AUTOMATION AND CONTROL LABORATORY
Course introduction and experiences' description

Prof. Gabriele Cazzulani

CONTACTS

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Course objective

Provide the ability to apply control structures on real systems and to critically analyse their modelling, by means of different experimental and numerical experiences.

Reference areas:

- Industrial automation
- Process control
- Vibration control
- Motion control
- Electrical drives and machine
- …

Pre-requisites

- System dynamics and modelling
  (mechanical, electrical, process)
- Drives and actuators
  (electrical and pneumatic actuators)
- Fundamentals of control engineering
  (Classical control theory, PID regulators)
- Automatic control and process control
  (Modern control – state observers – pole placement and optimal control)
- Industrial Automation/Informatics
  (Discrete event systems, digital control – PLC – PID controller design)

Development of the course

- <u>Experimental applications</u> emulating automatic plants or reproducing systems or processes to be controlled

- Single experience assigned to a team of students that develop it autonomously and thoroughly during all the course duration

Developmento of the course

What is required to each team

- Development of model/s for the assigned experience
- Identification of system parameters
- Implementation and verification of control algorithms on the model
- Implementation and verification of control algorithms on the real system
- Experimental tests and comparison between experimental and numerical results
- Final report on the carried out activities
- Final presentation to the classroom

What is required to each student

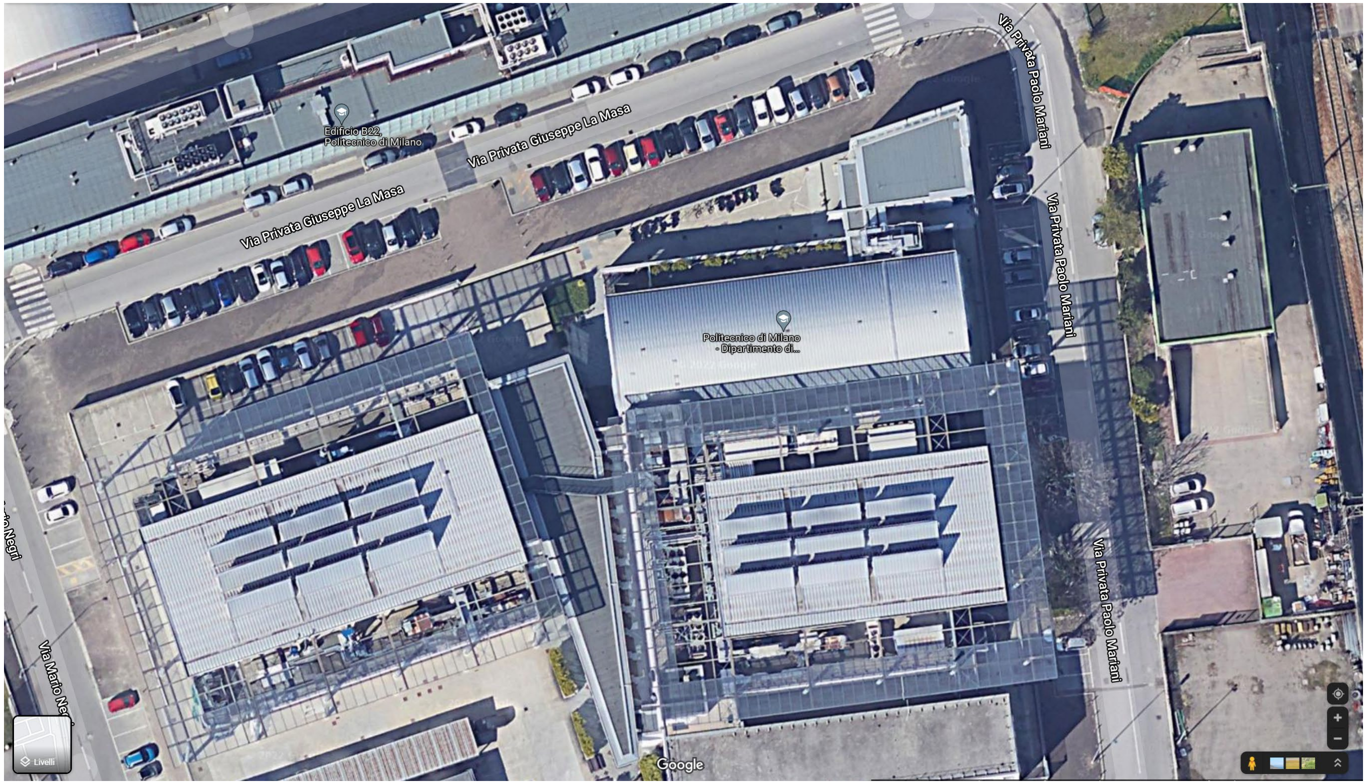
- Active involvement in the activities of the team
- Critical participation to the final presentation of the other teams

Course organization

- Each team should be composed by 4 students
- **The course is considered in presence**
- Partecipation to the lab sessions is mandatory
- It is possible that occasionally some group members are not present. In this case, they can connect from remote

Course room and schedule

- All the laboratory sessions (except this intro lesson) will be in the mechatronic lab, ground floor of building B23



Course room and schedule

- All the laboratory sessions (except this intro lesson) will be in the mechatronic lab, ground floor of building B23

- Course hour:
  - Monday from 14.15 to 19.15 (5 hours, all the Mondays except holidays)
  - Friday from 9.15 to 13.15 (4 hours, alternated with the other alphabetic group)

- The detailed calendar is made available on webeep
  (1st lab day: Friday 23)

Some additional organisation aspects

- For each team we will generate a room in MS Teams with the members, the teachers

- We will set up a dedicated schedule to guarantee experience usage for the “duplicated” experiences (if needed)

Exam rules

- The course evaluation is made on the output of the laboratory experience
- Report of the laboratory (max 50 pages)
- Presentation (20 minutes)
- Questions (approx. 10 minutes)

Note: please, keep the time/length within the indicated limit. The capability of using a limited resource is also evaluated

Evaluation criteria

- Evaluation of the team activities and of the single student contribution to the team activities, mainly based on participation to the laboratory activities during official hours (team/single student) – “continuous evaluation”
- Evaluation of the final report (team)
- Evaluation of the final presentation + Q&A (team/single student)
- Evaluation of the participation to the final presentation of the other student (single student)

Important dates

- February 22th, 2023 – 2:00 pm Deadline for the “Assignment Form” submission.
- Around the middle of April, 2023 mid-term reviews (if required, not mandatory)
- June 3th – end of the day, 2023 Deadline for the report submission
- June 7-8th, 2023 (tentative) Final presentation day(s)

Assignment form (file on webeep)

POLITECNICO MILANO 1863

Automation and Control Laboratory A.Y. 2021/22

Prof. G. Cazzulani

Dr. N. Toscani
Dr. H. Cholakkal

Team _______

Person code	First name	Last name

Order of preference	Experience
	Automation of an elevator plant
	Control of electric drives and pneumatic actuators in an automated plant
	Automation of a storage warehouse
	Control of a permanent-magnet DC motor (1)
	Control of a permanent-magnet DC motor (2)
	Control of a PMDC – PMDC system
	Control of a PMSM – PMDC system
	Control of linear vibrations
	Control of a linear pendulum
	Control of a rotational pendulum
	2D ball balancing
	Water tank
	Maglev
	Magnetic bearing (Maglev 2)
	Quanser Aero
	Quadcopter

Form to be filled and returned or sent by e-mail to (gabriele.cazzulani@polimi.it) by Thursday, February 24th , 2022, before 2 pm.

Available experiences (1/2)

1. Automation of an elevator plant
2. Control of electric drives and pneumatic actuators in an automated plant
3. Automation of a storage warehouse
4. Control of a PMDC – PMDC system
5. Control of a PMSM – PMDC system
6. …

Discrete event systems

Electrical drives

Available experiences (2/2)

6. Control of linear vibrations
7. Control of a linear pendulum
8. Control of a rotational pendulum (x2)
9. Control of a “reaction wheel” pendulum
10. 2D ball balancing
11. Industrial plant

Mechanical systems

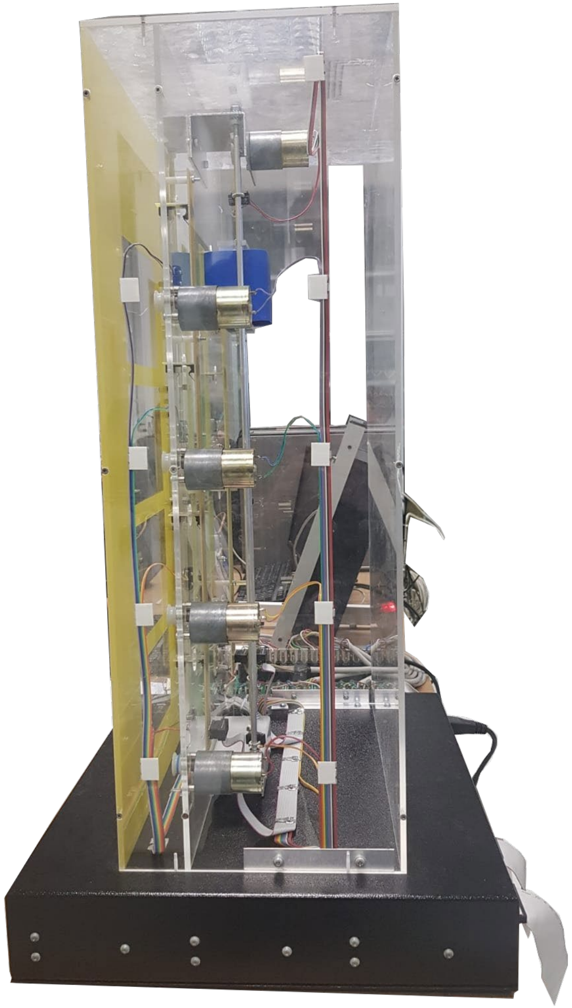
12. Control of a Maglev system
13. Magnetic bearing (Maglev 2)
14. Quanser Aero
15. Quadcopter

Mechanical systems with interaction with other physics

Automation of an elevator plant

- Small scale model of an elevator with 4 floors
- Typical example of discrete event system to be controlled
- The control system is based on a PLC (ABB)
- The motion actuations are electromechanical (on/off)
- The control typology can be developed through increasing complexity levels.

Automation of an elevator plant



Automation of an elevator plant

4 FLOORS, EACH ONE EQUIPPED WITH:	• 1 door with electric opening • 1 closed-door optical detector • 1 open-door optical detector • 2 non-programmable safety limits for open/closed door • 1 button for ascending calls (except for the third floor) with light sign • 1 button for descending calls (except for the ground floor) with light sign • 1 light sign for car presence • 1 car presence detector
CAR INTERNAL COMMAND	• 4 button for the different floors • 1 stop button • 1 switch for simulating an obstacle to door closure • 4 light signs indicating the floor • 1 light sign inside the car

Modelling and control approaches

- The system and the control evolve through discrete events.
- Possible modelling option:
  - finite state automaton (finite state machine)
  - Petri net
  - Flow diagram
  - SFC (Sequential Functional Chart also known as GRAFCET)
  - other forms

Automation of an elevator plant – suggested developments

- Definition and preliminary description of two basic control logics:
  - a) Logic without call storage
  - b) Logic with call storage and intermediate stops

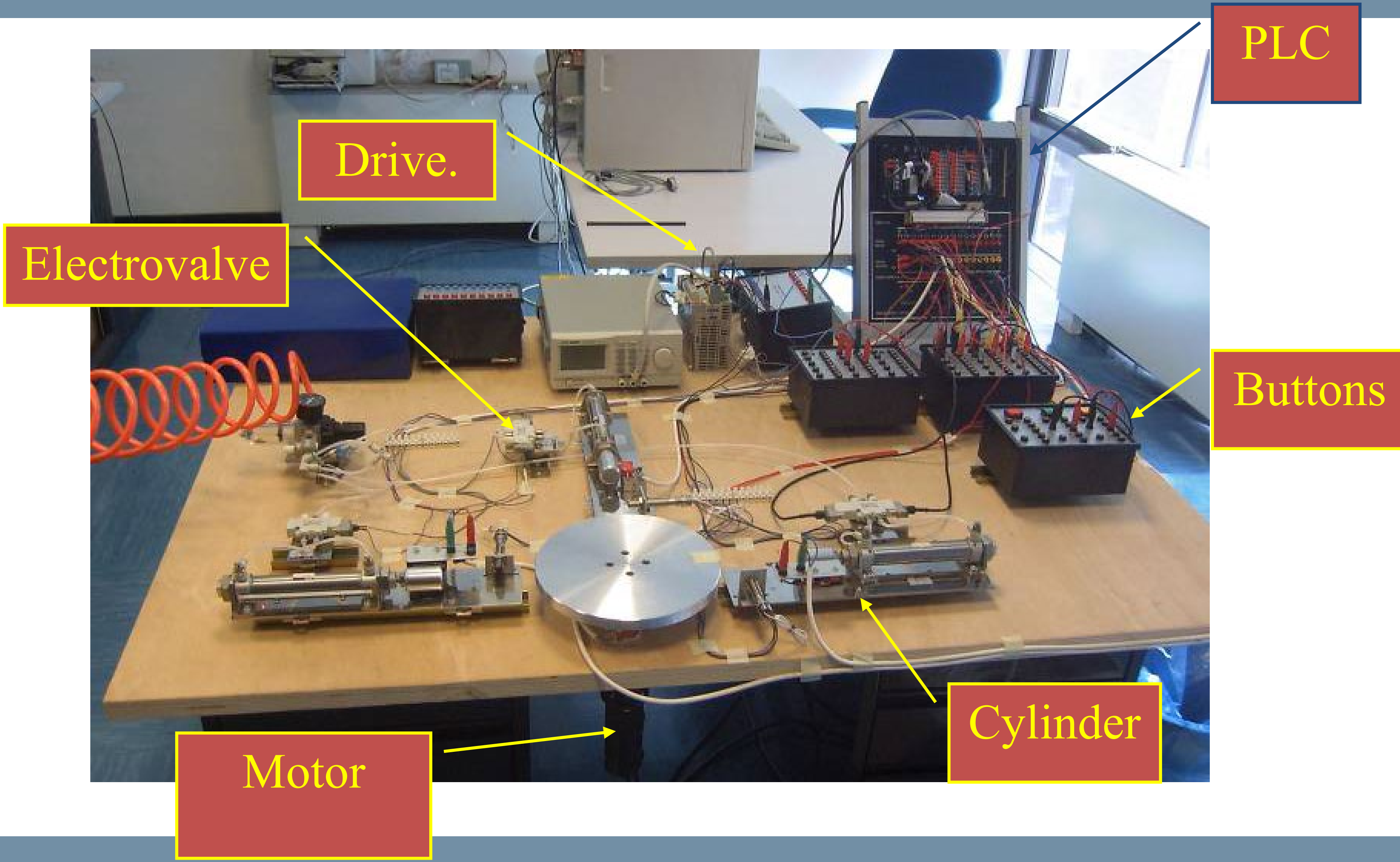
- Accurate description of the sequences and modelling.
- Characterisation of the command outputs and of the sensor and command signals (level and car calls)
- Implementation of the two logics a) and b) on the PLC (ladder diagram/ structure text /any of IEC 61131)
- Addition of all the safety features (obstacle detector and emergency stop)

Control of electric drives and pneumatic actuators in an automated plant

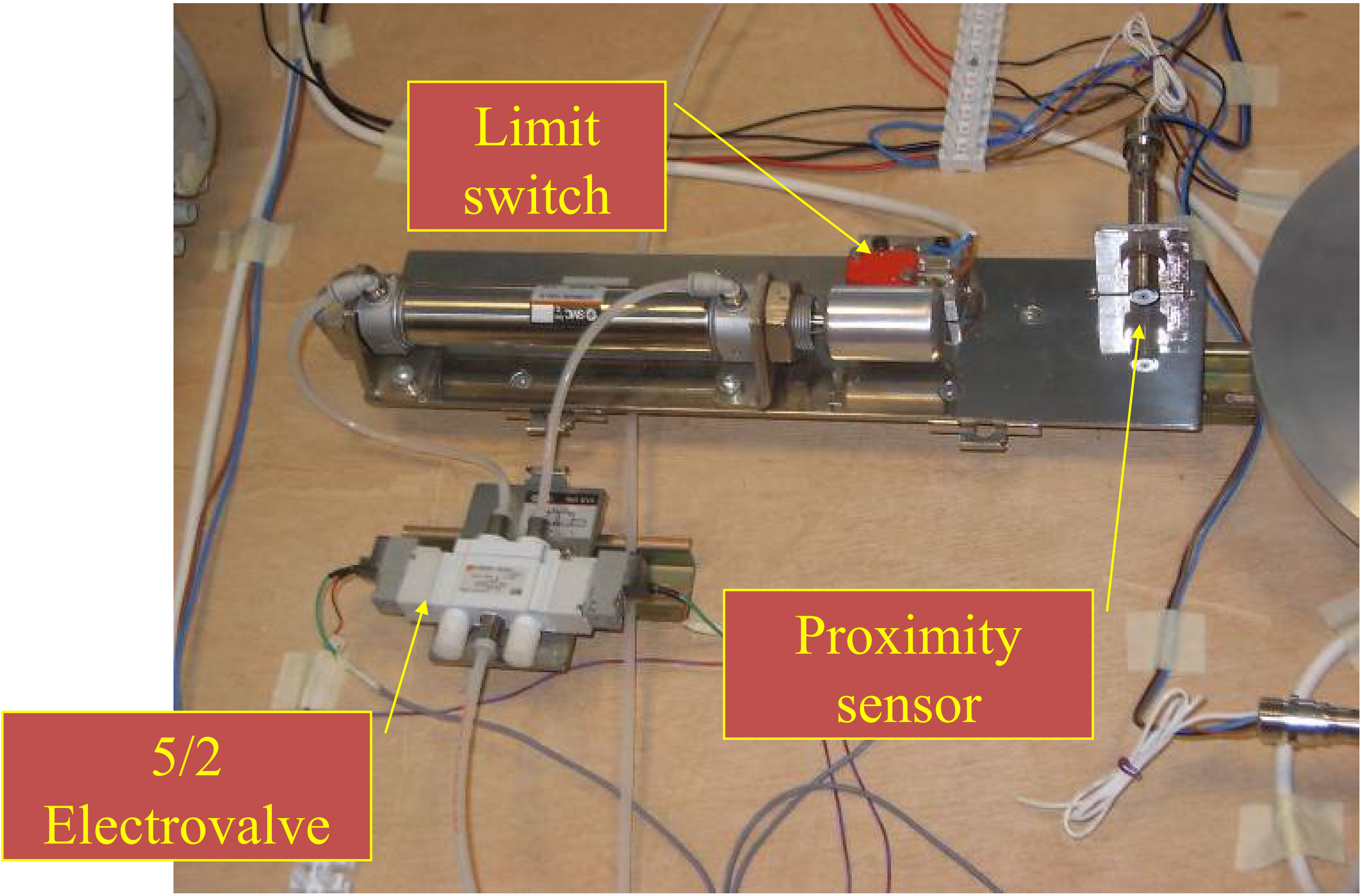
- The emulated plant is composed by:
  - a rotating plate, actuated through a brushless motor
  - three pneumatic actuators (double effect cylinders) that execute synchronised actions.
- Discrete event system to be controlled
- The control system is based on a PLC (ABB)

The rotating plate has a mark, representing the position of the specimen to be processed. The mark/specimen have to be moved according to a pre-defined sequence to different angular position, corresponding to the pneumatic cylinders' actions.

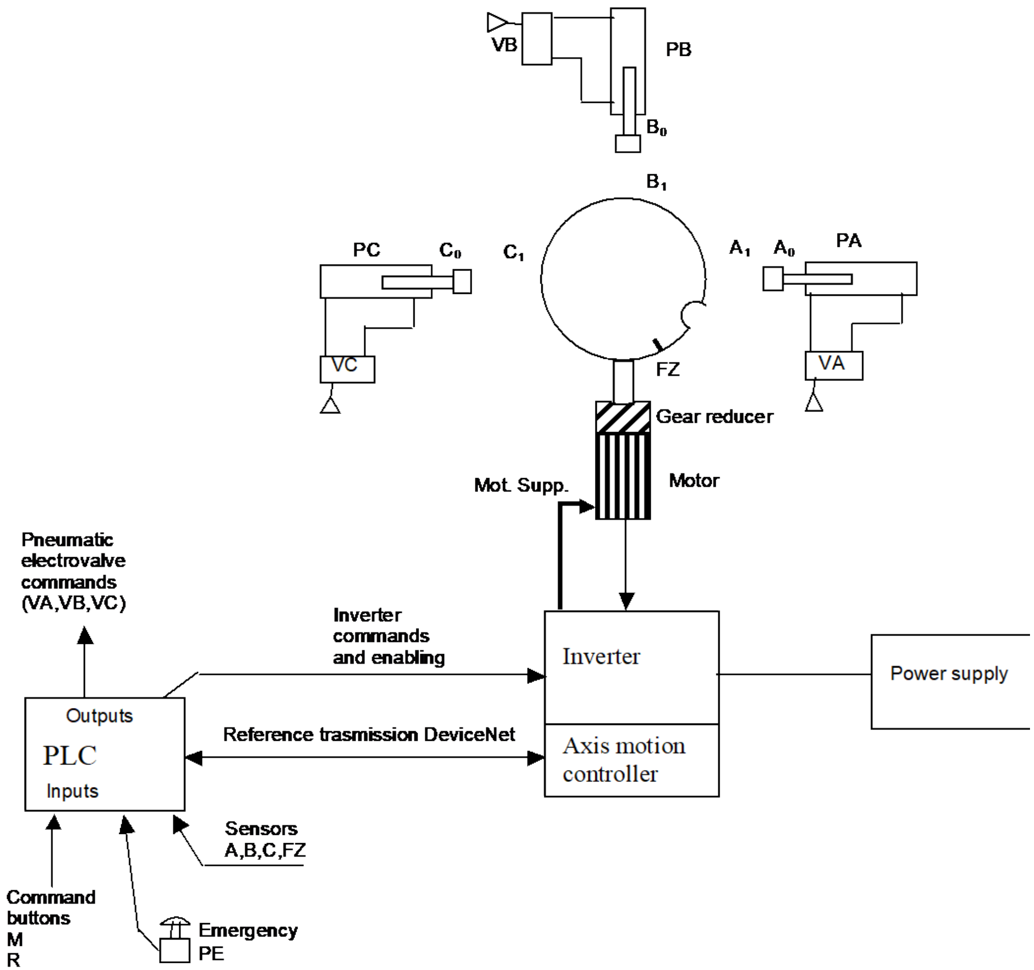
Control of electric drives and pneumatic actuators in an automated plant



Control of electric drives and pneumatic actuators in an automated plant



Control of electric drives and pneumatic actuators in an automated plant



The system is made up with industrial components:

- Electrical drive: industrial inverter + direct drive brushless motor;
- Software environment for the interface with the inverter, equipped with a data acquisition system;
- Programmable axis motion controller with developing environment;
- PLC (programmable logic controller) with interfacing and programming software;
- 3 pneumatic cylinders (2 double effect and 1 single effect), electrovalves and proximity sensors.

Modelling and control approaches

- The system and the control evolve through discrete events.
- Possible modelling option:
  - finite state automaton (finite state machine)
  - Petri net
  - Flow diagram
  - SFC (Sequential Functional Chart aka GRAFCET)
  - other forms

Control of electric drives and pneumatic actuators in an automated plant – suggested developments

PLC side

- Definition and preliminary description of the basic control logic:

  0->A->B->C   with actuator operations
- Accurate description of the sequence and modelling.
- Characterisation of the command outputs and of the sensor and command signals
- Implementation of the two logics a) and b) on the PLC (ladder diagram/ structure text /any of IEC 61131)
- Addition of all the safety features (obstacle detector and emergency stop)
- Definition and implementation of advanced control logic, with the possibility to define different working loops

Control of electric drives and pneumatic actuators in an automated plant – suggested develompents

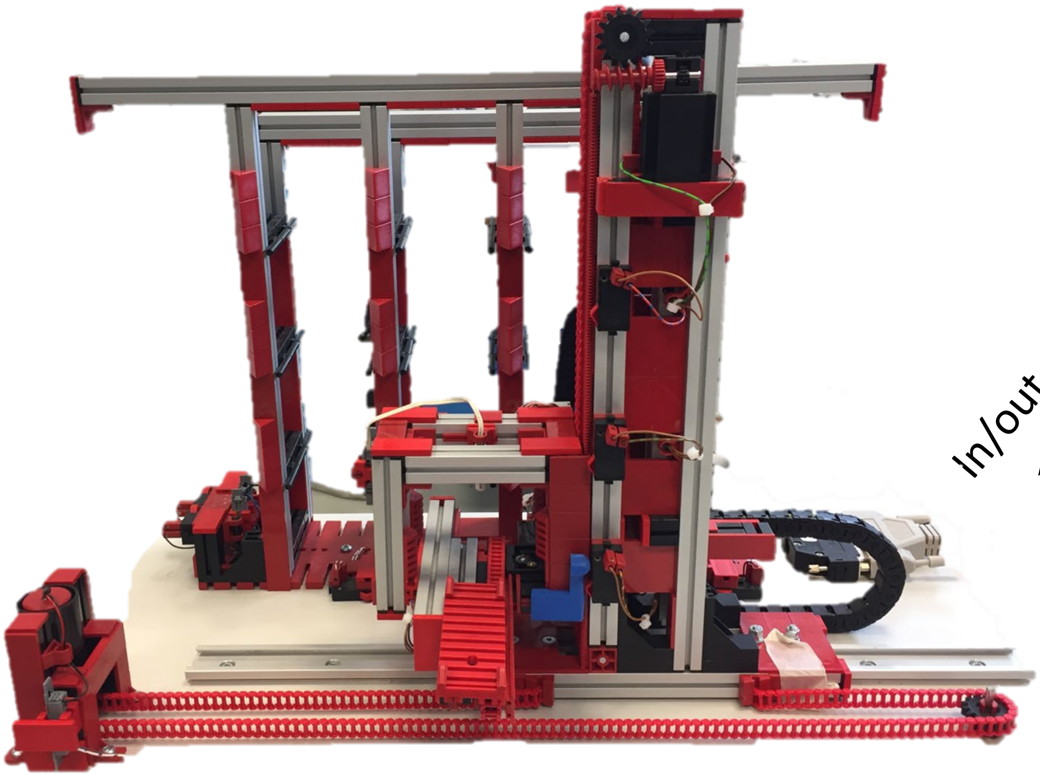
Electric drive side

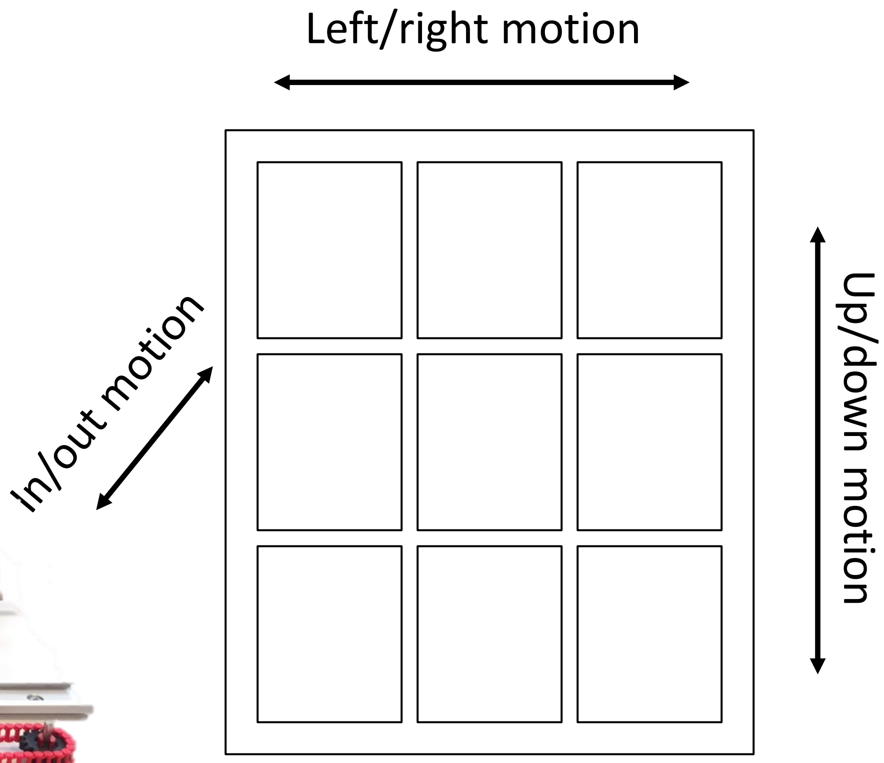
- Calibration of the speed control loop, through comparison with a Matlab/simulink model and/or experimental optimisation

Automation of a storage warehouse

- Small scale model of a storage warehouse with 3x3 storage places
- Typical example of discrete event system to be controlled
- The control system is based on a PLC (ABB)
- The motion actuations are electromechanical (on/off)
- The control typology can be developed through increasing complexity levels.

Automation of a storage warehouse





Switches defining position and pallet presence (in storage places/ on the carrier)

Modelling and control approaches

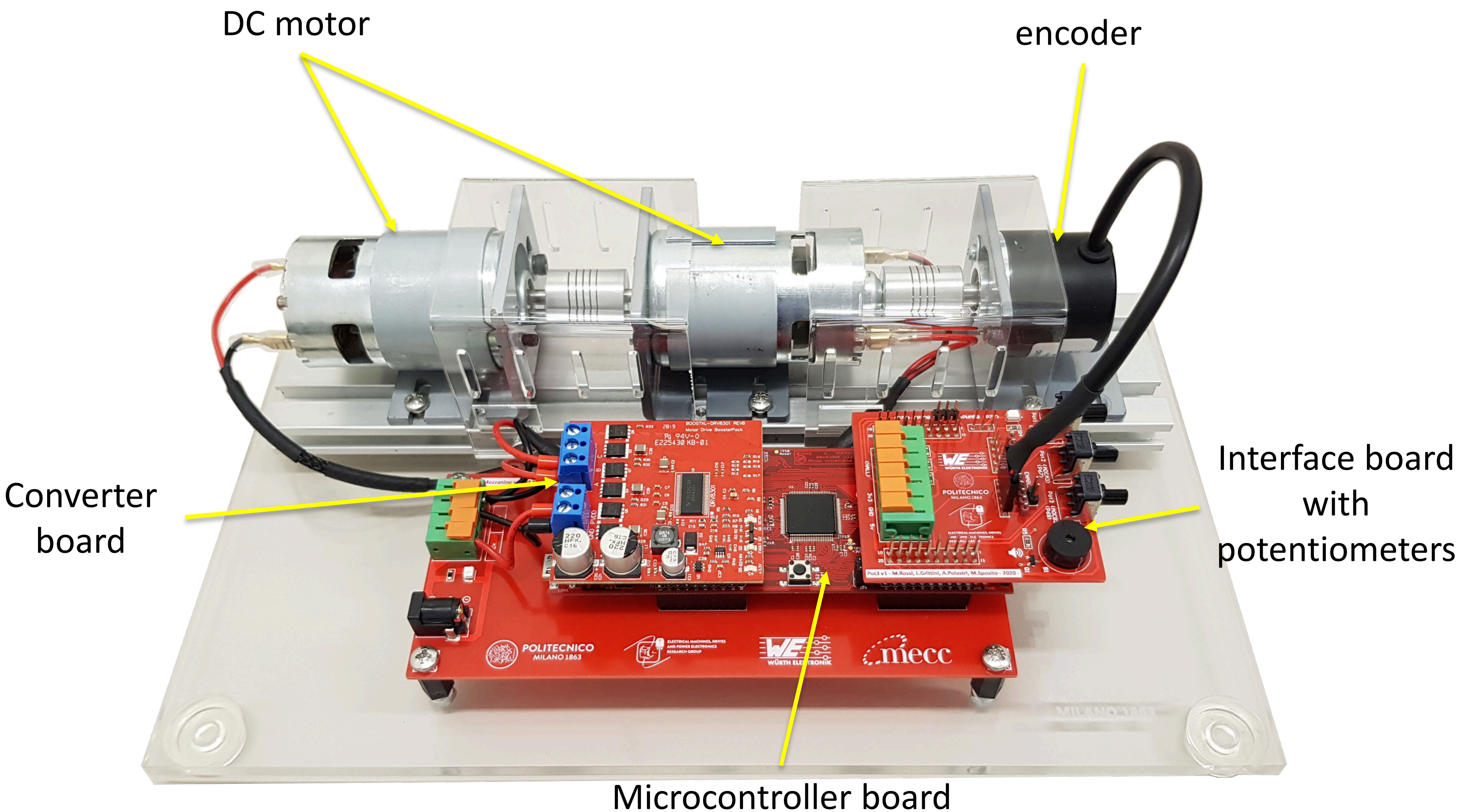
- The system and the control evolve through discrete events.
- Possible modelling option:
  - finite state automaton (finite state machine)
  - Petri net
  - Flow diagram
  - SFC (Sequential Functional Chart aka GRAFCET)
  - other forms

Automation of a storage warehouse

- Definition and preliminary description of two basic control logics:
    a) Simple storage/withdraw
    b) Complex management of pallets with user defined sequences (and sequence optimisation)

- Accurate description of the sequences and modelling.
- Characterisation of the command outputs and of the sensor and command signals (level and car calls)
- Implementation of the two logics a) and b) on the PLC (ladder diagram/ structure text /any of IEC 61131)
- Addition of all the safety features

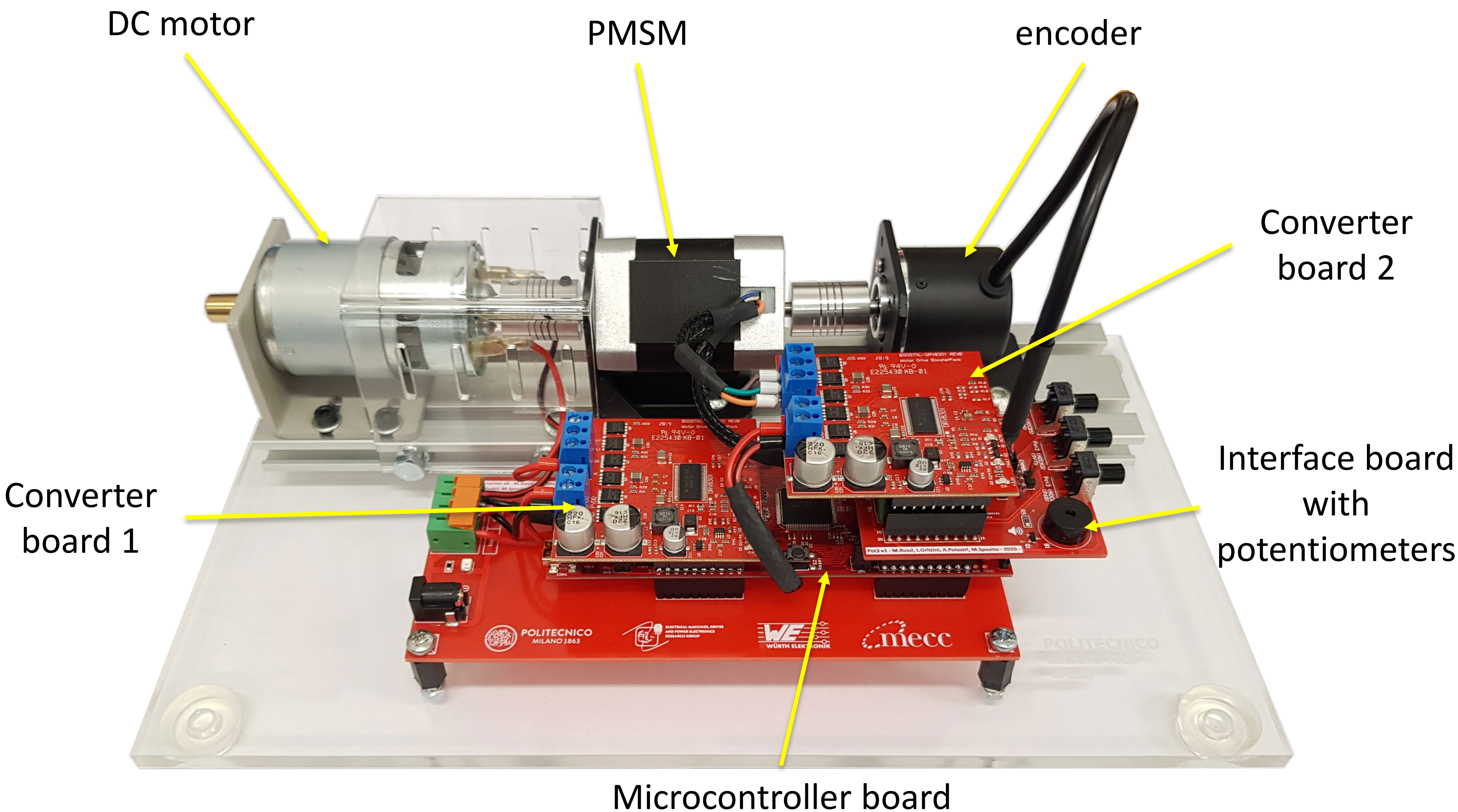
Control of a PMDC-PMDC back-to-back setup



Control of a PMDC-PMDC back-to-back setup – suggested steps

- Identification of the system parameters.
- Implementation of Matlab/Simulink simulation model, comprehensive of the board+inverter model
- Implementation and tuning of the current and speed loops (classical solution with PI-PI nested loops) with or without feed-forward on the current loop for the traction motor.
- Implementation and tuning of the current loop for the brake motor
- Control of the whole back-to-back setup (i.e., speed control with different loading conditions)
- Sensorless control of the back-to-back setup

Control of a PMSM-PMDC back-to-back setup



Control of a PMSM-PMDC back-to-back setup

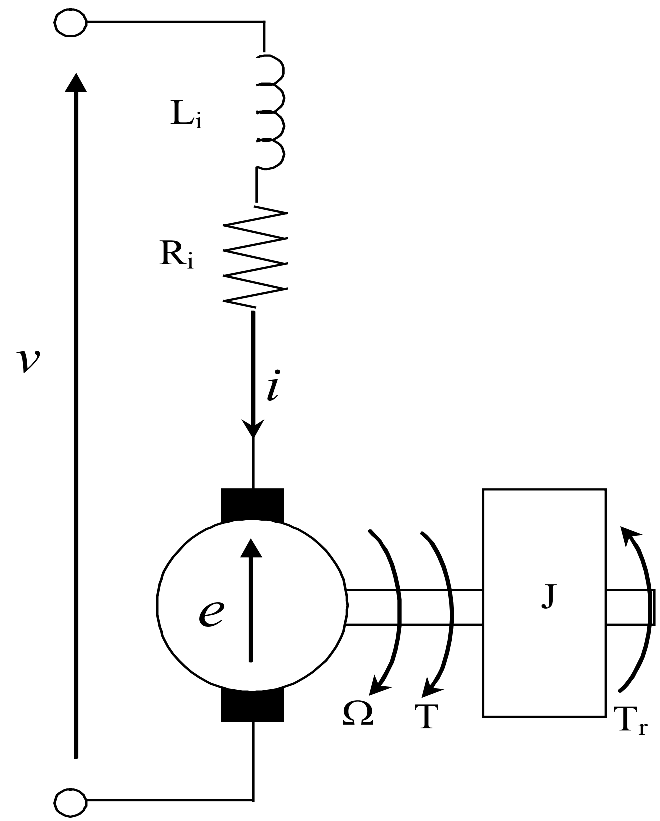
Suggested steps

- Identification of the system parameters.
- Implementation of Matlab/Simulink simulation model, comprehensive of the board+inverter model
- Implementation and tuning of the speed control algorithm for the PMSM (traction motor). Consider both ac or dc brushless control strategies.
- Implementation and tuning of the current loop for the brake PMDC motor
- Control of the whole back-to-back setup (i.e., speed control with different loading conditions)

Control of a permanent-magnet DC motor (1)

Model of the permanent-magnet DC machine

- The equivalent circuit represents the dynamic model of the machine.
- The state equations of the motor with inertial load J, resisting torque T_r can be written as (the state is represented by i, Ω):



$$\begin{cases} \mathrm{v} = R_i \cdot i + L_i \cdot \dfrac{\mathrm{d}i}{\mathrm{d}t} + e \\ T = T_r + J \cdot \dfrac{\mathrm{d}\Omega}{\mathrm{d}t} \end{cases}$$

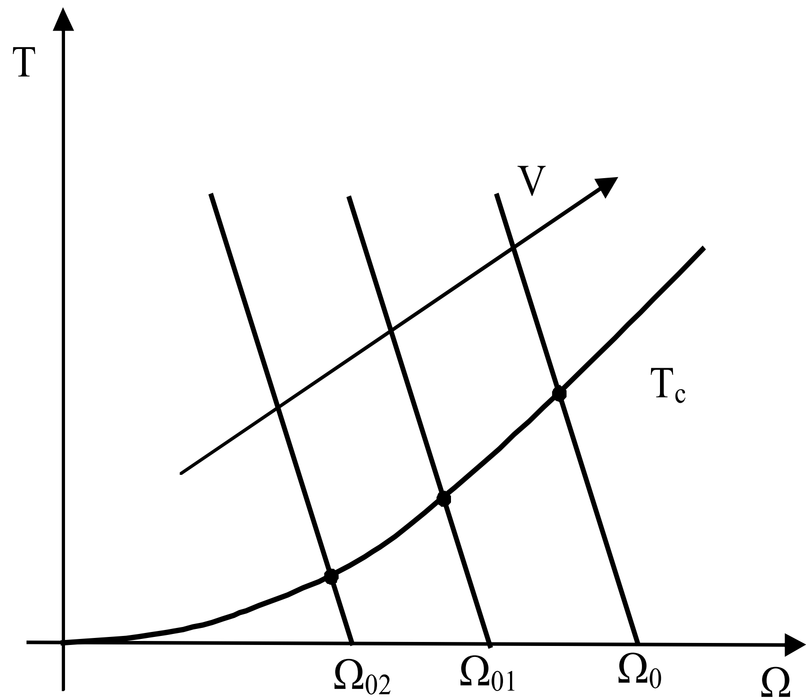
$$e = K_v \Omega$$

$$T = K_a \cdot i$$

$$K_a \approx K_a = K$$

Control of a permanent-magnet DC motor (1)

Through an adjustable voltage V source (converter), different characterisitcs T(Ω) can be obtained, presenting different Ω_0 (speed corresponding to zero current)



$$T(\Omega) = KI = K\frac{V-E}{R_i} = \frac{K^2}{R_i}(\Omega_0 - \Omega) = \frac{K^2}{R_i}(V/K - \Omega)$$

Control of a permanent-magnet DC motor (1)

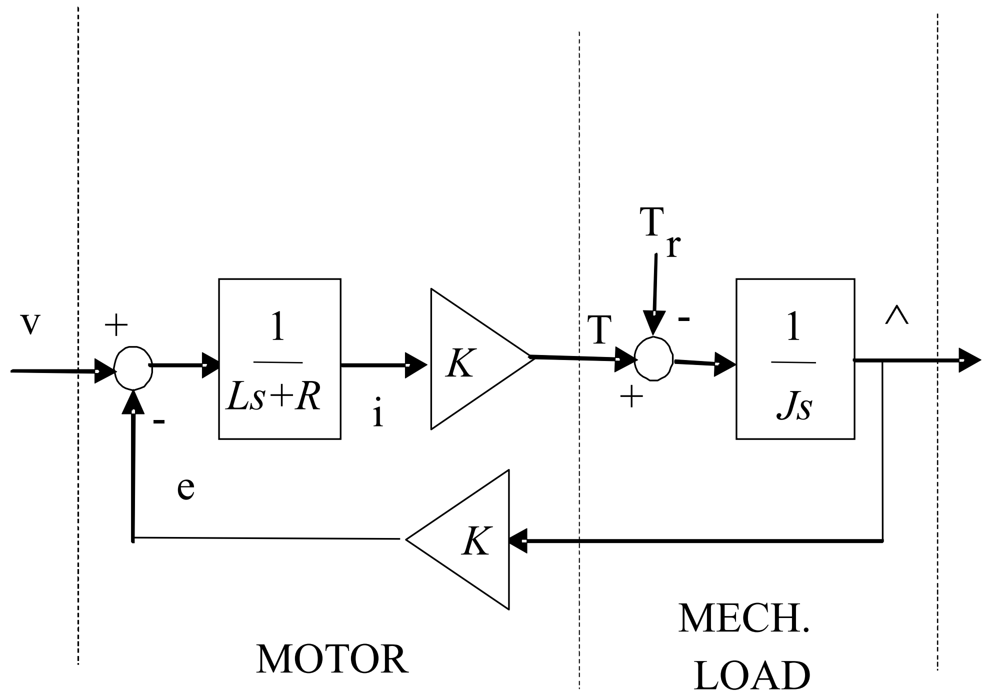
Moving to the Laplace domain…

$$V\text{-}E = R_i\, I + L_i\, s\, I$$

$$T\text{-}T_r = J_i\, s\, \Omega$$

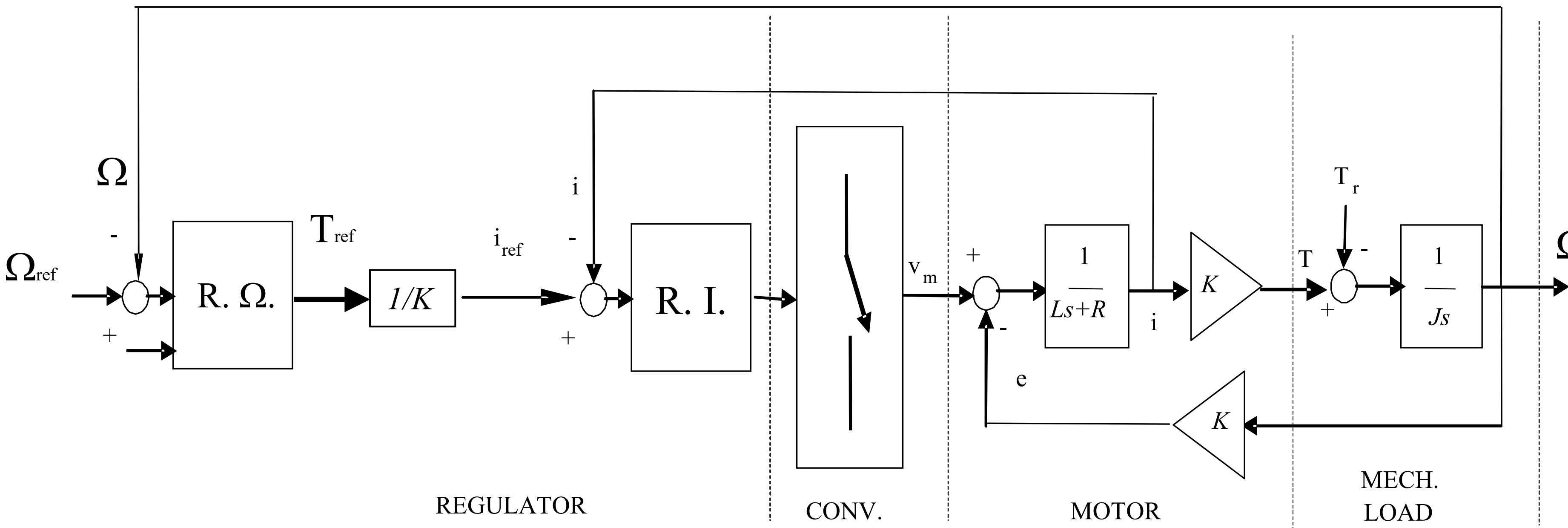
$$I = \frac{V - E}{R_i + L_i s}$$

$$\Omega = \frac{T - Tr}{Js}$$

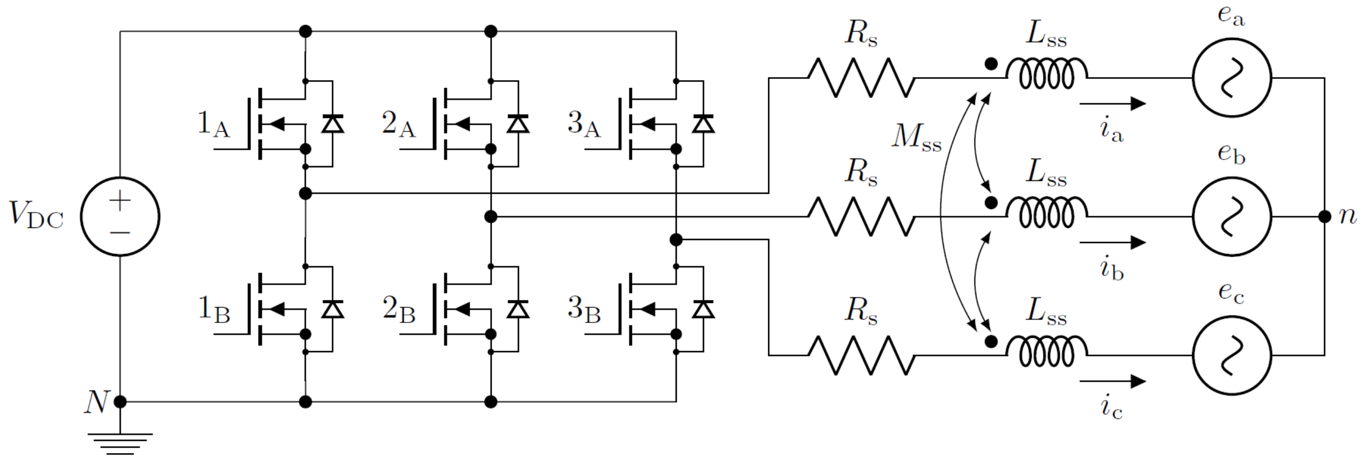


Control of a permanent-magnet DC motor (1)

The torque reference can descend from an external loop regulating the speed.
Two nested loops: the inner one regulates the current/torque,
the outer one regulates the speed.
<u>A coupling exists between the mechanical and electrical parts of the system, through the e.m.f.</u> $e=K\Omega$ (can be removed compensating the emf by adding a feed-forward contribution to the current loop)



Model of the PMSM



Electrical equations

$$
\begin{aligned}
v_{\mathrm{a}} &= R_{\mathrm{s}} i_{\mathrm{a}} + p\phi_{\mathrm{a}} \\
v_{\mathrm{b}} &= R_{\mathrm{s}} i_{\mathrm{b}} + p\phi_{\mathrm{b}} \\
v_{\mathrm{c}} &= R_{\mathrm{s}} i_{\mathrm{c}} + p\phi_{\mathrm{c}} \\
\phi_{\mathrm{a}} &= L_{\mathrm{ss}}(\theta_m) i_{\mathrm{a}} + M_{\mathrm{ss}}(\theta_m) i_{\mathrm{b}} + M_{\mathrm{ss}}(\theta_m - \tfrac{2}{3}\pi) i_{\mathrm{c}} + \phi_{\mathrm{PM}}(\theta_m) \\
\phi_{\mathrm{b}} &= M_{\mathrm{ss}}(\theta_m) i_{\mathrm{a}} + L_{\mathrm{ss}}(\theta_m - \tfrac{2}{3}\pi) i_{\mathrm{b}} + M_{\mathrm{ss}}(\theta_m + \tfrac{2}{3}\pi) i_{\mathrm{c}} + \phi_{\mathrm{PM}}(\theta_m - \tfrac{2}{3}\pi) \\
\phi_{\mathrm{c}} &= M_{\mathrm{ss}}(\theta_m - \tfrac{2}{3}\pi) i_{\mathrm{a}} + M_{\mathrm{ss}}(\theta_m + \tfrac{2}{3}\pi) i_{\mathrm{b}} + L_{\mathrm{ss}}(\theta_m + \tfrac{2}{3}\pi) i_{\mathrm{c}} + \phi_{\mathrm{PM}}(\theta_m + \tfrac{2}{3}\pi)
\end{aligned}
$$

$$\xrightarrow{i_{\mathrm{a}}+i_{\mathrm{b}}+i_{\mathrm{c}}=0}$$

$$
\begin{aligned}
v_{\mathrm{a}} &= R_{\mathrm{s}} i_{\mathrm{a}} + p\phi_{\mathrm{a}} \\
v_{\mathrm{b}} &= R_{\mathrm{s}} i_{\mathrm{b}} + p\phi_{\mathrm{b}} \\
v_{\mathrm{c}} &= R_{\mathrm{s}} i_{\mathrm{c}} + p\phi_{\mathrm{c}} \\
\phi_{\mathrm{a}} &= L_{\mathrm{s}} i_{\mathrm{a}} + \phi_{\mathrm{PM}}(\theta_m) \\
\phi_{\mathrm{b}} &= L_{\mathrm{s}} i_{\mathrm{b}} + \phi_{\mathrm{PM}}(\theta_m - \tfrac{2}{3}\pi) \\
\phi_{\mathrm{c}} &= L_{\mathrm{s}} i_{\mathrm{c}} + \phi_{\mathrm{PM}}(\theta_m + \tfrac{2}{3}\pi)
\end{aligned}
$$

with

$$
\begin{aligned}
p &= \frac{\mathrm{d}}{\mathrm{d}t} \\
L_{\mathrm{s}} &= L_{\mathrm{ss}} - M_{\mathrm{ss}}
\end{aligned}
$$

Model of the PMSM: AC brushless strategy

Park transformation is applied to the electrical variables

$$\mathbf{T}(\theta_m) = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta_m) & \cos\left(\theta_m - \frac{2}{3}\pi\right) & \cos\left(\theta_m + \frac{2}{3}\pi\right) \\ -\sin(\theta_m) & -\sin\left(\theta_m - \frac{2}{3}\pi\right) & -\sin\left(\theta_m + \frac{2}{3}\pi\right) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix}$$

$$\begin{bmatrix} v_{\mathrm{d}} \\ v_{\mathrm{q}} \\ v_0 \end{bmatrix} = \mathbf{T}(\theta_m) \begin{bmatrix} v_{\mathrm{a}} \\ v_{\mathrm{b}} \\ v_{\mathrm{c}} \end{bmatrix}$$
$$\begin{bmatrix} i_{\mathrm{d}} \\ i_{\mathrm{q}} \\ i_0 \end{bmatrix} = \mathbf{T}(\theta_m) \begin{bmatrix} i_{\mathrm{a}} \\ i_{\mathrm{b}} \\ i_{\mathrm{c}} \end{bmatrix}$$
$$\begin{bmatrix} \phi_{\mathrm{d}} \\ \phi_{\mathrm{q}} \\ \phi_0 \end{bmatrix} = \mathbf{T}(\theta_m) \begin{bmatrix} \phi_{\mathrm{a}} \\ \phi_{\mathrm{b}} \\ \phi_{\mathrm{c}} \end{bmatrix}$$

Therefore

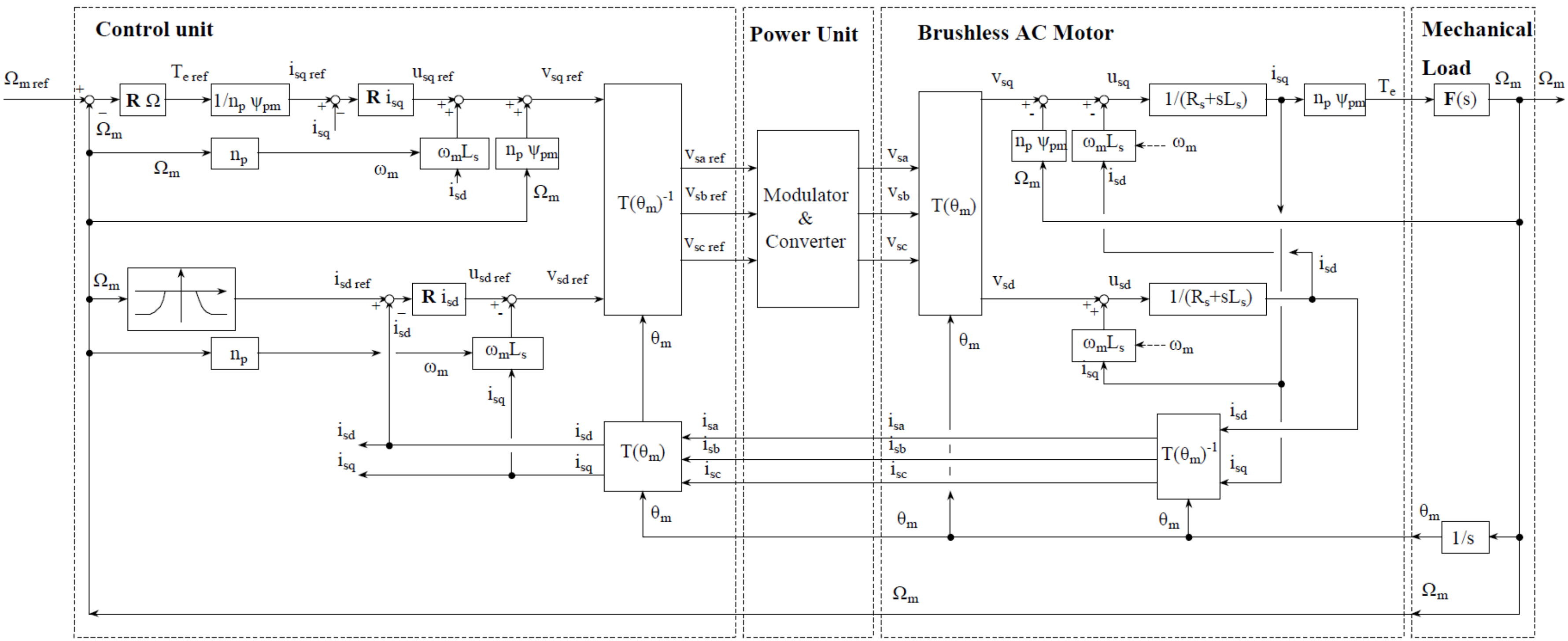
$$\begin{gathered} v_{\mathrm{d}} = R_{\mathrm{s}} i_{\mathrm{d}} + p\phi_{\mathrm{d}} - n_p \Omega \phi_{\mathrm{q}} \\ v_{\mathrm{q}} = R_{\mathrm{s}} i_{\mathrm{q}} + p\phi_{\mathrm{q}} + n_p \Omega \phi_{\mathrm{d}} \\ \phi_{\mathrm{d}} = L_{\mathrm{s}} i_{\mathrm{d}} + \phi_{\mathrm{PM}} \\ \phi_{\mathrm{q}} = L_{\mathrm{s}} i_{\mathrm{q}} \end{gathered}$$

Mechanical equations

$$\begin{gathered} J_{\mathrm{eq}} p\Omega + \beta\Omega = m_e - m_l \\ m_e = n_p \phi_{\mathrm{PM}} i_{\mathrm{q}} \end{gathered}$$

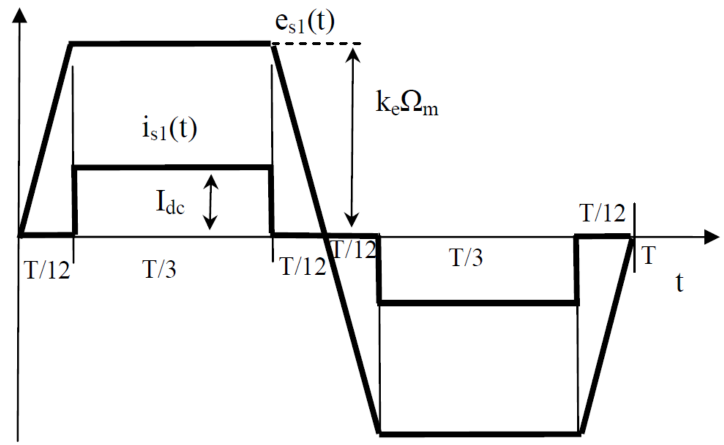
Control of the PMSM: AC brushless strategy

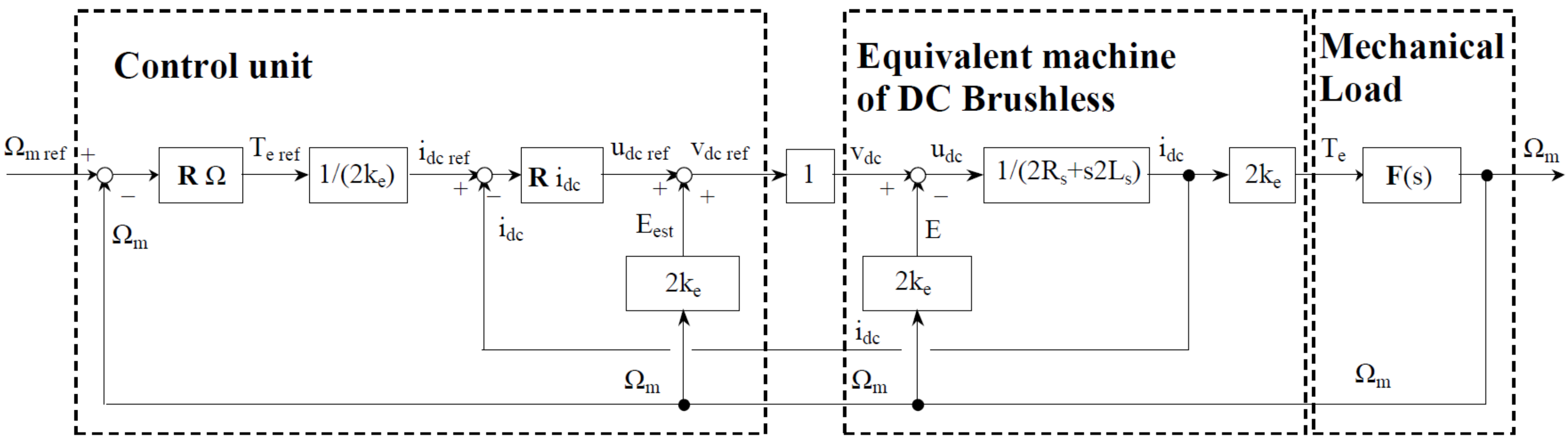
$$v_\mathrm{d} = R_\mathrm{s} i_\mathrm{d} + p\phi_\mathrm{d} - n_p \Omega \phi_\mathrm{q}$$
$$v_\mathrm{q} = R_\mathrm{s} i_\mathrm{q} + p\phi_\mathrm{q} + n_p \Omega \phi_\mathrm{d}$$
$$\phi_\mathrm{d} = L_\mathrm{s} i_\mathrm{d} + \phi_\mathrm{PM}$$
$$\phi_\mathrm{q} = L_\mathrm{s} i_\mathrm{q}$$
$$J_\mathrm{eq} p \Omega + \beta \Omega = m_e - m_l$$
$$m_e = n_p \phi_\mathrm{PM} i_\mathrm{q}$$



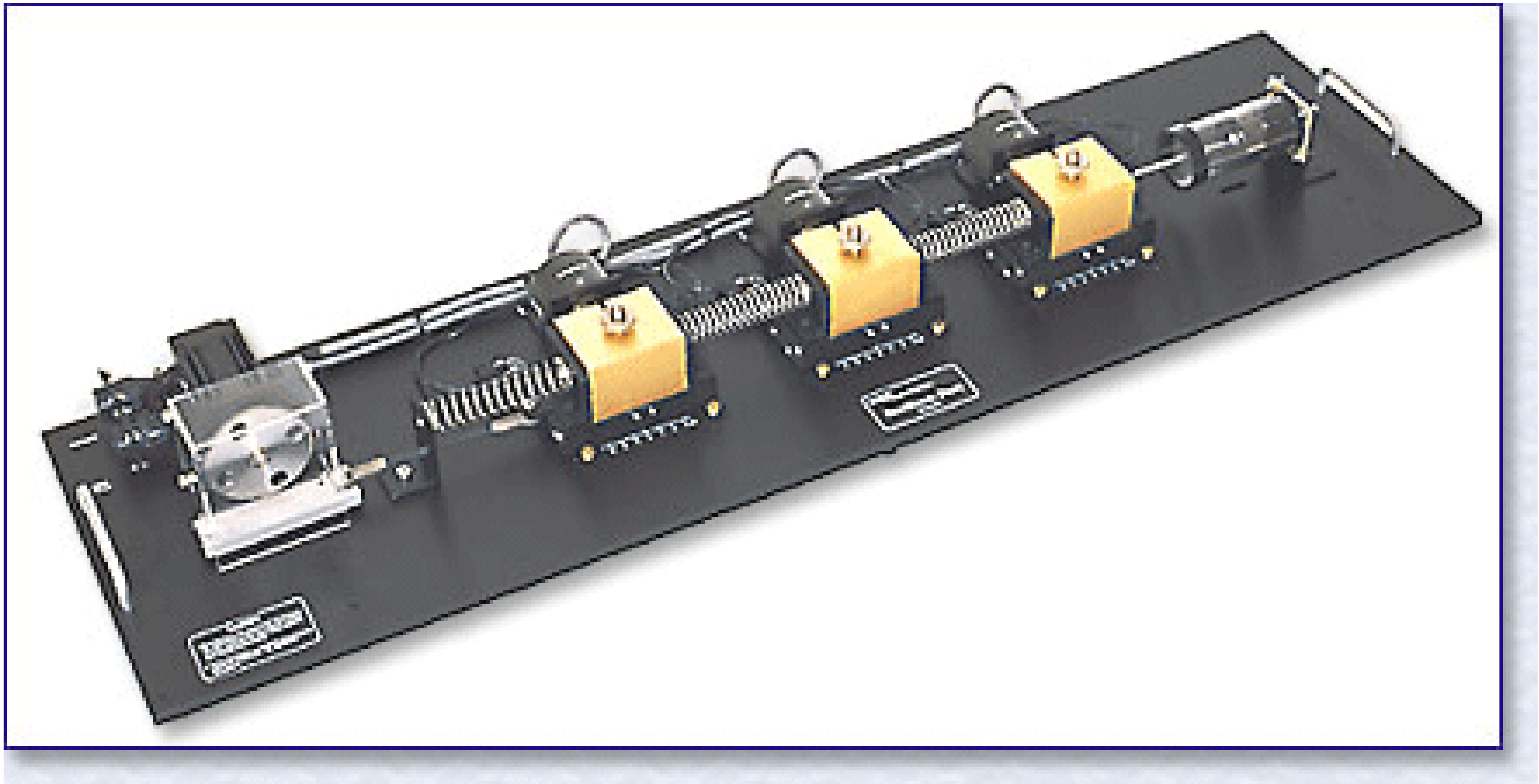
Control of the PMSM: DC brushless strategy

$$
\begin{aligned}
v_a &= R_s i_a + p\phi_a \\
v_b &= R_s i_b + p\phi_b \\
v_c &= R_s i_c + p\phi_c \\
\phi_a &= L_s i_a + \phi_{PM}(\theta_m) \\
\phi_b &= L_s i_b + \phi_{PM}(\theta_m - \tfrac{2}{3}\pi) \\
\phi_c &= L_s i_c + \phi_{PM}(\theta_m + \tfrac{2}{3}\pi) \\
J_{eq} p\Omega + \beta\Omega &= m_e - m_l \\
m_e &= 2k_e I_{dc}
\end{aligned}
$$



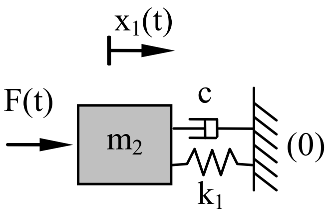


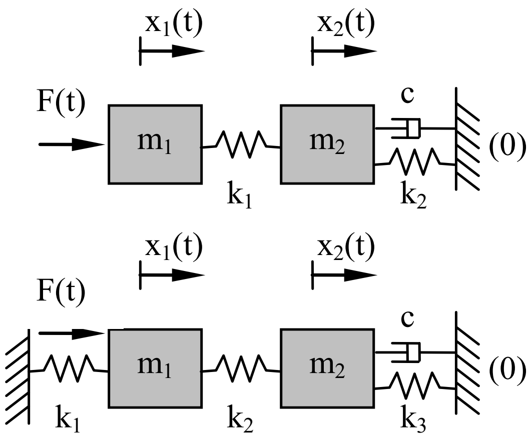
Control of linear vibrations

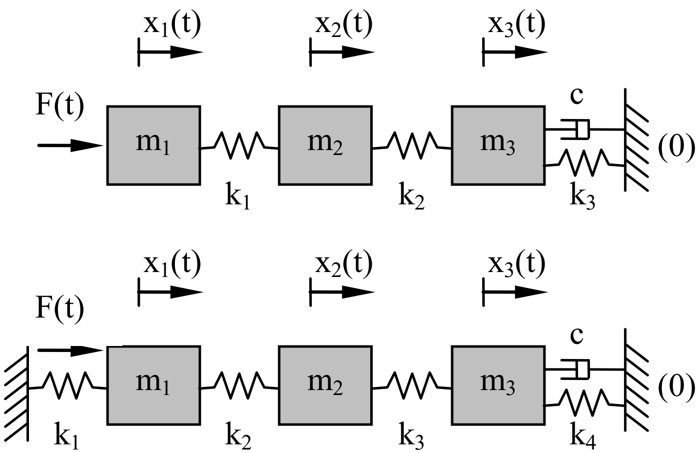


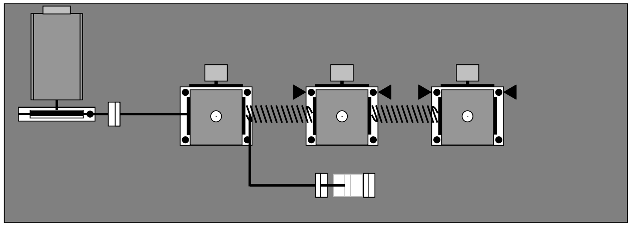
The system is composed by 3 masses and different springs for the connection to the ground or between the masses

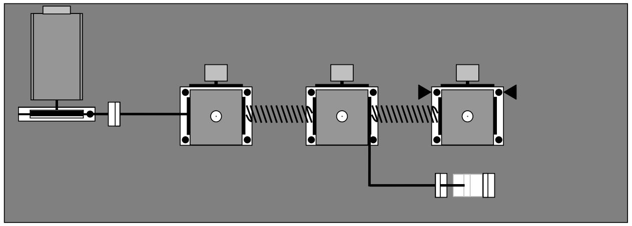
By applying different connections 1, 2 and 3 DoF systems can be realised.

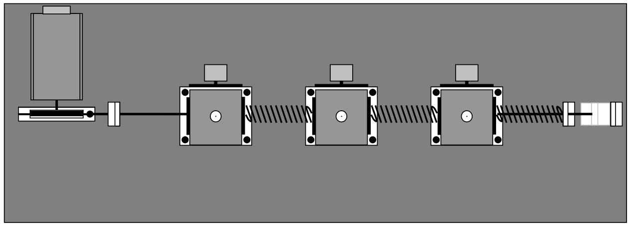






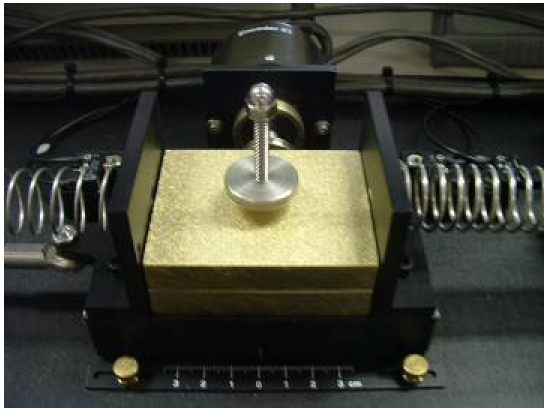


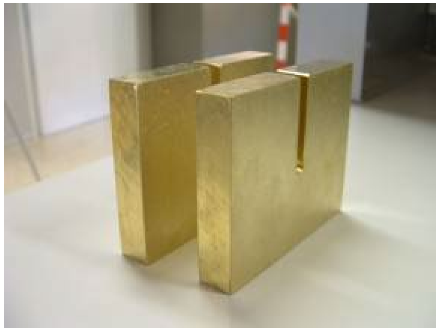




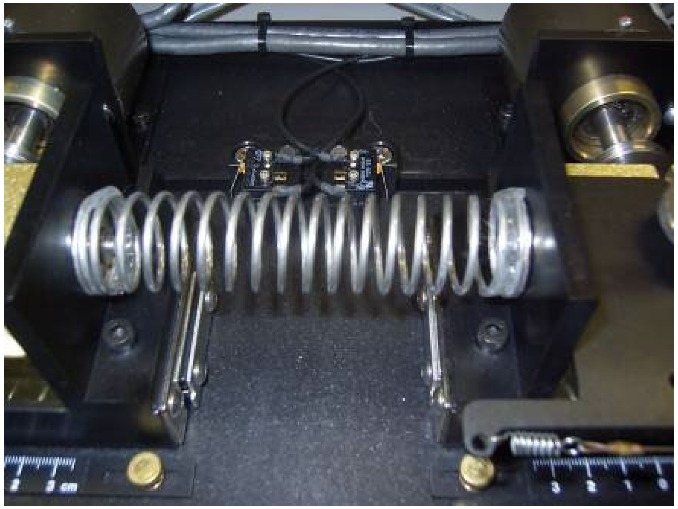
Control of linear vibrations

The inertia of the moving masses can be varied by changing the number of brass weights (500 ± 5g weight each).



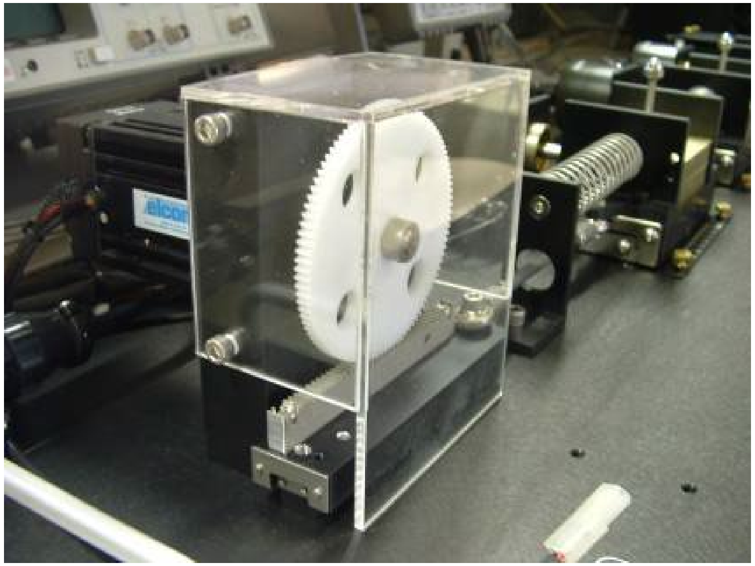


The bi-directional springs can be dismounted and changed. Springs with different stiffness are available.

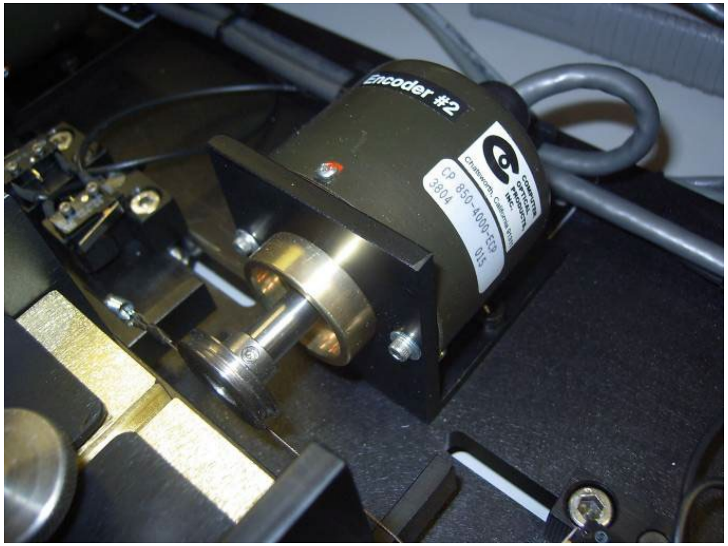


Control of linear vibrations

The linear drive is comprised of a gear rack suspended on an anti-friction carriage and a pinion (pitch diameter 7.62 cm (3.00 in)) coupled to the (DC) motor shaft. The carriage is rigidly connected to the first mass.

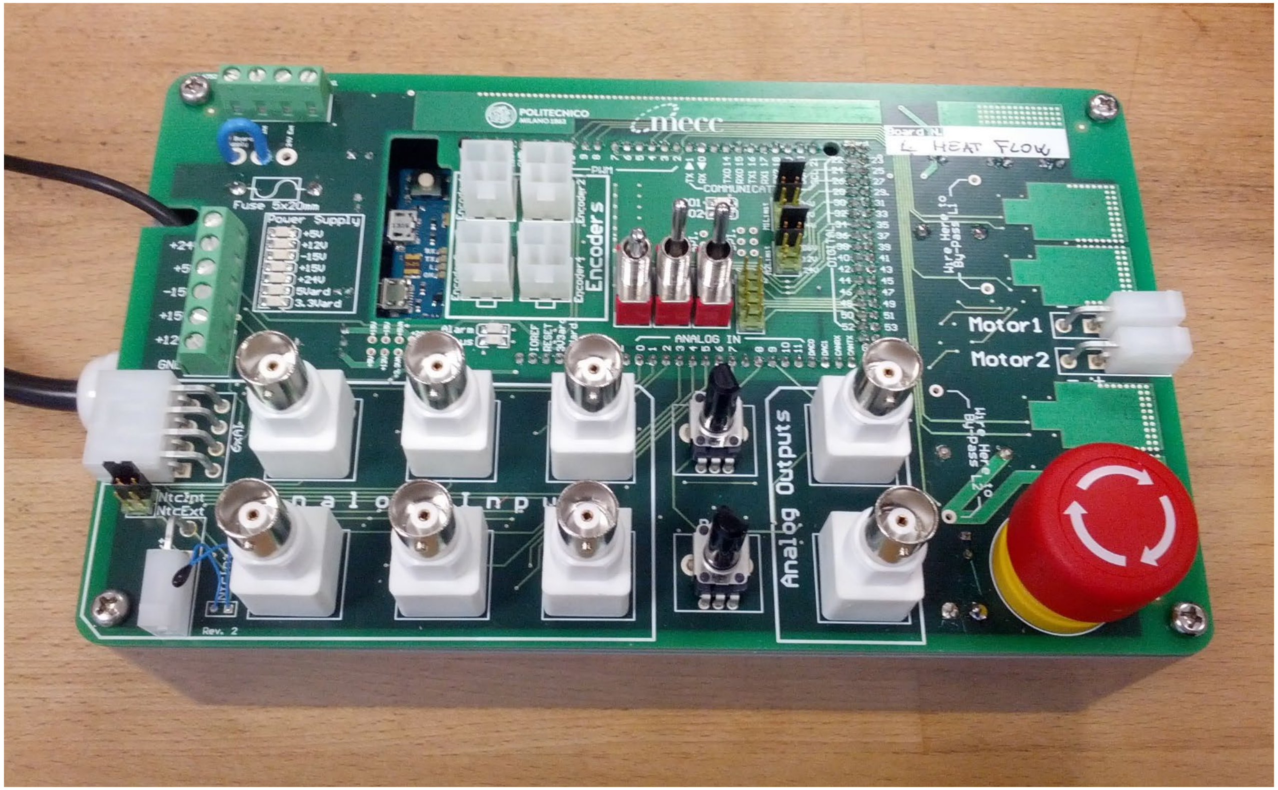


Optical encoders measure the mass carriage positions – through a capstan system, pinion pitch diameter 3.18 cm (1.25 in)

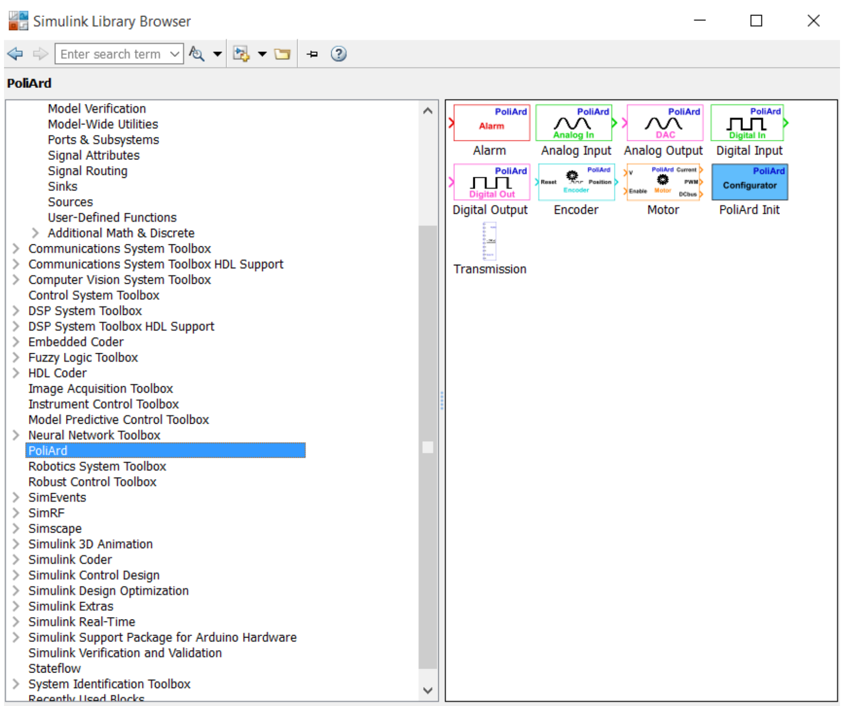


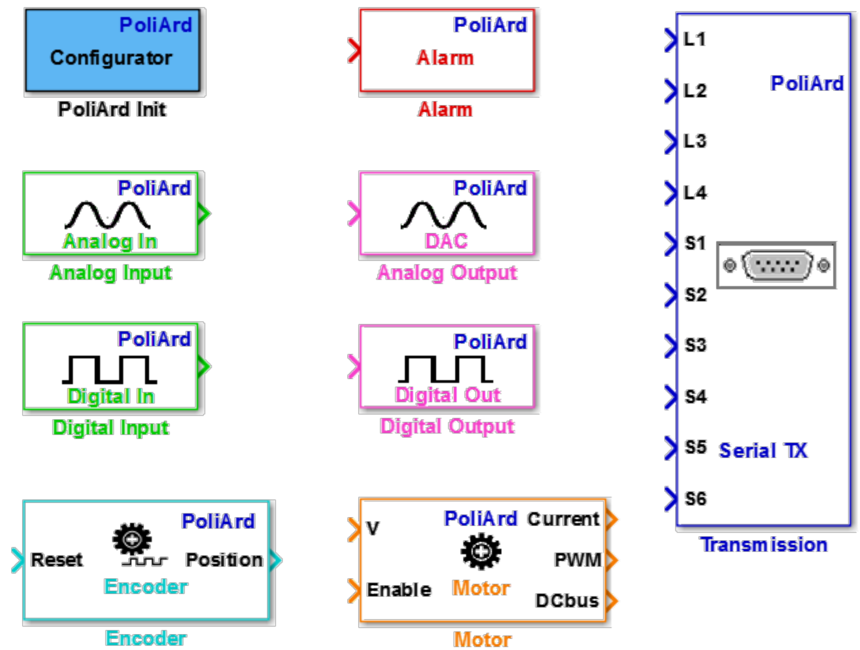
Control of linear vibrations

PoliArd Board allows to perform real-time control logics thanks to an Arduino Due board (32-bit ARM Cortex-M3).

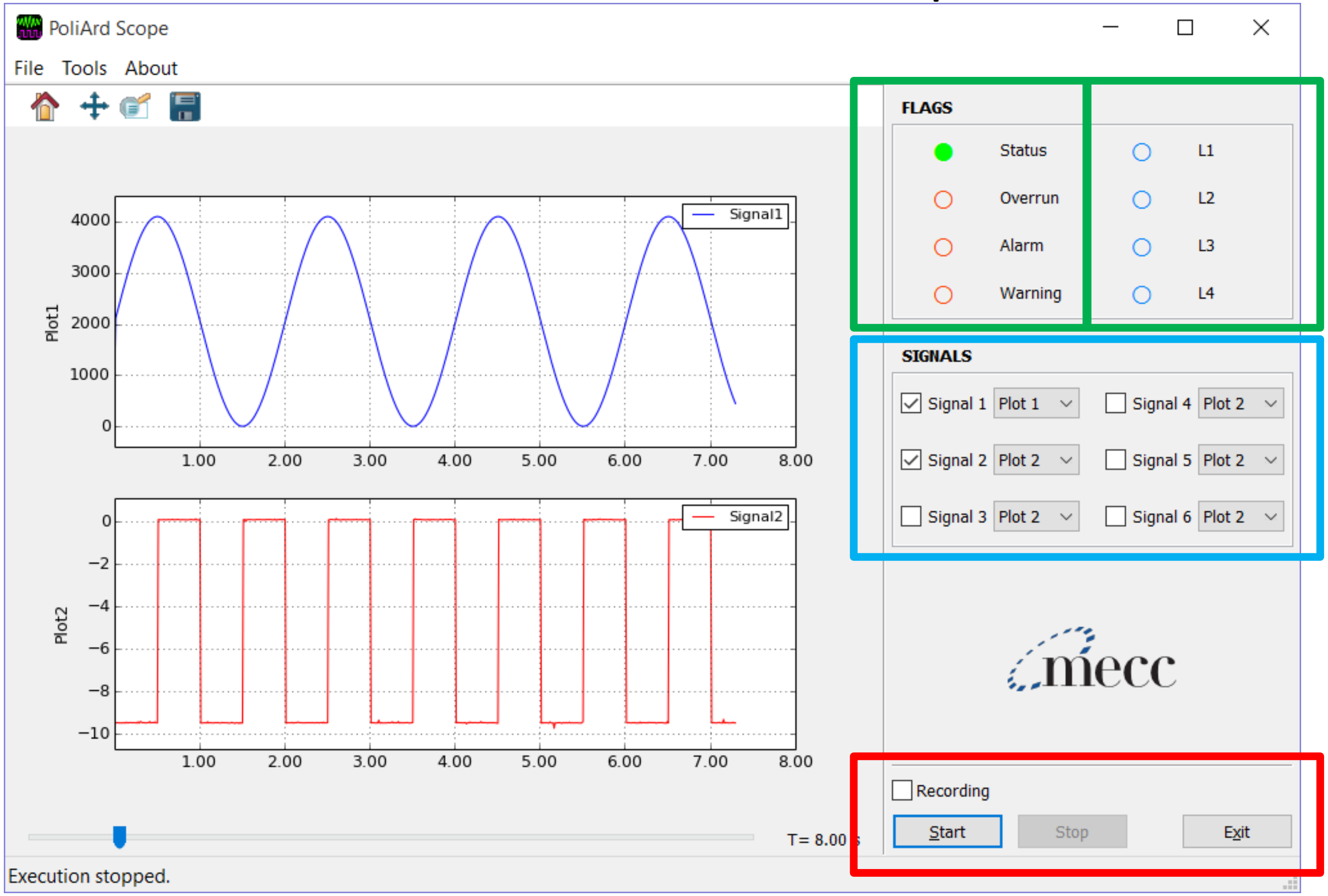


PoliArd Library (Matlab 2015a 64 bit)





PoliArd Scope



Boolean flags visualization

Float signals configuration

Acquisition controls

Control of linear vibrations – suggested steps

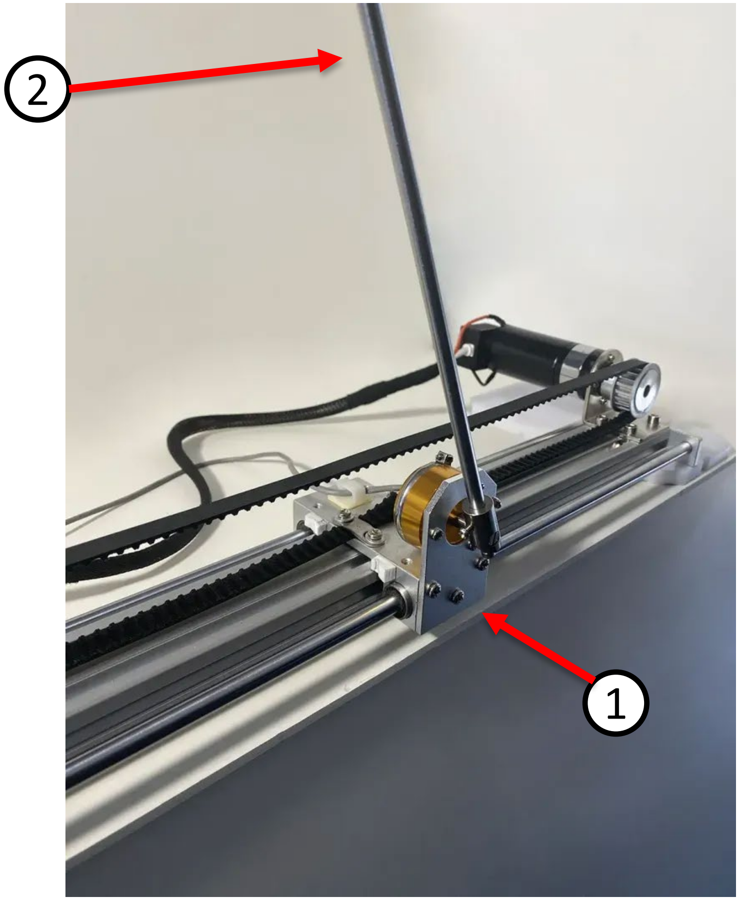
Consider different system configurations (with increasing difficulty levels). Steps for each subsystem:

1. Development of models for simulation (time domain) and for control synthesis and tuning (Laplace domain)
2. Identification of unknown parameters of the model/s
3. Numerical implementation and verification of different control logics (for position control of one of the masses) (classical control and modern control, if appl.)
4. Implementation of the control on the real system and comparison between numerical and experimental results (with possible optimisation of the control parameters for the real system)
5. Comparison of the performances of the different control logics/calibrations (robustness)

Linear pendulum

The **linear pendulum** is composed of

- a **cart (1) connected with a belt to a motor** that moves along a linear guide
- a **pendulum (2)** hinged to the cart
- **two encoders** to measure the position of the cart and the angle of the pendulum

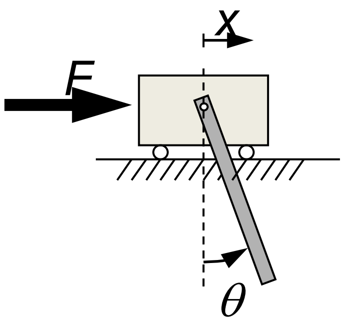


Linear pendulum

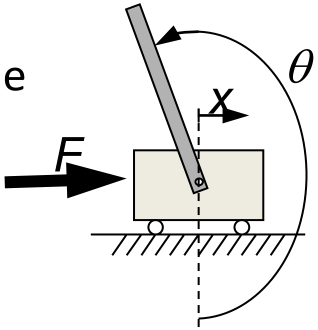
CONTROL GOAL

- Actuate the cart to control the pendulum in its two equilibrium points

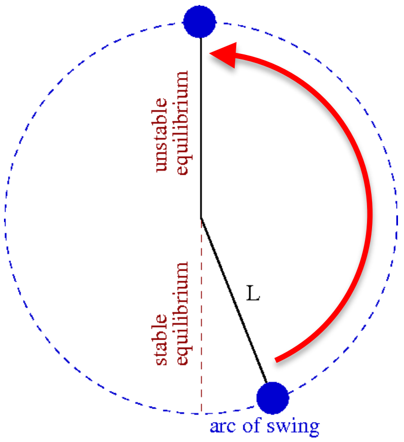
Stable

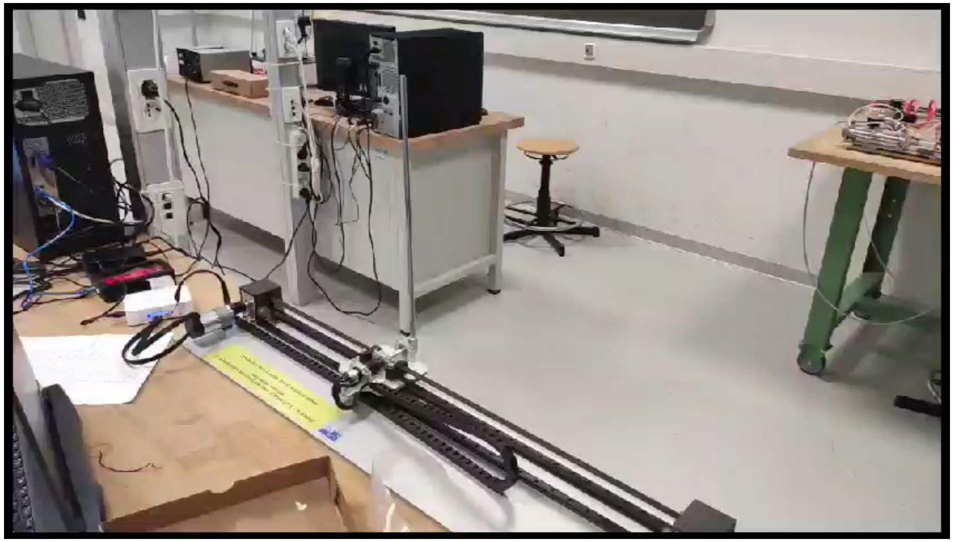


Unstable



- Swing the pendulum up



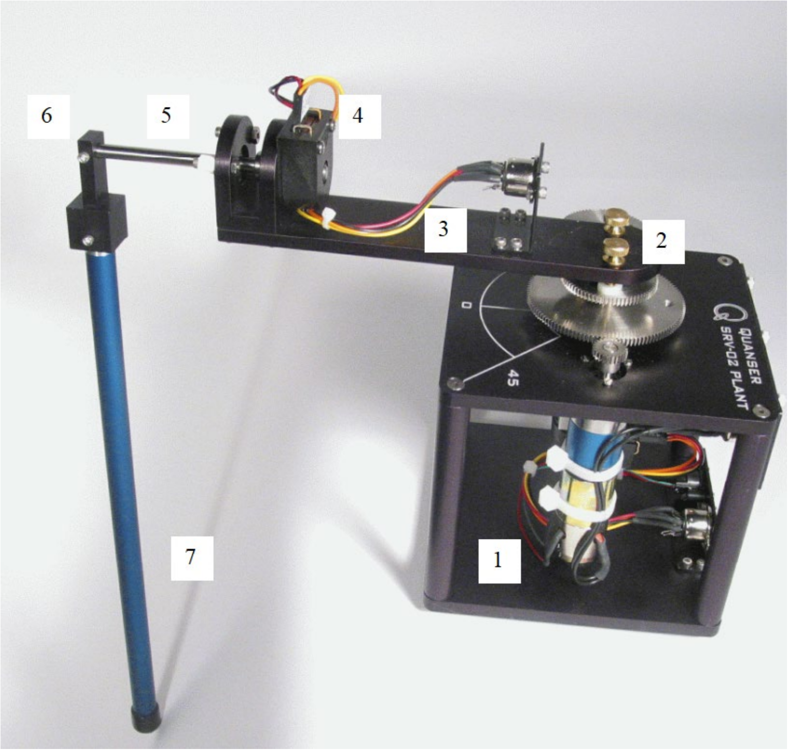


Control of a linear pendulum – suggested steps

Consider different system configurations (with increasing difficulty levels). Steps for each subsystem:

1. Development of models for simulation (time domain) and for control synthesis and tuning (Laplace domain)
2. Identification of unknown parameters of the model/s
3. Numerical implementation and verification of different control logics (classical control and modern control, if applicable)
4. Implementation of the control on the real system and comparison between numerical and experimental results (with possible optimisation of the control parameters for the real system)
5. Comparison of the performances of the different control logics/calibrations (robustness)

Control of a rotational pendulum/flexible link

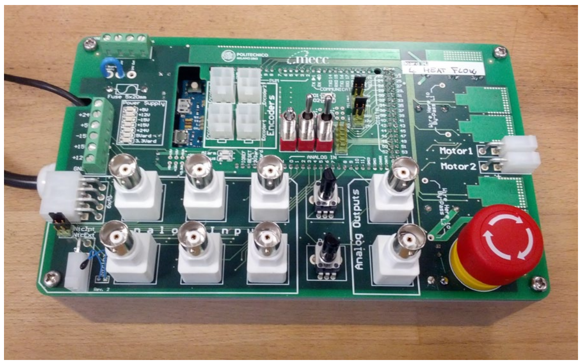


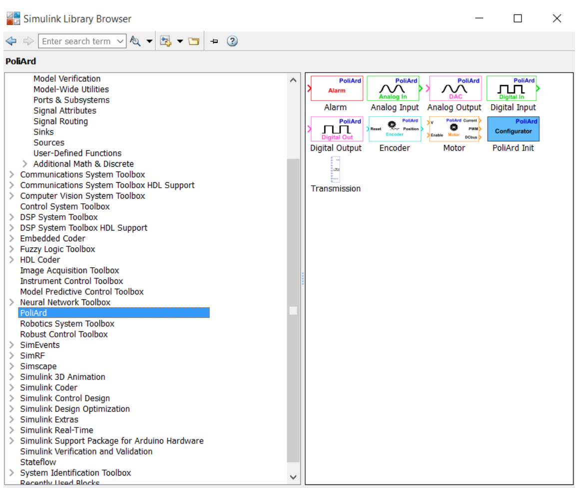
Control of a rotational pendulum/flexible link

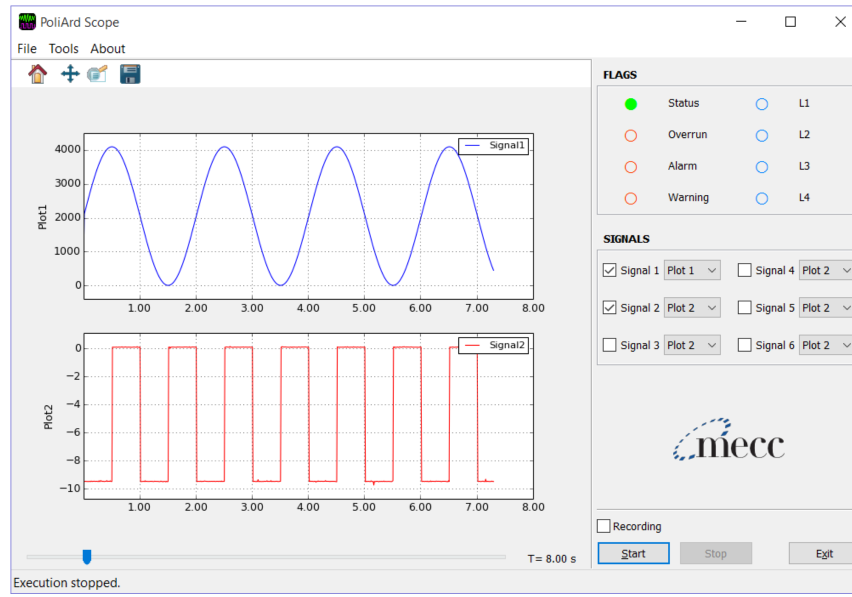
The system consists of a DC motor in a solid aluminum frame. The motor is equipped with a gearbox. The gearbox output drives external gears. The basic unit is equipped with an encoder to measure the output/load angular position.

Control of a rotational pendulum/flexible link

PoliArd board







Rotational pendulum

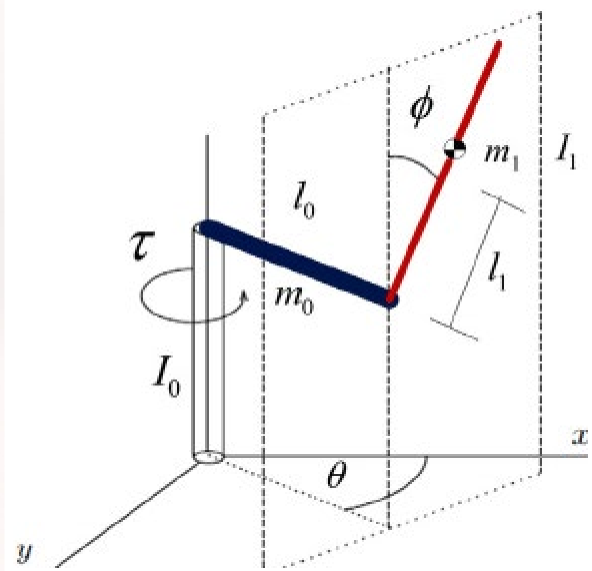
The **rotational pendulum** is composed of

Motorized rotational guide (1)

- *Encoder to measure its rotation*

Rotational pendulum (2)

- *Encoder to measure its rotation*



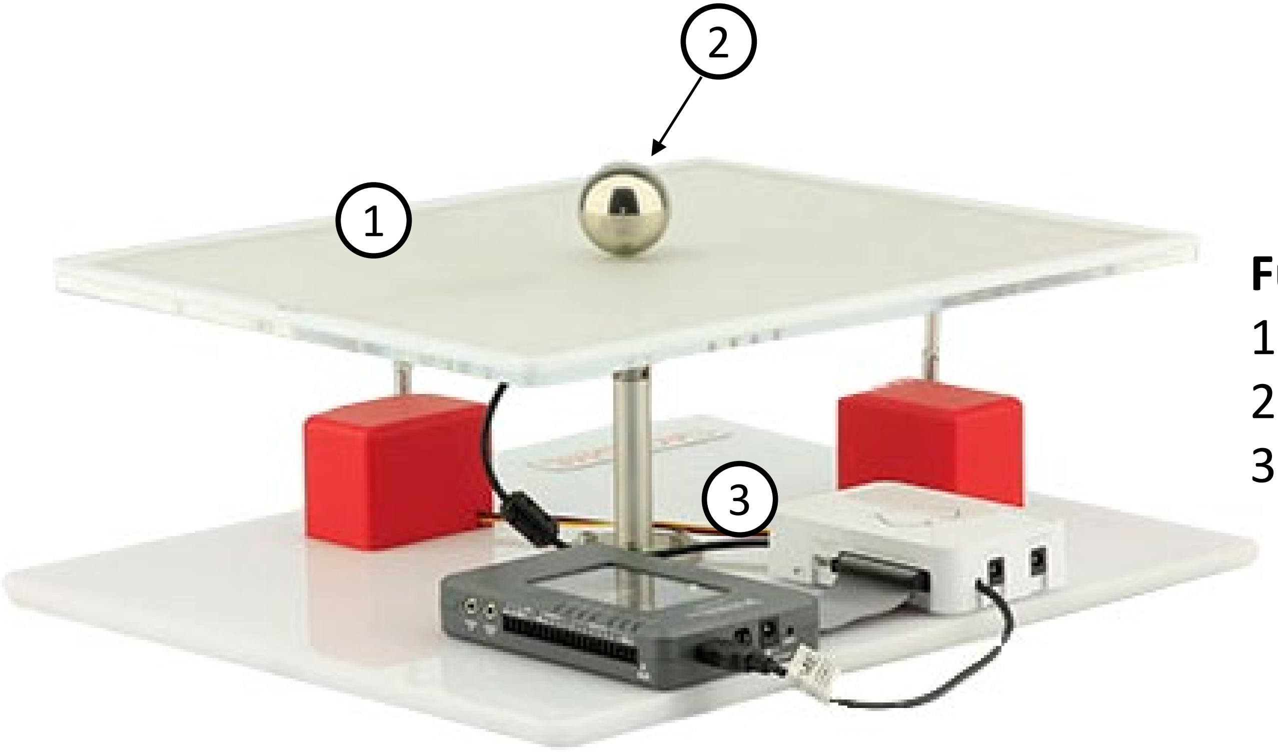
Control of a rotational pendulum/flexible link

Consider different system configurations (with increasing difficulty levels). Steps for each subsystem:

1. Development of models for simulation (time domain) and for control synthesis and tuning (Laplace domain)
2. Identification of unknown parameters of the model/s
3. Numerical implementation and verification of different control logics (classical control and modern control, if applicable)
4. Implementation of the control on the real system and comparison between numerical and experimental results (with possible optimisation of the control parameters for the real system)
5. Comparison of the performances of the different control logics/calibrations (robustness)

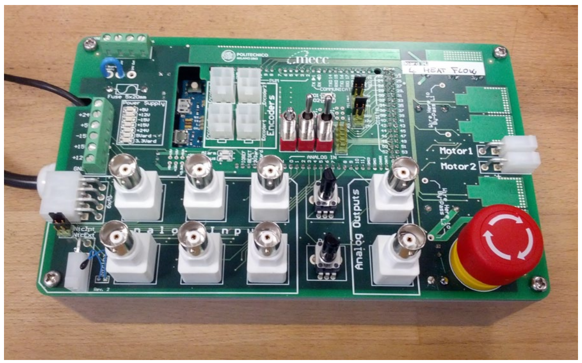
2D ball balancing

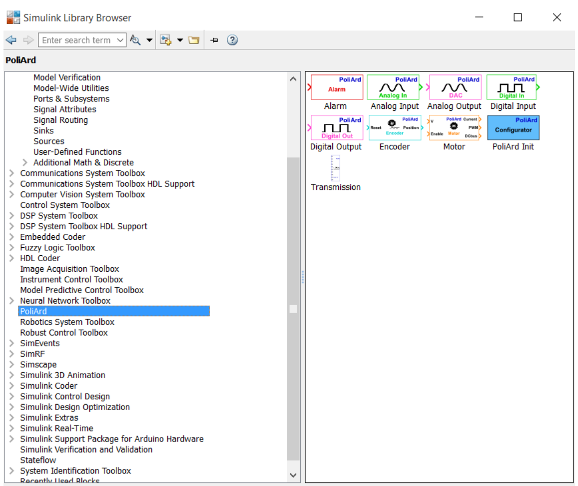
The system is composed by an unstable ball on a table

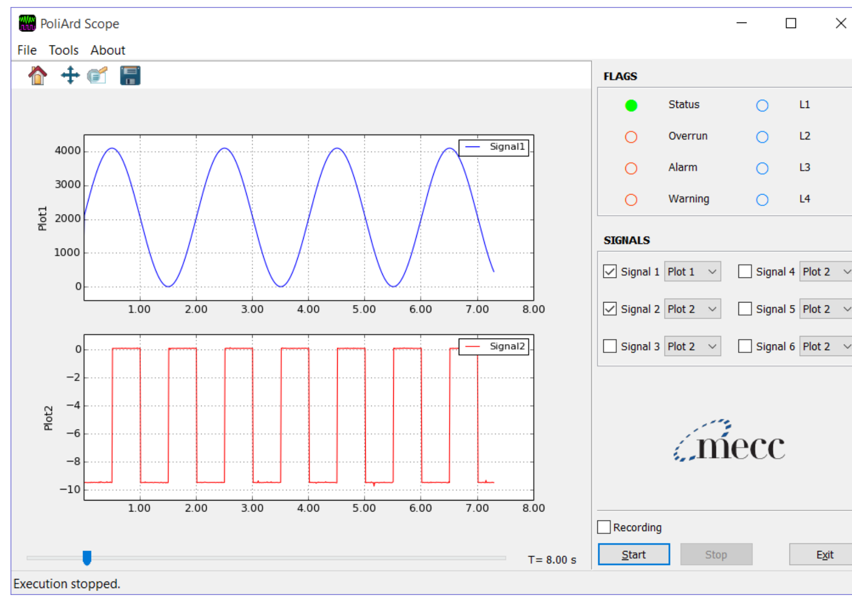


Fundamental parts:
1. Touch-sensitive table
2. Ball
3. Joint + 2 servos

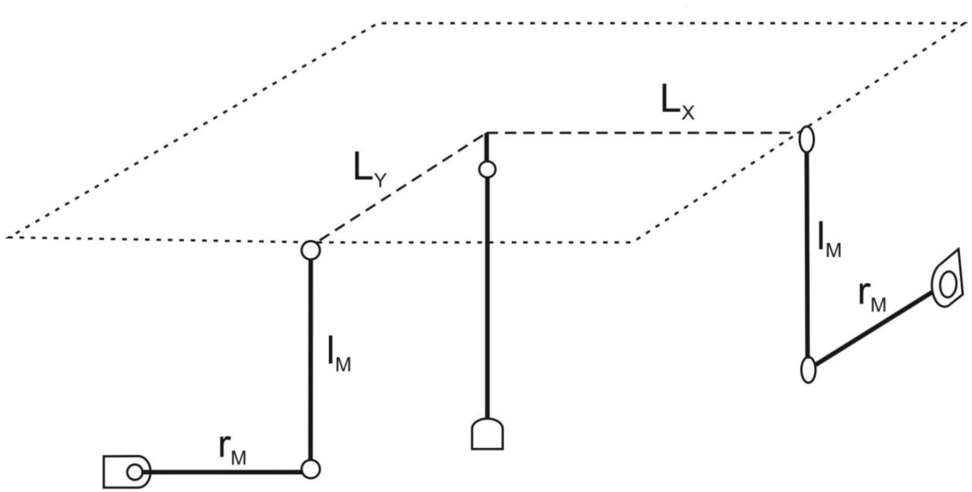
PoliArd board





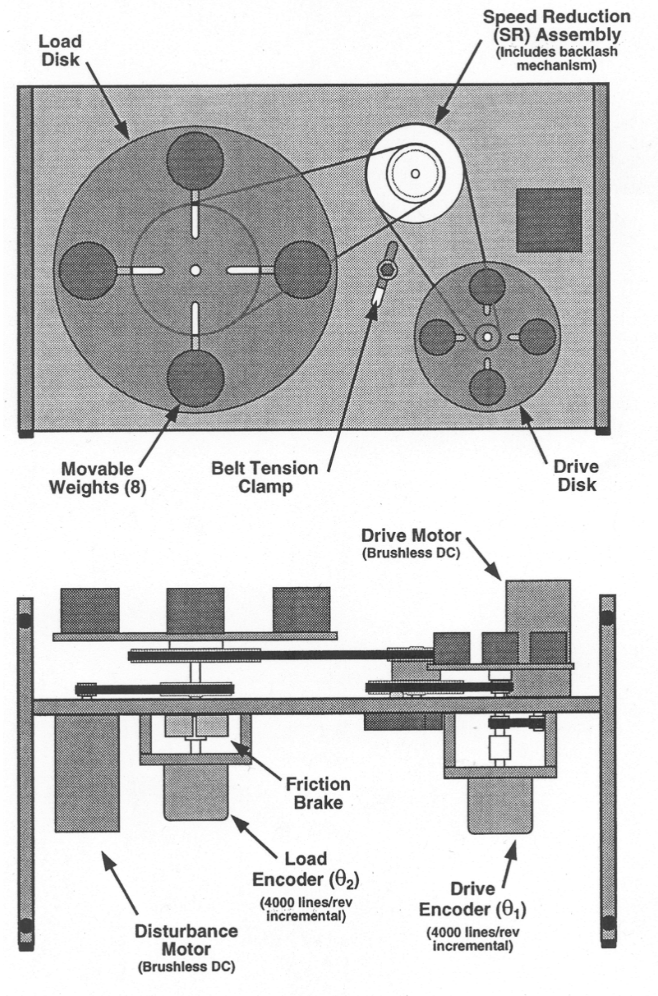


2D ball balancing – suggested steps



1. Modelling, identification and simulation of the system
2. Stabilisation of the ball
3. Placement of the ball
4. 1D trajectory tracking
5. 2D trajectory tracking

Industrial Plant

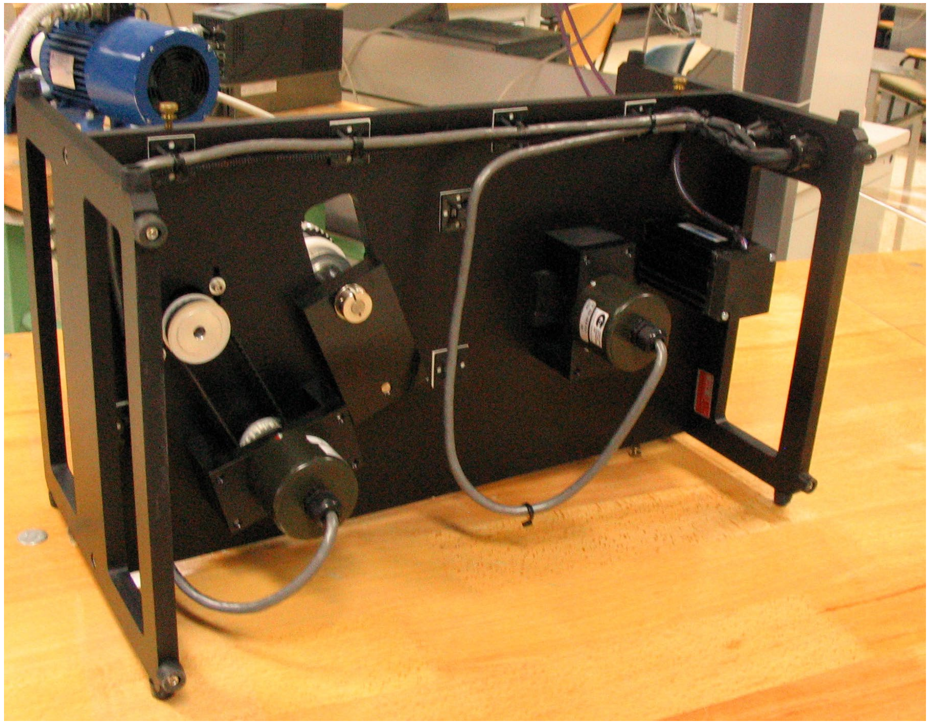


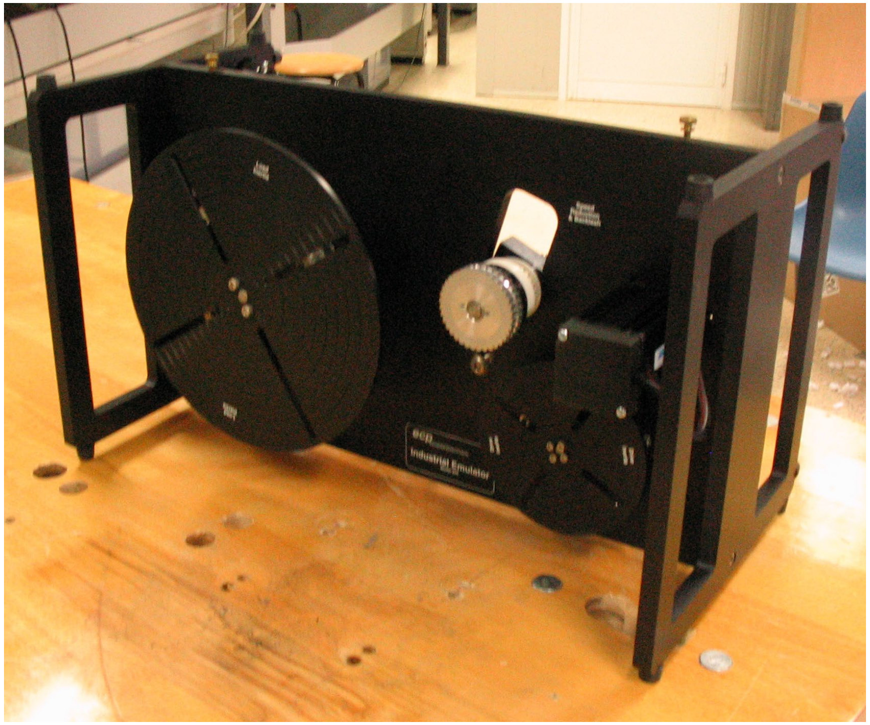
The system consists of a *drive motor* which is coupled via a timing belt to a *drive disk* with variable inertia. Another timing belt connects the drive disk to the *speed reduction (SR)* assembly while a third belt completes the drive train to the *load disk.* The load and drive disks have variable inertia which may be adjusted by moving (or removing) brass weights.

Speed reduction is adjusted by interchangeable belt pulleys in the SR assembly.

A disturbance motor is connected to the load to give any kind of resisting torque.

Industrial Plant

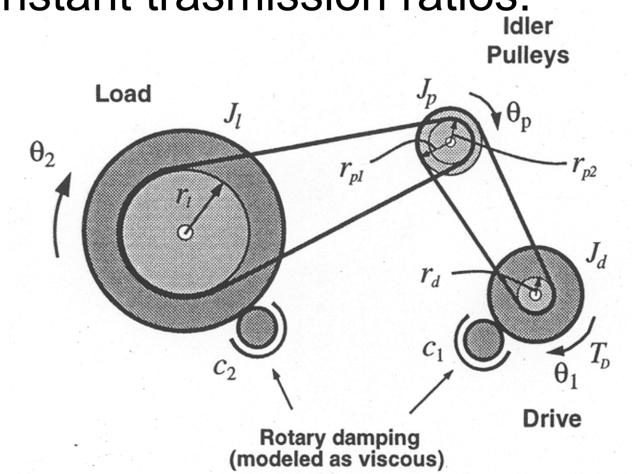




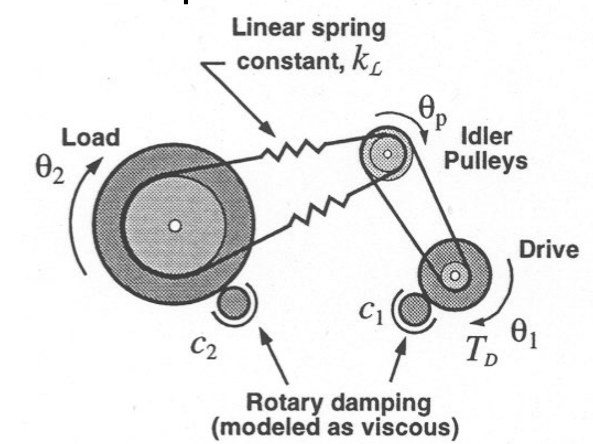
Industrial Plant

The belt connecting the speed reduction assembly and the drive disk can be rigid or flexible. Backlash may be introduced through a mechanism incorporated in the SR assembly.

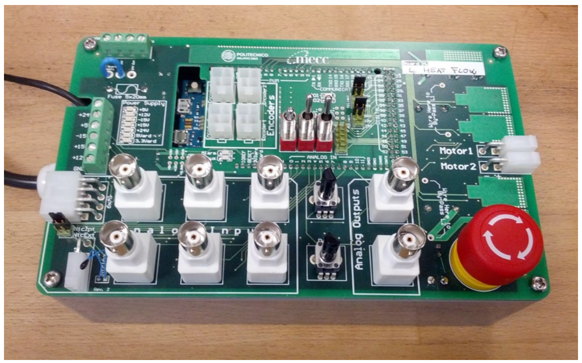
1 dof system
The rotations are related through constant trasmission ratios.

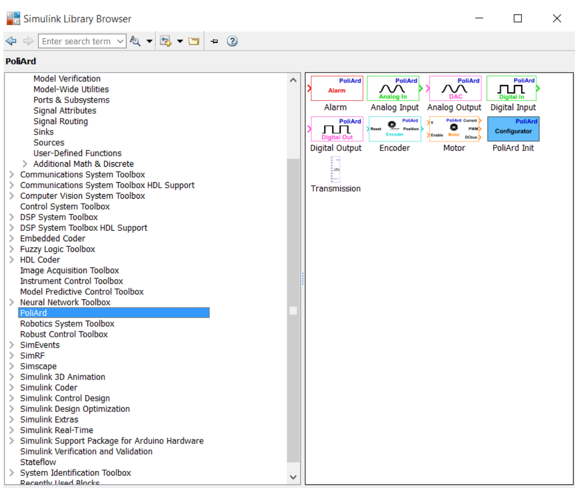


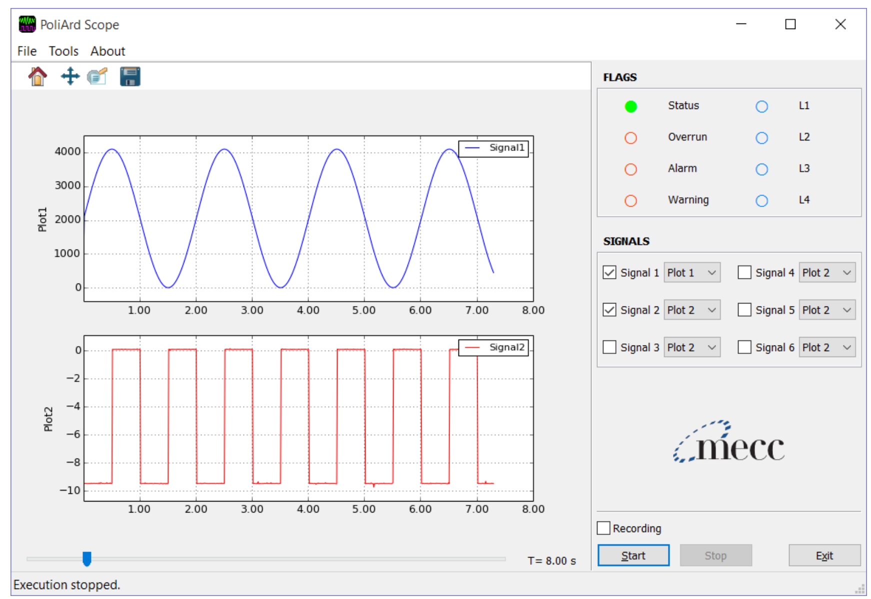
2 dof system
The rotations of the drive and of the load are independent.



PoliArd board







Industrial plant – suggested steps

Consider different system configurations (with increasing difficulty levels).

Steps for each subsystem:

1. Development of models for simulation (time domain) and for control synthesis and tuning (Laplace domain)
2. Identification of unknown parameters of the model/s
3. Numerical implementation and verification of different control logics (for position control of one of the masses) (classical control and modern control, if appl.)
4. Implementation of the control on the real system and comparison between numerical and experimental results (with possible optimisation of the control parameters for the real system)
5. Comparison of the performances of the different control logics/calibrations (robustness)
6. Development of a speed observer for the load disk

Reaction pendulum

The **reaction pendulum** is composed of

Reaction wheel (1)

- *Encoder to measure its rotation*
- *DC motor to control it*

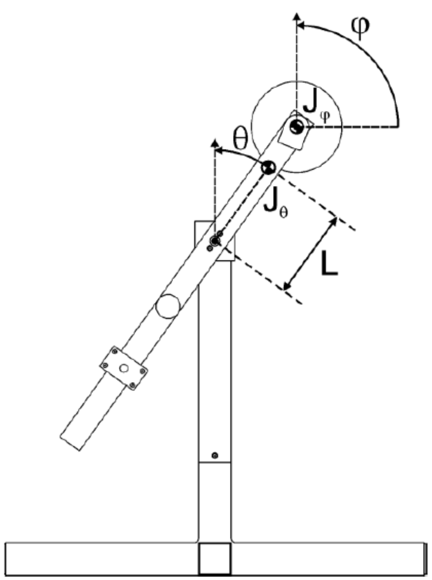
Rotational pendulum (2)

- *Encoder to measure its rotation*

Rotational pendulum

CONTROL GOAL: actuate the motor to

- control the pendulum in its two equilibrium points
- swing up the pendulum



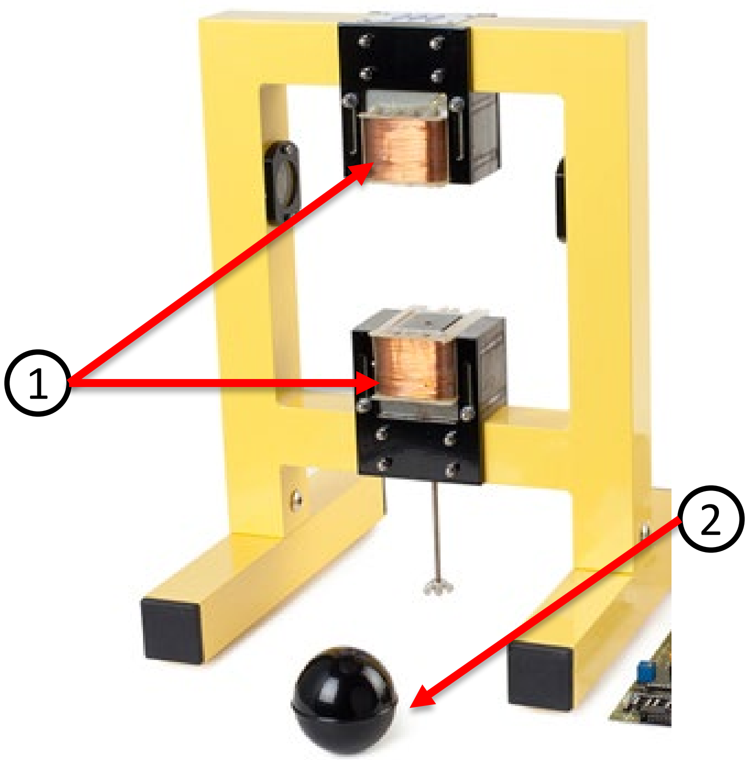
Rotational pendulum

Roadmap of the activity

- ✓ Modeling of the system:
  - ✓ Full nonlinear and linearized model
  - ✓ Mechanical and electrical parameters identification
- ✓ Pendulum stabilization
  - ✓ Downward and upward stabilization
  - ✓ Control logics: PID, root-locus, pole placement, LQR, LQG,…
- ✓ Swing-up
  - ✓ Energy control, positive feedback, heuristic,…
- ✓ …

Maglev

The **Maglev** is an electromagnetic levitation system.

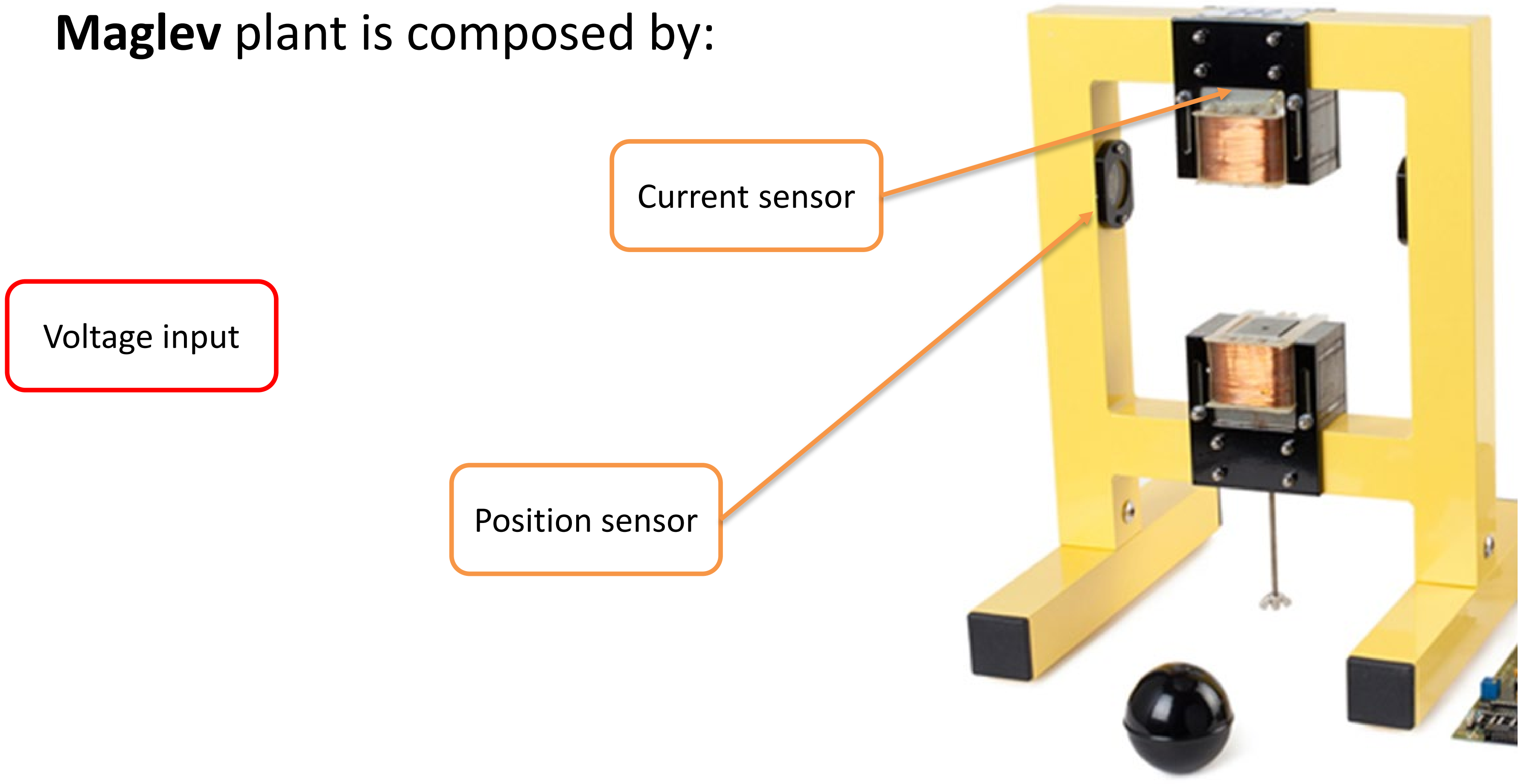


The solenoid2 **(1)**, thanks to the current flow, generates a magnetic field inside the internal chamber

The ferromagnetic ball **(2)** is attracted by the solenoid: (as function of ball vertical position and current intensity)

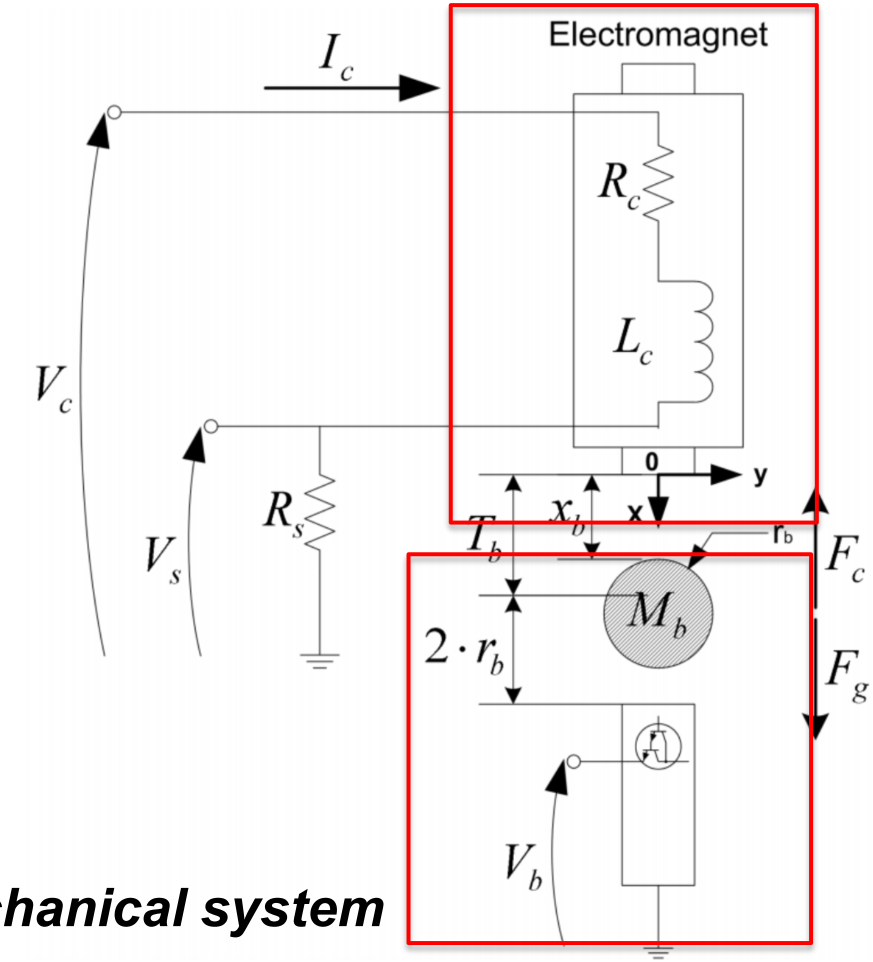
Equilibrium is obtained when attractive force equals gravity force

Maglev plant is composed by:



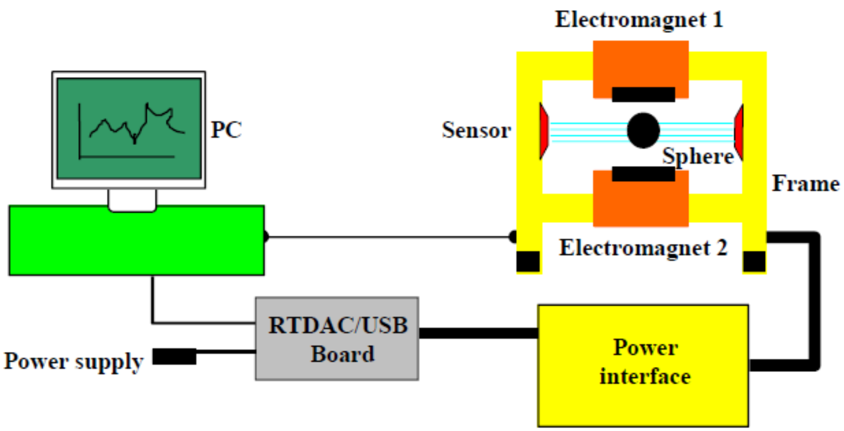
Maglev

electromagnetic system

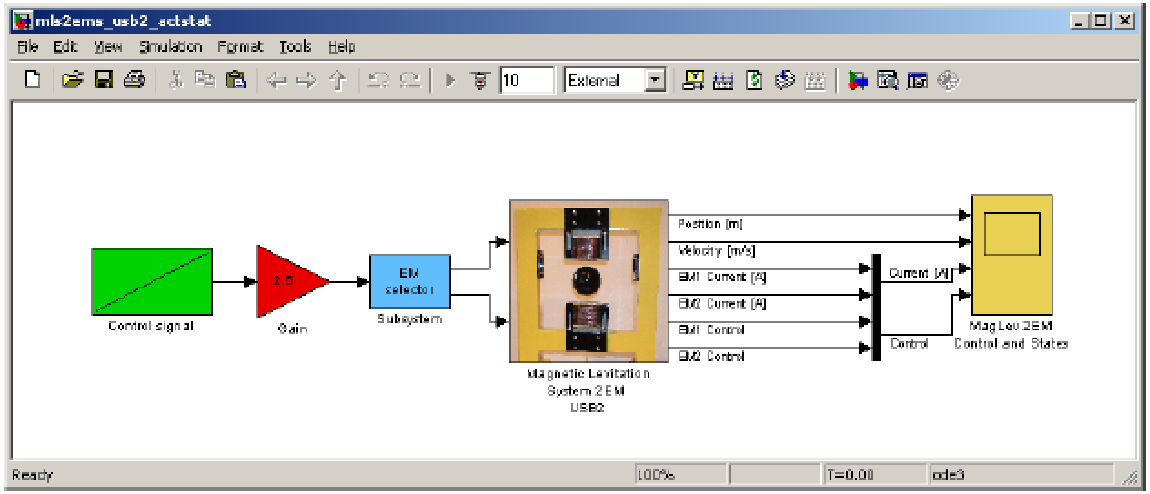


Mechanical system

Maglev



Simulink based



Maglev – suggested execution steps

Modelling and linearisation of the system.

Identification of parameters

Numerical simulation.

Current loop synthesis.

Position-loop synthesis.

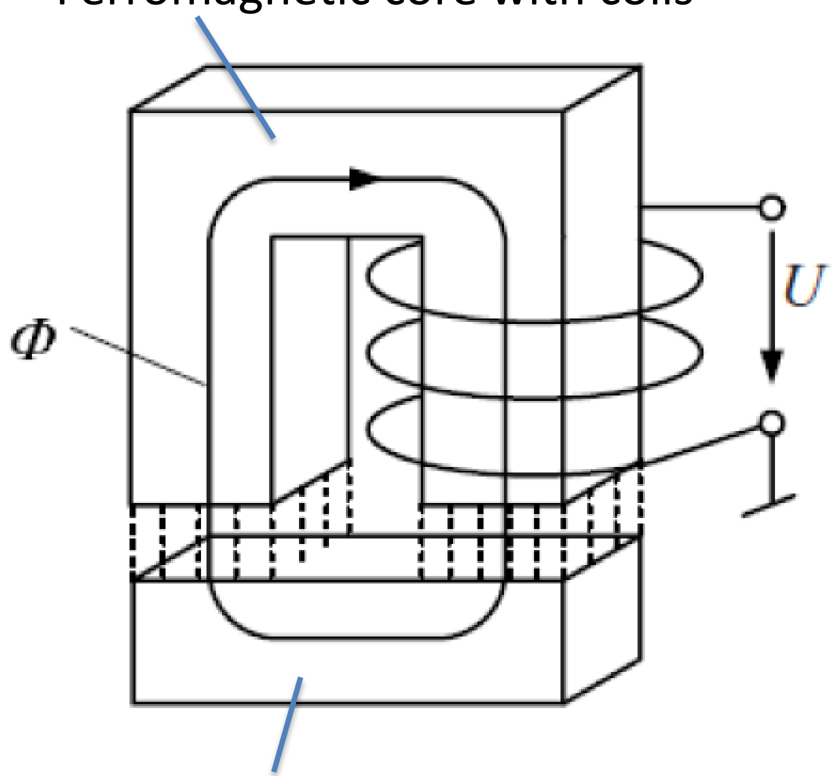
…other kind of controllers

Verification of the numerical model through comparison with experimental data.

Experimental analysis of the different control schemes (static positioning, imposed motion,…).

Results' analysis and comparison.

Magnetic bearing (Maglev 2)



Input:

Voltage

Output

Current

Position

Model

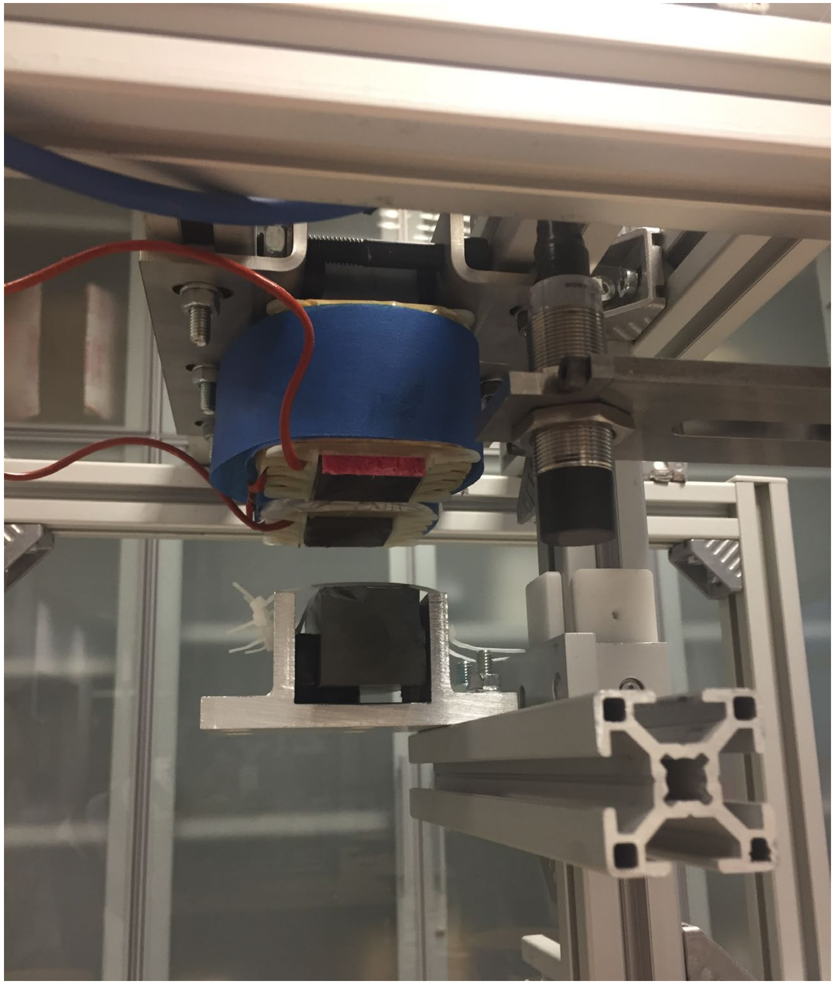
Electromechanical model

(attractive force, gravity, losses, inductance resistance…)

Magnetic bearing (Maglev 2)

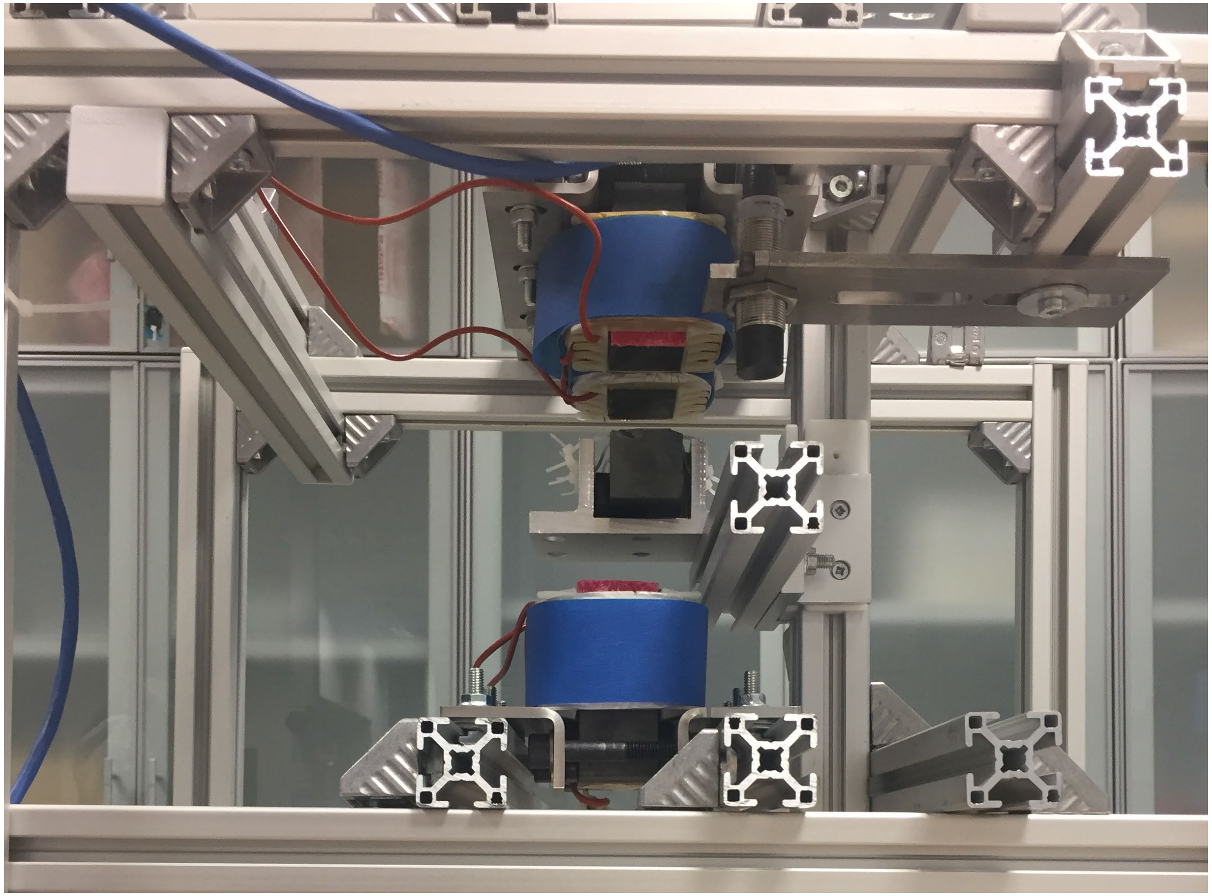
The specimen is mounted on a slider, whose position is measured by means of a laser sensor.

Magnetic levitation technology
@QUANSER.COM

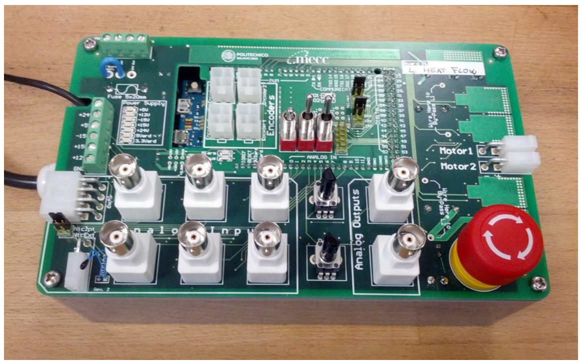


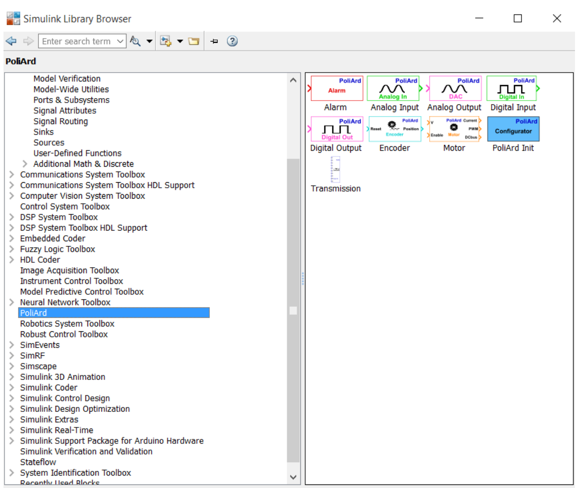
Magnetic bearing (Maglev 2)

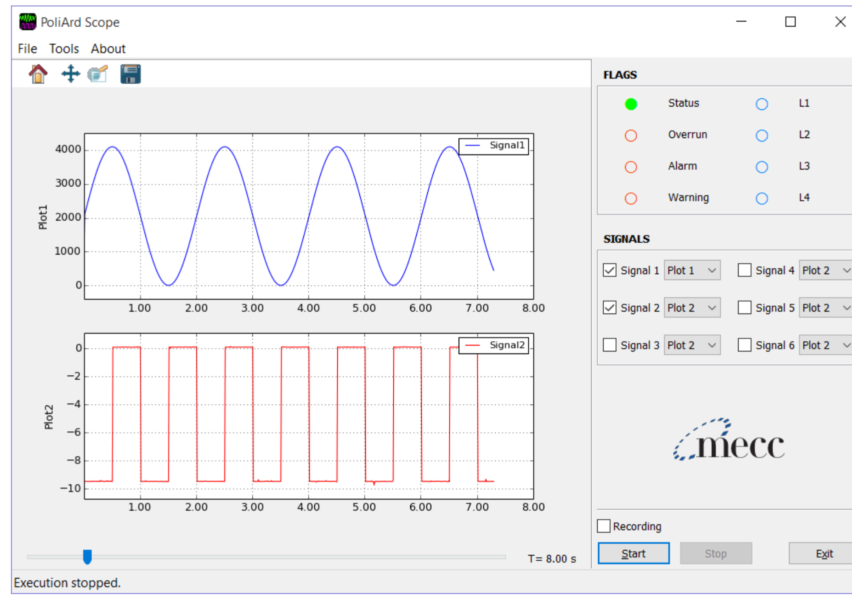
Possibility to consider a MISO system configuration



PoliArd board



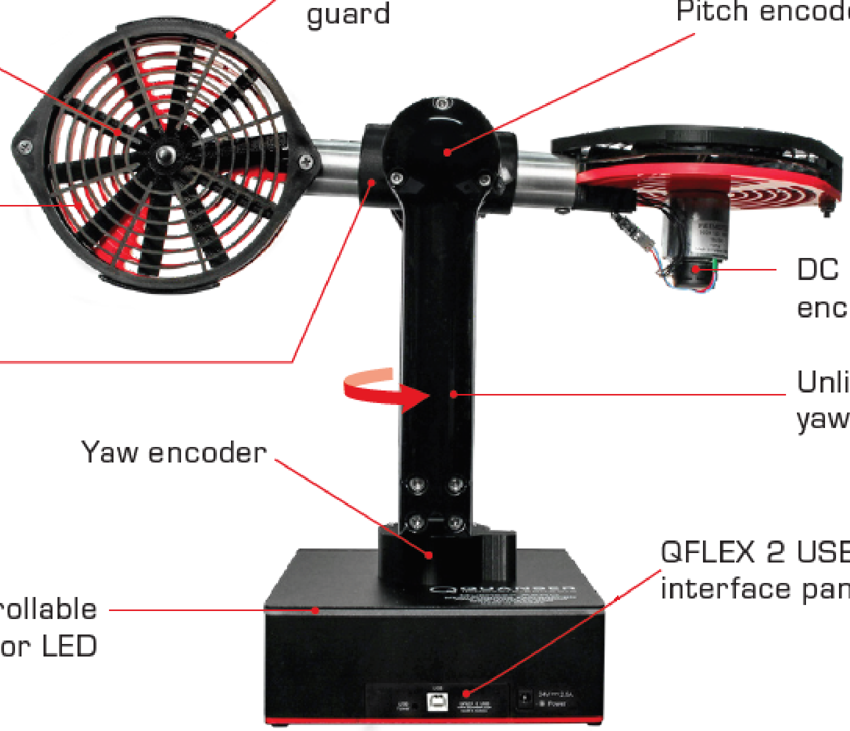




Magnetic bearing (Maglev 2) – suggested execution steps

- Modelling of the system
- Identification of parameters
- Numerical simulation
- Current loop synthesis
- Position-loop synthesis
- …other kind of controllers
- Verification of the numerical model through comparison with experimental data
- Experimental analysis of the different control schemes (static positioning, imposed motion,…)
- Results' analysis and comparison

Quanser Aero



Different propellers with different efficiency

Quanser Aero

Dual-rotor helicopter configuration

- One horizontal rotor and one vertical rotor
- Both pitch and yaw are free

The front rotor that is horizontal to the ground predominantly affects the motion about the pitch axis while the back or tail rotor mainly affects the motion about the yaw axis (about the shaft).
Coupling exist and is experienced when using low efficiency rotors.

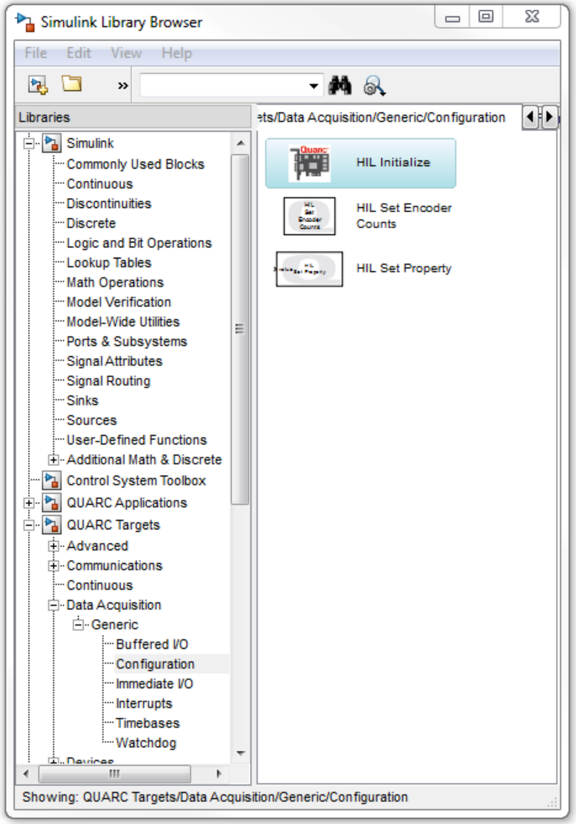
Quanser Aero

Half quadrotor system configuration

- Both rotors are horizontal
- Yaw is free and pitch is locked

By changing the direction and speed of the rotors, users can change the yaw angle.

QUARC Toolbox



Quanser Aero – suggested steps

Consider different system configurations. Steps for each subsystem:

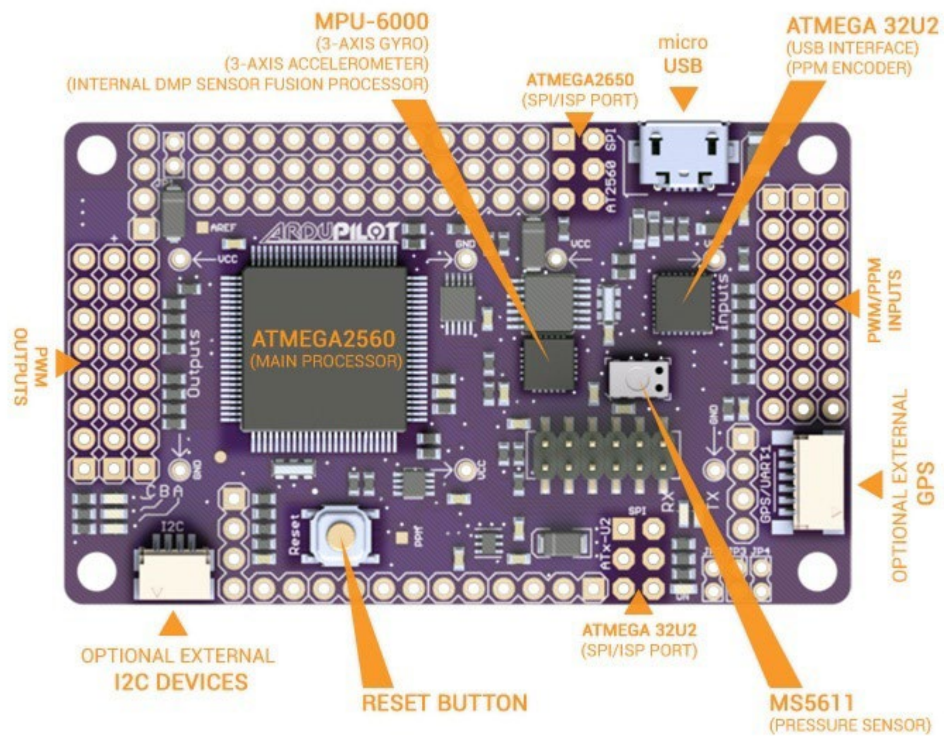
1. Development of models for simulation (time domain) and for control synthesis and tuning (Laplace domain)
2. Identification of unknown parameters of the model/s
3. Numerical implementation and verification of different control logics (classical control and modern control, if applicable)
4. Implementation of the control on the real system and comparison between numerical and experimental results (with possible optimisation of the control parameters for the real system)
5. Comparison of the performances of the different control logics/calibrations (robustness)

Quadcopter – system overview

The system is made of an aluminum and carbon fiber quadrotor

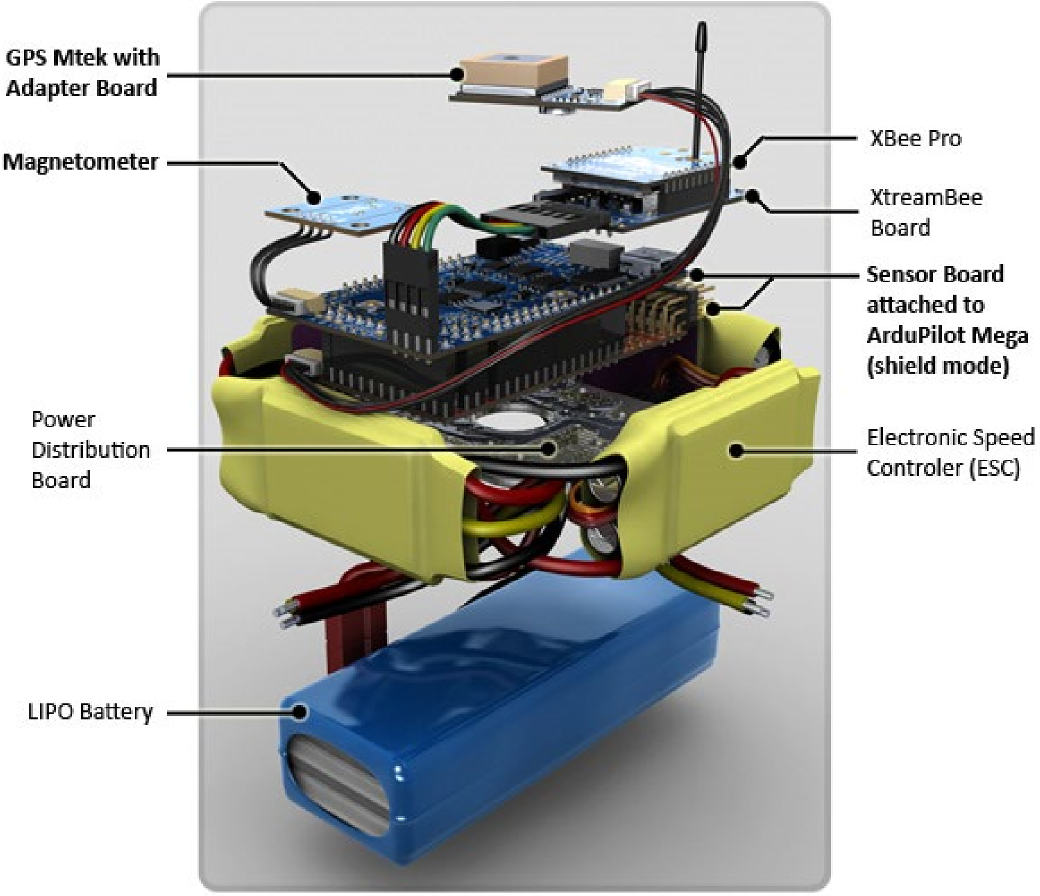
Quadcopter – system overview

The electronic board is an inertial platform with an Arduino-compatible microcontroller.

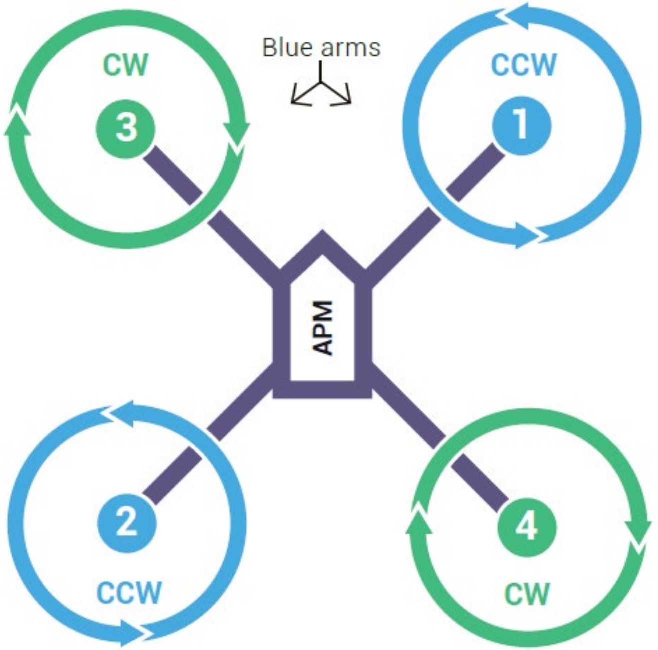


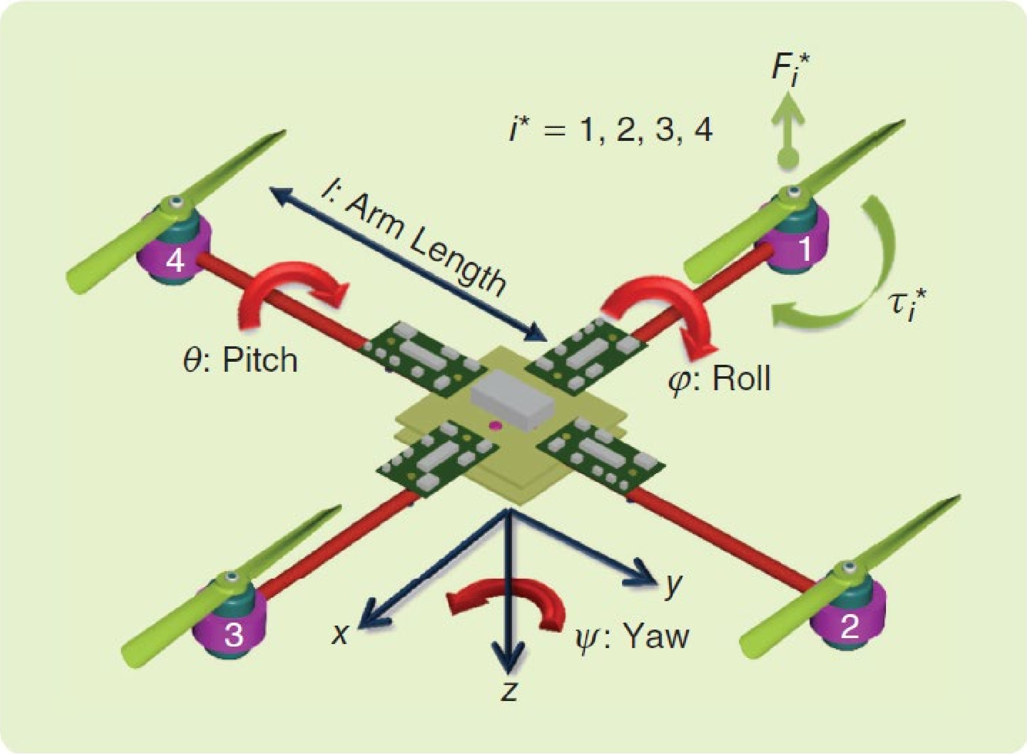
ARDUINO

Quadcopter – system overview



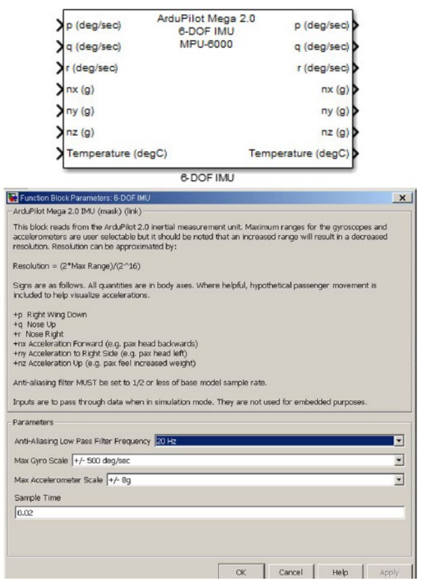
Quadcopter – system modeling

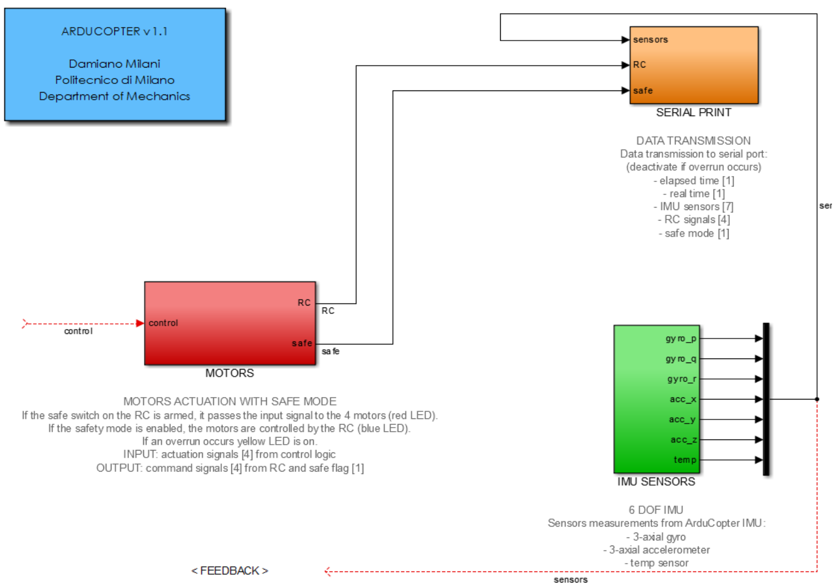




Quadcopter – development environment

Simulink block-sets are pre-installed on the PC in the lab. Documentation is provided in order to understand how to access the IMU (Inertial Measurement Unit) with its on board tools (RC, GPS…) and how to control the propellers.





Quadcopter – suggested execution steps

Development of a dynamic model of the system

Mechanical parameters identification

Motors characterisation

Linear and non-linear model

Stabilisation (1 dof, 2 dof, …)

Robustness analysis