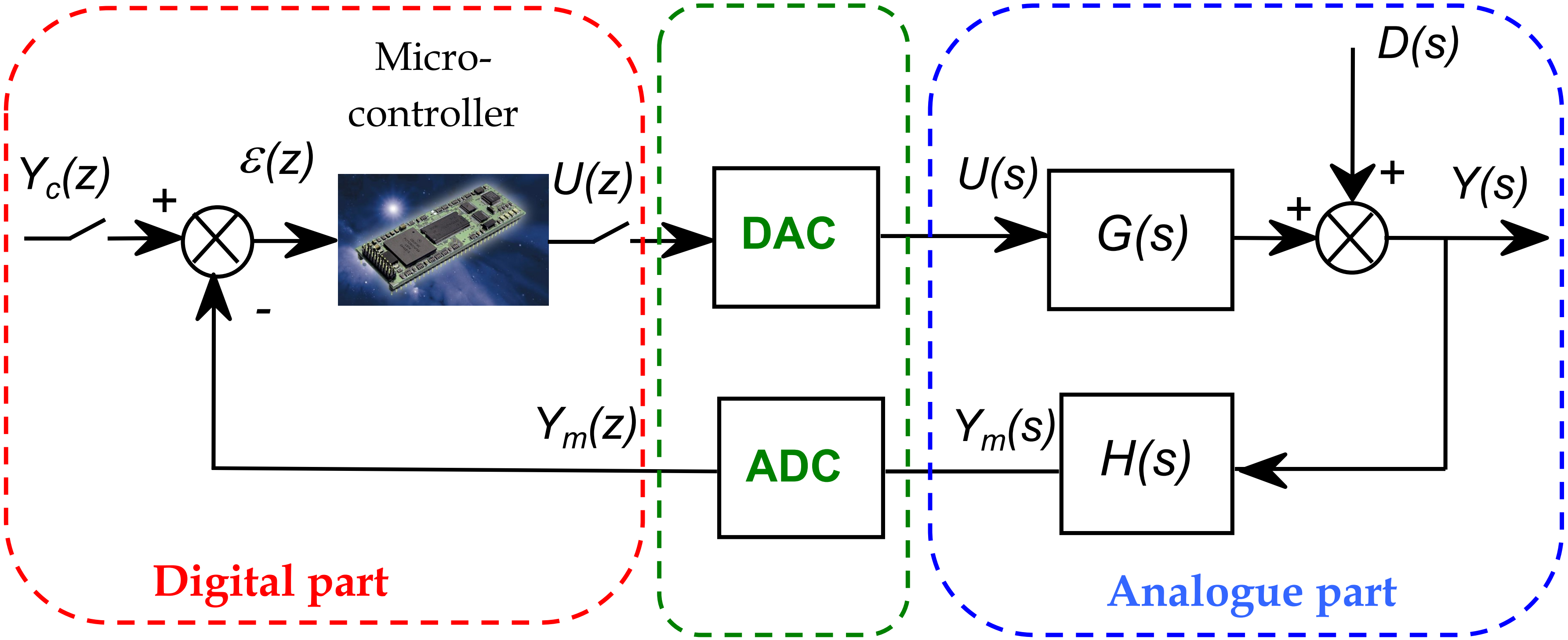
- Designing a control system means inserting:
  - a feedback loop
  - a control element: the controller or regulator



Typical feedback loop in analogue control

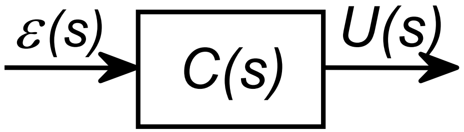


Typical feedback loop in digital control



- Advantages: low cost, speed, high accuracy, insensitivity to noise, ease of implementation and flexibility with regard to modifications
- Need for blocks to enable analogue and digital parts to interact: **DAC** and **ADC**

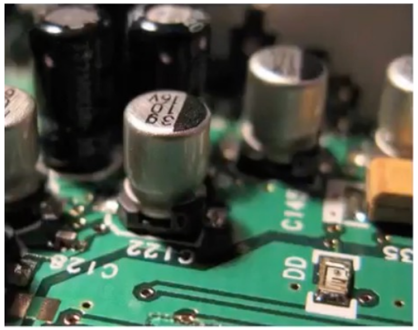
Technology of analogue/digital controllers



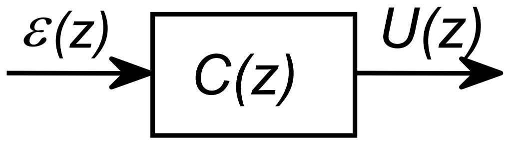
Tool: Laplace transform

$$u(t) = k_p\,\varepsilon(t) + k_i \int_0^t \varepsilon(\tau)d\tau + k_d\,\frac{\varepsilon(t)}{dt}$$

Differential equation



Electronic board



Tool: *z* transform

$$u(k) = K_p\varepsilon(k) + u_i(k) + u_d(k)$$

Difference equation

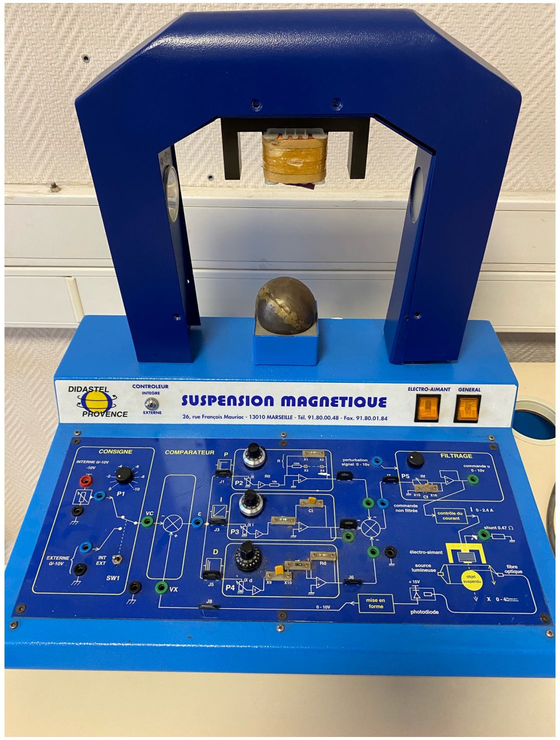
```
program CruiseControl

repeat
  r = getReferenceMeasurement
  y = getSpeedMeasurement
  u = K*(r-y);
  sendCommandToEngine(u)
end
```

Micro-controller

Lab platform example:

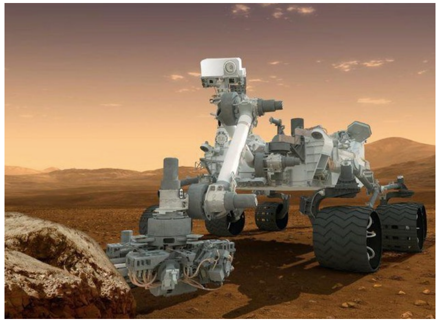
analogue versus digital PID controller for magnetic levitation

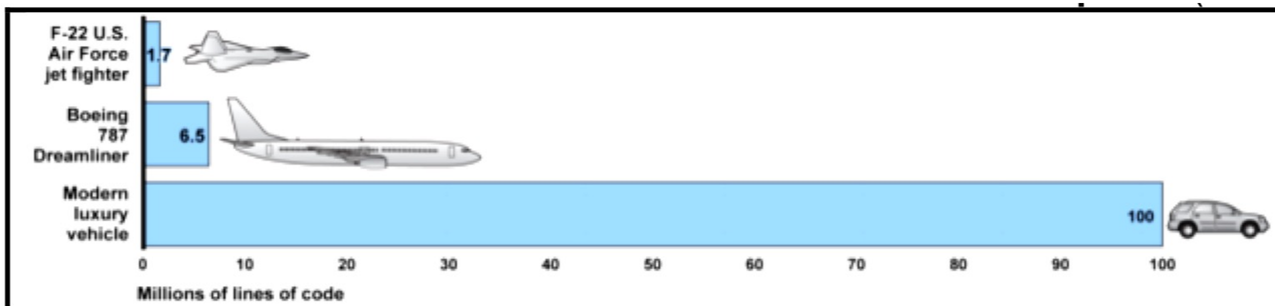


Implementation of the
analogue PID controller
Via electronic amplifiers

Implementation of the digital
PID controller
via code

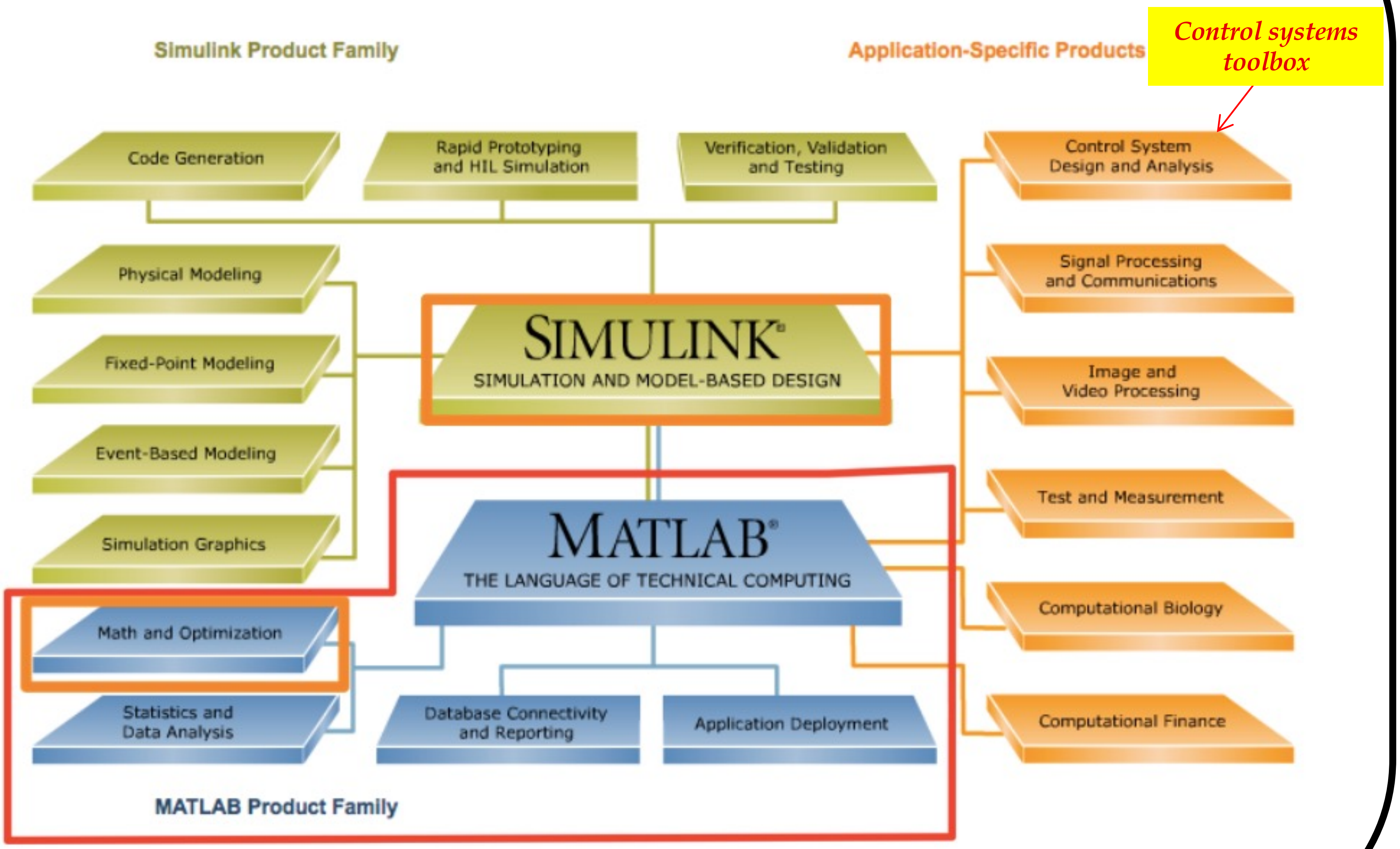
Digital control is everywhere





Vehicles need more complex computer systems than aircraft, due to the complexity of roadway interactions.

Use of Matlab/Simulink in the tutorial and lab sessions



Objectives of the digital control course

- To provide tools and methods for:
  - analyzing digital control, i.e. the problem of using digital computers or micro-controllers in real time to control physical processes
  - modelling and studying the various interactions between analogue and digital components (ADC/DAC)
  - designing and implementing digital PID controllers

Outline of the digital control course

I. The z-transform

II. Analogue to digital converter

III. Sampled systems

IV. Discrete-time systems

V. Design and implementation of digital PID controllers