



POLITECNICO
MILANO 1863

Automation and Control Laboratory

[M-Z]

Prof. Alessio La Bella
DEIB – Politecnico di Milano

AY 2023/24 - II semester

Teacher

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Tutors

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Office hours

By appointment (ask via e-mail)

Course website

WeBeep Portal (<https://webeep.polimi.it/>)





Course objective

Challenge the students in applying the theoretical skills acquired during the study program on a real apparatus

Topics

Span the design and development of automated systems:

- system modeling and analysis
- controller synthesis and analysis of the closed-loop system
- implementation on a real apparatus
- validation of the model/controller performance

Format

Numerical simulations and real experiments via a *team project work*

Prerequisites

Students are expected to have previous knowledge about

- mechanical systems modeling and dynamics
- fundamentals of control theory
- electrical actuators and sensors
- system identification
- advanced and multivariable control techniques

Laboratory material

In the laboratory there are different set-ups, each one simulating (on a small scale) a real system to be controlled

Available control problems

- control of unstable systems
- control of critically stable systems
- control of underdamped systems

Course organization

- students are asked to form teams of 4 people each
- each team will receive one laboratory set-up
- each team will work autonomously on the assigned set-up (with the support of a teacher/tutor)
- all team members are required to be in the lab

Laboratory availability

Every Tuesday: 2:15 pm → 7:15 pm (5 hours)

Every Other Friday: 9:15 am → 1:15 pm (4 hours)

Shared set-ups

- 7 set-ups are available in the lab
- at most 14 teams will be formed
- some set-up may be shared among two teams
- access to shared set-up is scheduled in time slots (A/B)

First weeks

	W2	W3	W4	W5	
Monday	Feb 27	Mar 05	Mar 12	Mar 19	...
Friday	Mar 01	Mar 08	Mar 15	Mar 24	...

■ Slot A
 ■ Slot B
 ■ No Lab

A complete schedule will be available on WeBeep

Note

The team not using the set-up has still access to the lab to work and receive support on design/simulations activities

Expected steps

- preliminaries
 - model of the set-up at hand
 - identification of those parameters that are difficult to measure (friction coefficient, spring stiffness, efficiencies, etc.)
 - model validation via time/frequency responses
 - open-loop analysis
- list of self-given specifications for the close-loop system
- for each controller
 - design based on a linearized/nonlinear model
 - test of the controller on the model via simulation
 - controller validation via time/frequency responses
- critical analysis/comparison of all developed control strategies

Controller design

- Frequency-Based (FB) techniques
 - compute the transfer function $G(s)$ of the linearized system
 - design the $R(s)$ such that $L(s)$ has desired properties
 - design via Bode diagrams (or root locus or Nyquist)
- State-Space (SS) techniques
 - compute the state-space representation of the linearized system
 - design state estimators (Luenberger observer & Kalman filter)
 - design Pole-Placement & Linear-Quadratic controllers
- Advance-Control (AC)^a techniques
 - Model Predictive Control (MPC)
 - Sliding Mode
 - Feedback Linearization
 - Adaptive/Robust Control

^aFor top grades

Time validation

- input impulse/step to $u(t)$ (or $y^\circ(t)$ in close loop)
- record output response $y(t)$ (and $u(t)$ in close loop)
- compare with model impulse/step response in terms of gain, settling time, ...

Frequency validation

- input sine waves to $u(t)$ (or $y^\circ(t)$ in close loop)
- record output (sine) responses $y(t)$ (and $u(t)$ in close loop)
- compare with model frequency response on a Bode diagram




Expected timeline



Suggestions

- use the time when you don't have access to the set-up
- plan activity for the next lab session
- have a backup plan

Team duties

- final report (max 40 pages,  / ) describing all the work done by the team on the assigned set-up
- final presentation (20+5 min, ) to the whole class describing the work done by the team



Evaluation criteria

- participation to the team activity during laboratory hours
- content, clarity, and technical soundness of the final report
- content and clarity of the final presentation
- overall approach to the lab experience

Mid-term review

Halfway through the semester there will be a 30 minutes private review meeting with each group

Format

You will be asked to discuss (free format,  / ) the result achieved so far and a planned schedule for the future work

Outcome

The meeting is not graded: it is only meant to give you feedback about your progress

Key dates

Feb 22: deadline for the “preference form” submission

Apr 12: review meetings (a schedule will follow)

May 31: end of the course

Jun 2: deadline for the final report submission (groups in Slot A)

Jun 5: deadline for the final report submission (groups in Slot B)

Jun XX: final presentations (during the exam period)

(tentative dates, you will be notified in case of changes)

Note

Attendance of all students to all presentations is recommended

Preference form

Each team has to provide (by email) the following information:

- team nickname
- ID (Codice Persona), Name, and Surname of each component
- a ranking of all available set-ups and alphabetical group, ordered by preference

The preference form can be downloaded from the WeBeep portal

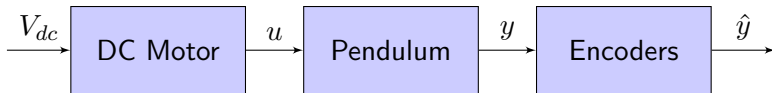
Available set-ups

- inverted pendulum
- ball and beam
- rotating masses
- magnetic levitation
- helicopter
- rotary flexible joint
- CNC machine

Rotary Inverted Pendulum



System



Quantities

- V_{dc} is the voltage applied to the motor
- u is the resulting torque applied to the horizontal arm
- y contains the angular position of the two arms
- \hat{y} contains the *relative* angular position of the two arms

Main challenge

Dynamical model and instability of the upright equilibrium position of the pendulum

Control objectives

- 1 position control of the horizontal arm (FB)
- 2 stabilization of the vertical arm in the upright position (SS)
- 3 position control of the horizontal arm while keeping the vertical arm in the upright position (SS)
- 4 swing-up of the vertical arm (AC)

Ball and Beam



System



Quantities

- V_{dc} is the voltage applied to the motor
- u is the resulting torque applied to the gear of the lever arm
- y contains the gear angular position and ball position
- \hat{y} contains the gear *relative* angular position and the ball *absolute* position on the beam

Main challenge

Marginal stability of equilibrium position of the ball on the beam
and presence of state constraints

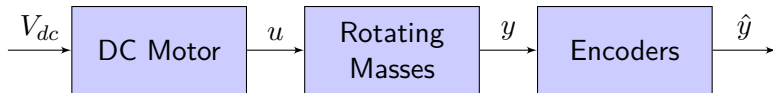
Control objectives

- 1 tilting control of the horizontal beam (FB)
- 2 ball position stabilization (FB+SS)
- 3 1D ball trajectory tracking (SS+AC)

Rotating Masses



System



Quantities

- V_{dc} is the voltage applied to the motor
- u is the resulting torque applied to the gear shaft
- y contains the masses angular position
- \hat{y} contains the masses *relative* angular position

Main challenge

Low damping of the system

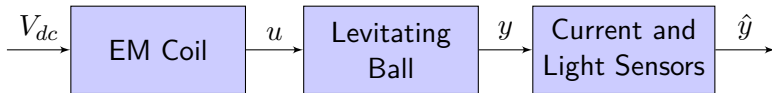
Control objectives

- 1 speed control of the first masses (FB)
- 2 position control of the first masses (FB+SS)
- 3 position control of the other two masses (SS+AC)

Magnetic Levitation



System



Quantities

- V_{dc} is the voltage applied to the electromagnet (EM)
- u is the resulting induced magnetic field
- y contains the coil current and the ball position
- \hat{y} contains the measured current and *absolute* ball position

Main challenge

Highly nonlinear system and instability of the ball position

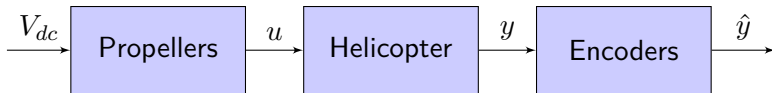
Control objectives

- 1 EM coil current control (FB)
- 2 ball position stabilization (FB+SS)
- 3 1D ball trajectory tracking and lift up (SS+AC)

Helicopter



System



Quantities

- V_{dc} is the voltage applied to the propellers' motors
- u is the resulting thrust generated by the propellers
- y contains the pitch and yaw angles
- \hat{y} contains the pitch and yaw *relative* angles

Main challenge

Coupled MIMO nonlinear system

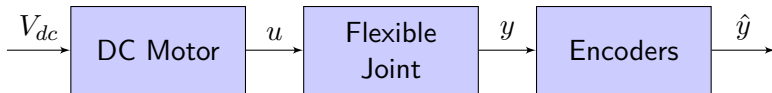
Control objectives

- 1 pitch control with yaw rotation locked (FB)
- 2 fixed attitude control (FB+SS)
- 3 reference attitude tracking (SS+AC)

Rotary Flexible Joint



System



Quantities

- V_{dc} is the voltage applied to the motor
- u is the resulting torque applied to the top base
- y contains top base and arm angular positions
- \hat{y} contains the top base and arm *relative* angular position

Main challenge

Low damping of the system and variable parameters

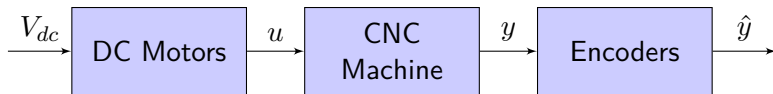
Control objectives

- 1 position control of the top base (FB)
- 2 position control of the the arm tip (FB+SS)
- 3 position control of the the arm tip with uncertainty in the spring stiffness and arm moment of inertia (SS+AC)

CNC Machine



System



Quantities

- V_{dc} contains voltages applied to both motors
- u contains the resulting torques acting on the chain
- y contains the coordinates of the end effector
- \hat{y} contains the motors' *relative* angular position

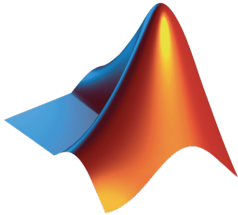
Main challenge

Coupled MIMO nonlinear system

Control objectives

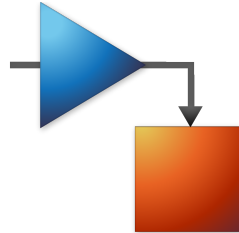
- 1 motor position control (FB)
- 2 end effector 2D position control (FB+SS)
- 3 2D trajectory tracking (SS+AC)

Laboratory environment



MATLAB

+

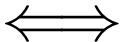


SIMULINK

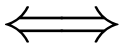
Note

We will use R2019b: be careful to avoid compatibility issues

PC



Set-up



Material provided

For each set-up there is a zip file (NameOfTheSetup.zip) on WeBeep containing the following files:

- datasheet for the data acquisition board (DAQ)
- datasheet for the power amplifier (PA)
- datasheet for the DC motor and the gearbox
- datasheet for the specific set-up
- simulink template file containing appropriate input/output blocks to start experimenting right away

Note

Some experiments connect to the PC directly via USB and the zip file contains one datasheet only and the simulink template

Quick-start guide


Example

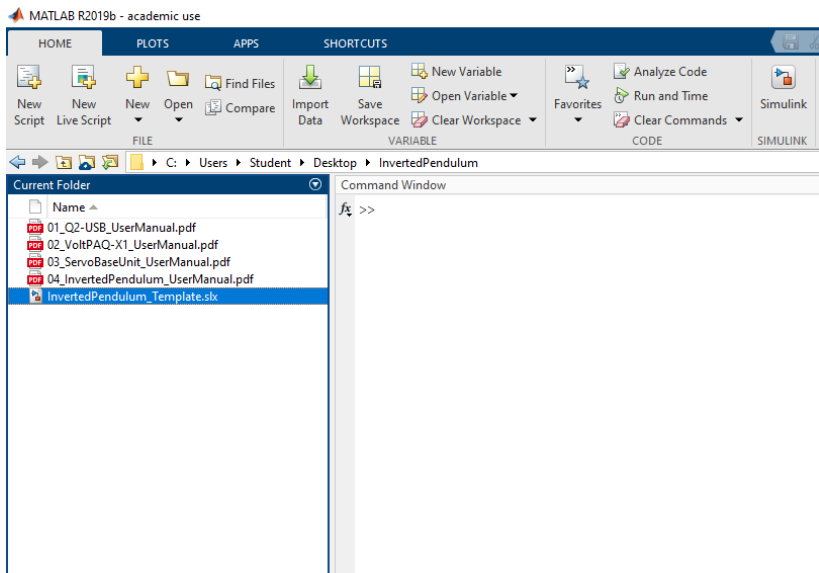
In the following assume a group received the *inverted pendulum* and the time slots marked with A

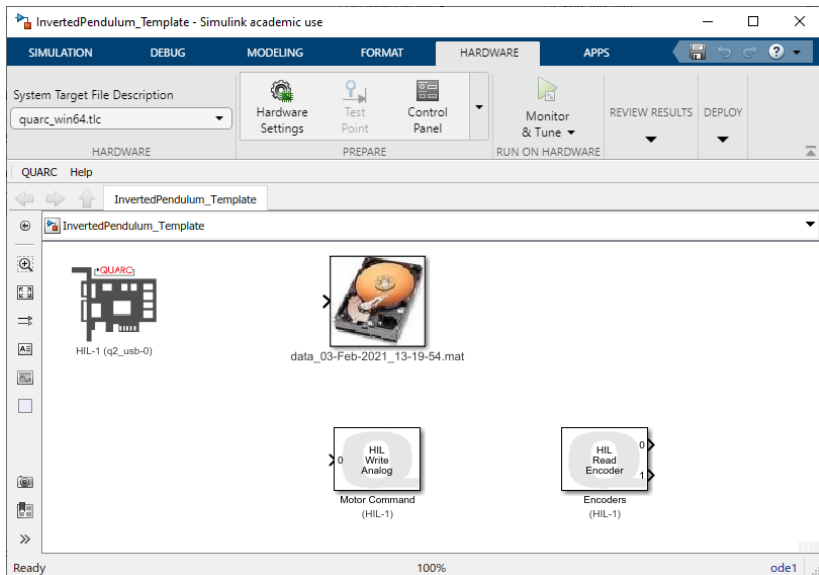
Beginning of the lecture

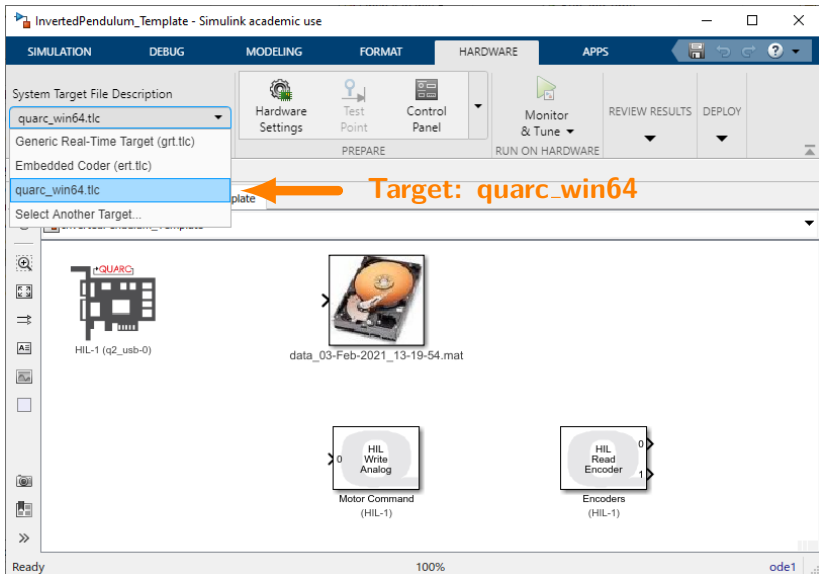
- connect the DAQ board to a USB3 socket
- connect PA to the nearest AC plug and turn it on
- turn on the lab PC (use the “Student” account)

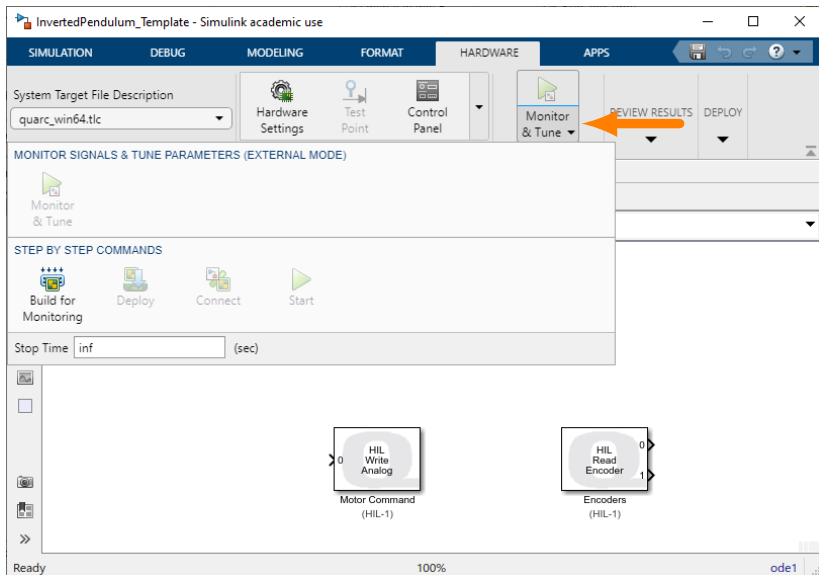
First steps for using the set-up

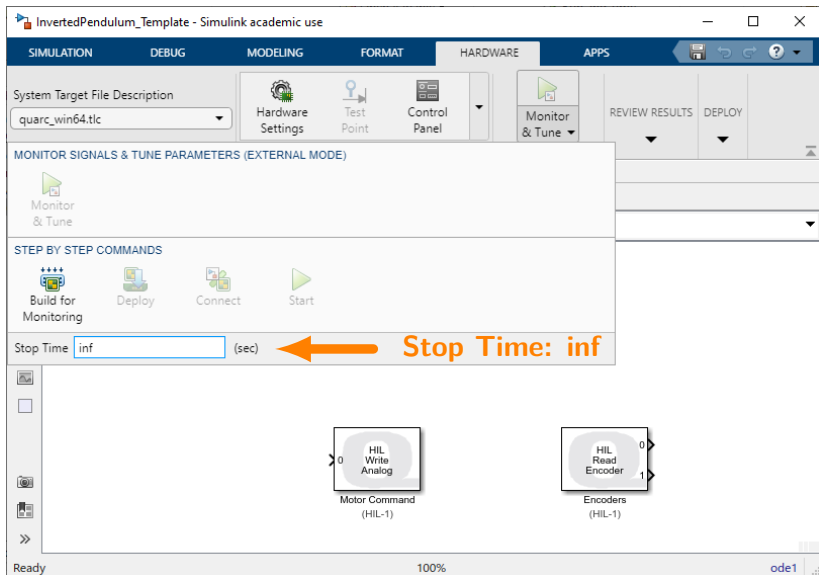
- open the browser and go to the WeBeep portal
- login with your credentials, download `InvertedPendulum.zip`
- drag the folder inside the zip and drop it onto the desktop
- open MATLAB R2019a
- click on the icon  in the top-left part of the screen and navigate to the `InvertedPendulum` folder

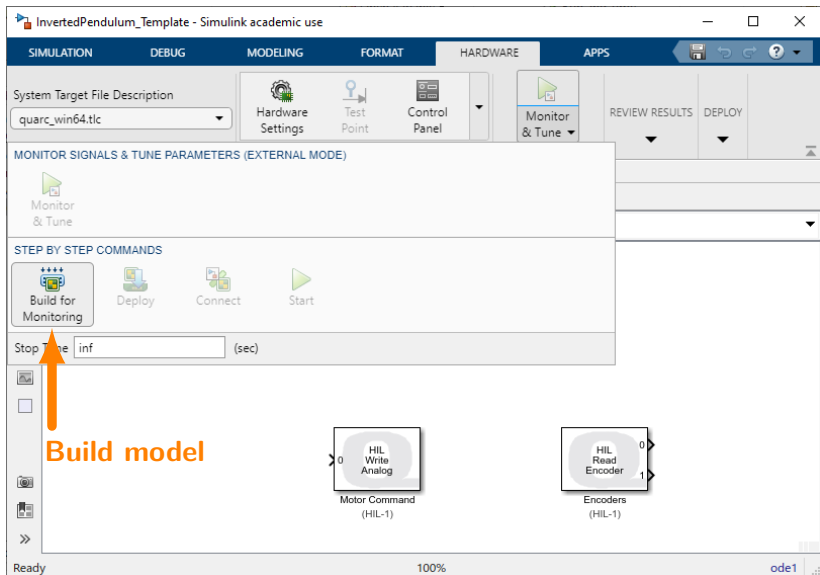


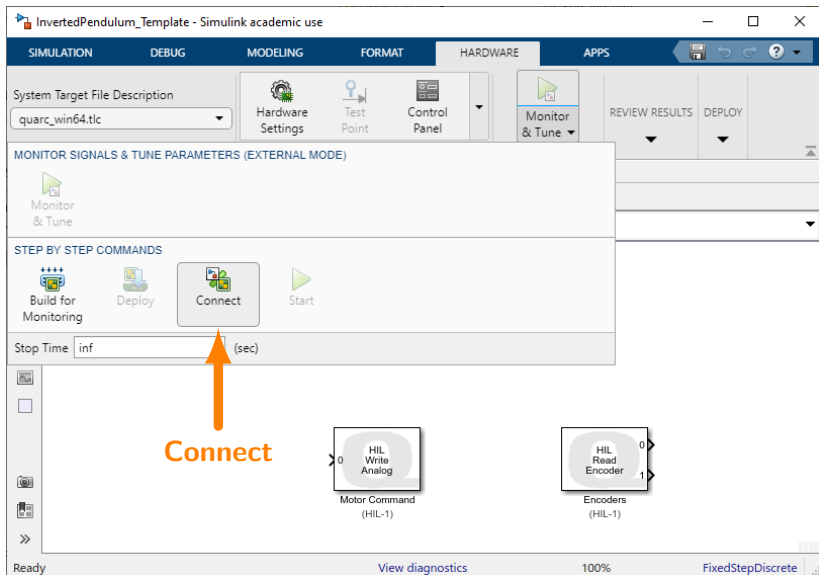


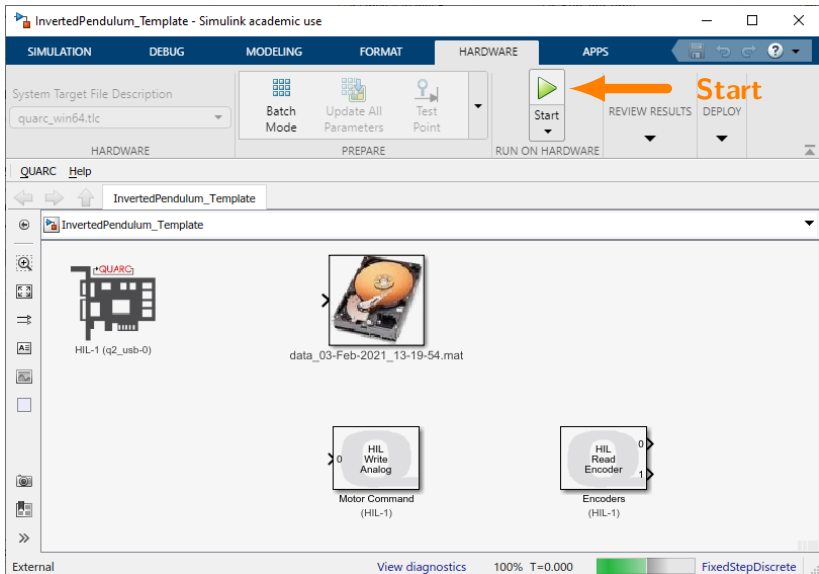


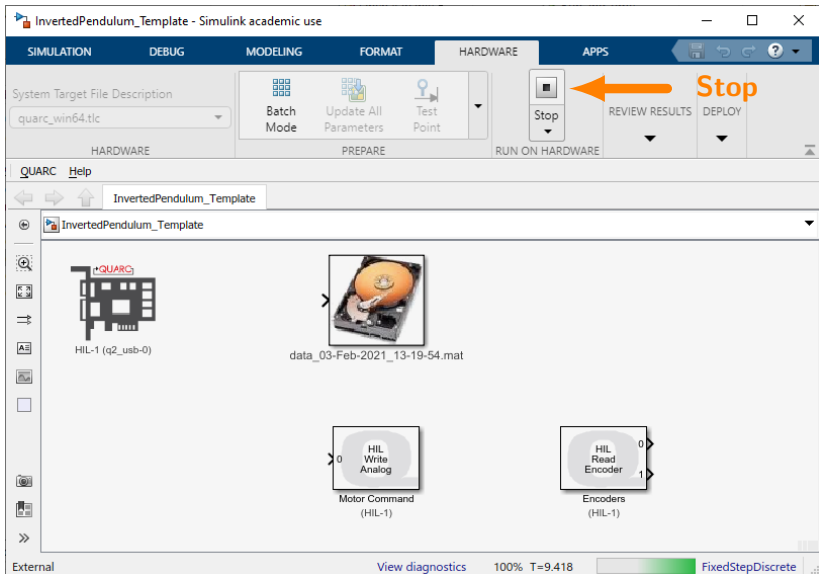












Note

While the Simulink model is running you can change constant values, amplitude/frequency of some signals, values of gains, etc.

Other blocks

There are other blocks in the QUARC library and you can refer to their documentation for additional information

<https://docs.quanser.com/quarc/documentation/index.html>

Asking for help

- if you need quick technical assistance call the tutor first
- if you have a conceptual doubt or you are lost call me

Warnings

- the first time, ask the teacher before running the Simulink model on the real set-up
- keep away from all moving parts when experiment is running
- remember that set-ups are real, please be careful when you are performing tests

End of the lecture

- make sure you stop all running Simulink models
- close Matlab
- zip all of your files
- transfer them to a personal device (thumb-drive or OneDrive)
- delete all files on the lab PC
- shut down the lab PC
- switch off the PA and remove the AC plug
- disconnect the DAQ from the PC
- collect all cables under the side table housing the set-up

Enjoy the course! =)