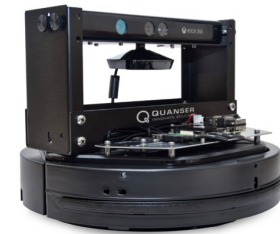
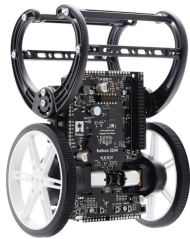


Control of mobile robots



Hugues GARNIER

hugues.garnier@univ-lorraine.fr

12 September 2023

Volumes horaires

- **Contrôle de robots mobiles**
 - 1 séance de cours/TD de 2h 2h
 - 8 séances de TP de 4h 32h

Supports de cours en anglais

- Intervenants en cours/TD
 - Hugues Garnier
- Intervenants en TP
 - Hugues Garnier (5 premiers TP)
 - Mayank Jha (3 derniers TP)

Contrôle des connaissances

- 2 compte-rendus (CR) de TP
 - A faire en binôme
- 1 présentation orale d'un des TP
 - A faire en binôme/trinôme
- Calcul de la note finale

$$\text{Note EC} = 0,3 \text{ CR TP1} + 0,3 \text{ CR TP2} + 0,4 \text{ Oral}$$




Website for the course : *Labs & tutorials*

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

Dashboard Content Structure Appearance People Modules Configuration Reports Help
Hello **garnier8** [Log out](#)

Add content Find content Edit
[Edit sho](#)

Q



Hugues Garnier

Navigation

[Add content](#)

Teaching

Basic page *Teaching* has been updated. ×

View [Edit](#)

Teaching activities

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

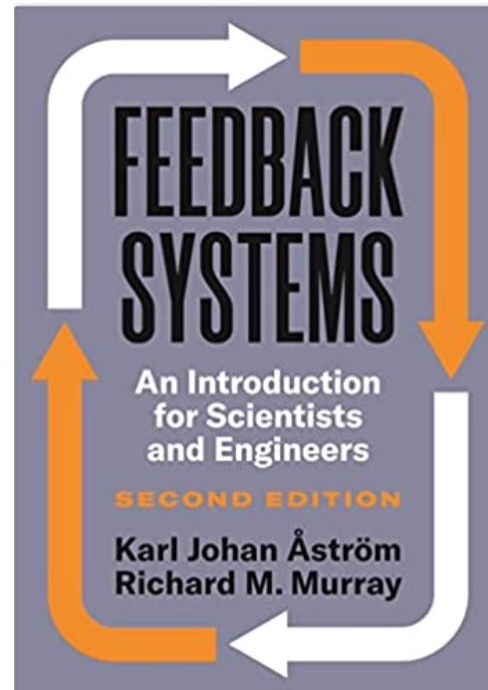
I teach the following courses:

Control of Mobile Robots (5A IA2R Parcours SIA)

- [Tutorials](#)
- Labs
 - [Lab n°1 - The Qcar](#)
 - [Lab n°2 - The Qbot](#)
 - [Lab n°3 - The 3pi+](#)
 - [File for 3pi+](#)
- Feedback about the course from the students
 - [Feedback](#) from students 2021-2022

Recommended book in Control Feedback Systems

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



pdf version of the book available

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

Other ressource recommended in Control

Matlab Tech Talks with *Brian Douglas*

Understanding PID control

YouTube FR

Rechercher

MATLAB
Tech Talks
with *Brian Douglas*

0:33 / 11:41

What Is PID Control? | Understanding PID Control, Part 1

Understanding PID Control

MATLAB - 1/7

- 1 **PID CONTROL** What Is PID Control? | Understanding PID Control, Part 1 (11:42) MATLAB
- 2 **PID CONTROL** Anti-windup for PID control | Understanding PID Control, Part 2 (10:44) MATLAB
- 3 **PID CONTROL** Noise Filtering in PID Control | Understanding PID Control, Part 3 (11:53) MATLAB
- 4 **PID CONTROL** A PID Tuning Guide | Understanding PID Control, Part 4 (12:05) MATLAB
- 5 **PID CONTROL** 3 Ways to Build a Model for Control System Design | Understanding PID Control, Part 5 (13:45) MATLAB

Other ressource recommended in Control

Matlab Tech Talks with *Brian Douglas*

State Space

The screenshot shows a YouTube video player interface. The video title is "MATLAB Tech Talks with Brian Douglas". The video is currently playing at 0:35 / 14:11. The video content shows the text "MATLAB Tech Talks with Brian Douglas" on a black background. Below the video player, the title "Introduction to State-Space Equations | State Space, Part 1" is visible. To the right of the video player, there is a playlist titled "State Space" with 4 items. The items are:


- 1. Introduction to State-Space Equations | State Space, Part 1 (14:12)
- 2. What is Pole Placement (Full State Feedback) | State Space, ... (14:55)
- 3. A Conceptual Approach to Controllability and Observability... (13:30)
- 4. What Is Linear Quadratic Regulator (LQR) Optimal Control... (17:24)

At the bottom of the playlist, there are tabs for "Tout", "De la série", "Équations", and "Leçons".

Other ressource recommended in Control

Youtube channel by *Steve Brunton*

- <https://www.youtube.com/playlist?list=PLMrJAhleNNR20Mz-VpzgfQs5zrYi085m>



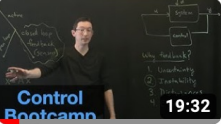
Control Bootcamp


Steve Brunton


39 vidéos 1 305 289 vues Dernière modification le 8 oct....

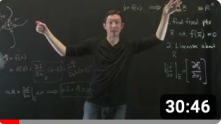
This course provides a rapid overview of optimal control (controllability, observability, LQR, Kalman filter, etc.). It is not meant to be an exhaustive treatment, but instead provides a high-level overview of some of the main approaches, applied to simple examples in Matlab.

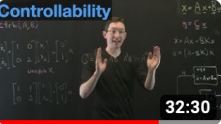
These lectures follow Chapter 8 from: "Data-Driven Science and Engineering: Machine Learning, Dynamical Systems, and Control" by Brunton and Kutz


- 

Control Bootcamp: Overview
Steve Brunton • 325 k vues • il y a 5 ans
- 

Linear Systems [Control Bootcamp]
Steve Brunton • 125 k vues • il y a 5 ans
- 

Stability and Eigenvalues [Control Bootcamp]
Steve Brunton • 115 k vues • il y a 5 ans
- 

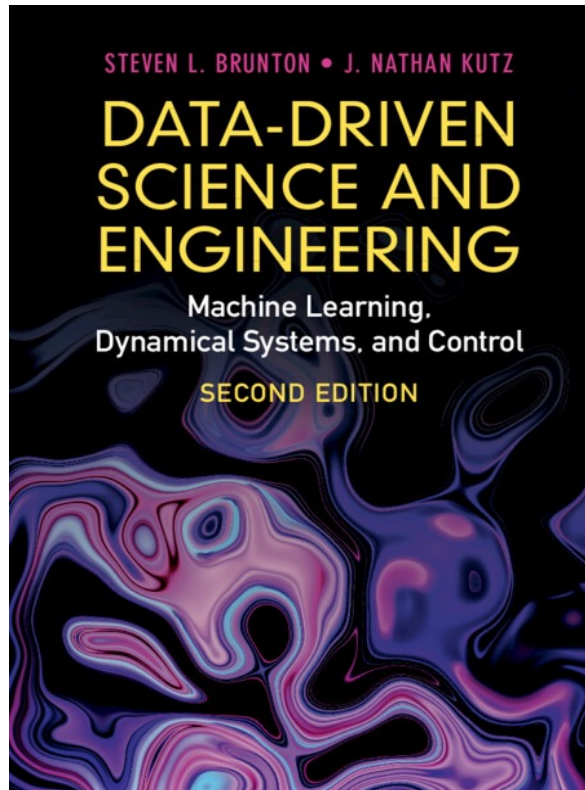
Linearizing Around a Fixed Point [Control Bootcamp]
Steve Brunton • 107 k vues • il y a 5 ans
- 

Controllability [Control Bootcamp]
Steve Brunton • 115 k vues • il y a 5 ans
- 

Controllability, Reachability, and Eigenvalue Placement [Control Bootcamp]
Steve Brunton • 57 k vues • il y a 5 ans

Other book recommended Data-Driven Science and Engineering

Machine Learning, Dynamical Systems, and Control *S. Brunton & N. Kutz 2022*



Part I. Dimensionality Reduction and Transforms:

1. Singular Value Decomposition
2. Fourier and Wavelet Transforms
3. Sparsity and Compressed Sensing

Part II. Machine Learning and Data Analysis:

4. Regression and Model Selection
5. Clustering and Classification
6. Neural Networks and Deep Learning

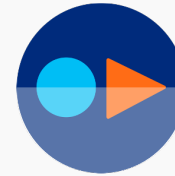
Part III. Dynamics and Control:

- 7. Data-Driven Dynamical Systems*
- 8. Linear Control Theory*
- 9. Balanced Models for Control*

Part IV. Advanced Data-Driven Modeling and Control:

10. Data-Driven Control
11. Reinforcement Learning
12. Reduced Order Models (ROMs)
13. Interpolation for Parametric ROMs
14. Physics-Informed Machine Learning

Other resource recommended in Control : 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



Recommended book in mobile robots

The screenshot shows the PeterCorke.com website. At the top left is a profile picture and the name 'PeterCorke.com'. Navigation links include HOME, ABOUT, TOOLBOXES, BOOKS, and RESOURCES. A search icon is on the right. The main content area features a book icon and the title 'Robotics, Vision and Control' with the subtitle 'Fundamental algorithms in MATLAB: Second Edition'. Below this is a 'BUY ONLINE NOW' button and logos for Google Books, Amazon, and Springer. A bottom navigation bar lists: HOME, I. FUNDAMENTALS, II. MOBILE ROBOTS, III. ROBOT MANIPULATORS, IV. COMPUTER VISION, V. VISUAL SERVOING, and TOOLBOXES.

Home

This book makes the fundamental algorithms of robotics, vision and control accessible to all. It weaves together theory, algorithms and examples in a narrative that covers robotics and computer vision separately and together. The author shows how complex problems can be decomposed and solved using just a few simple lines of code, supported by two MATLAB® Toolboxes. The topics covered are guided by real problems observed by the author over many years as a practitioner of both robotics and computer vision.

It is written in a light but informative style, it is easy to read and absorb, and includes over 1000 MATLAB® and Simulink® examples and figures. The book is a walk through the fundamentals of mobile robots, navigation, localization, arm-robot kinematics, dynamics and joint level control, then camera models, image processing, feature

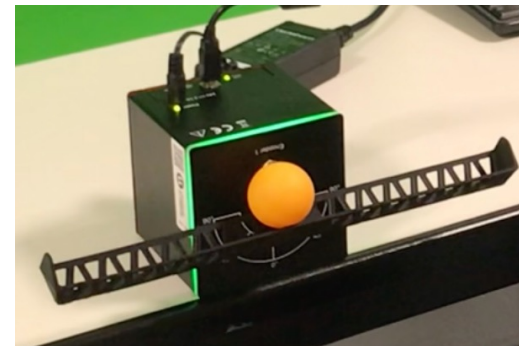


Mobile robots used during the first 2 labs

The QUBE-
Servo 2



The Ball & Beam



Lab 1 - PID angular position control of the QUBE inertia disk



Instrumentation

Hardware

Software

Modeling

Transfer function
Modeling

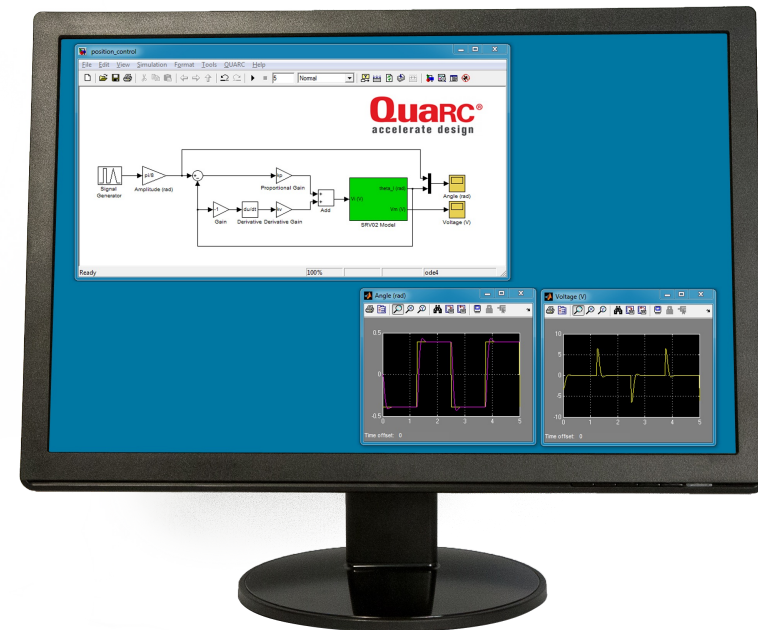
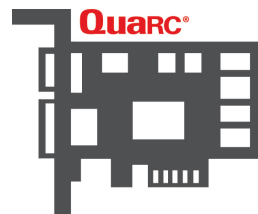
Model
identification from
Step response

Control Design

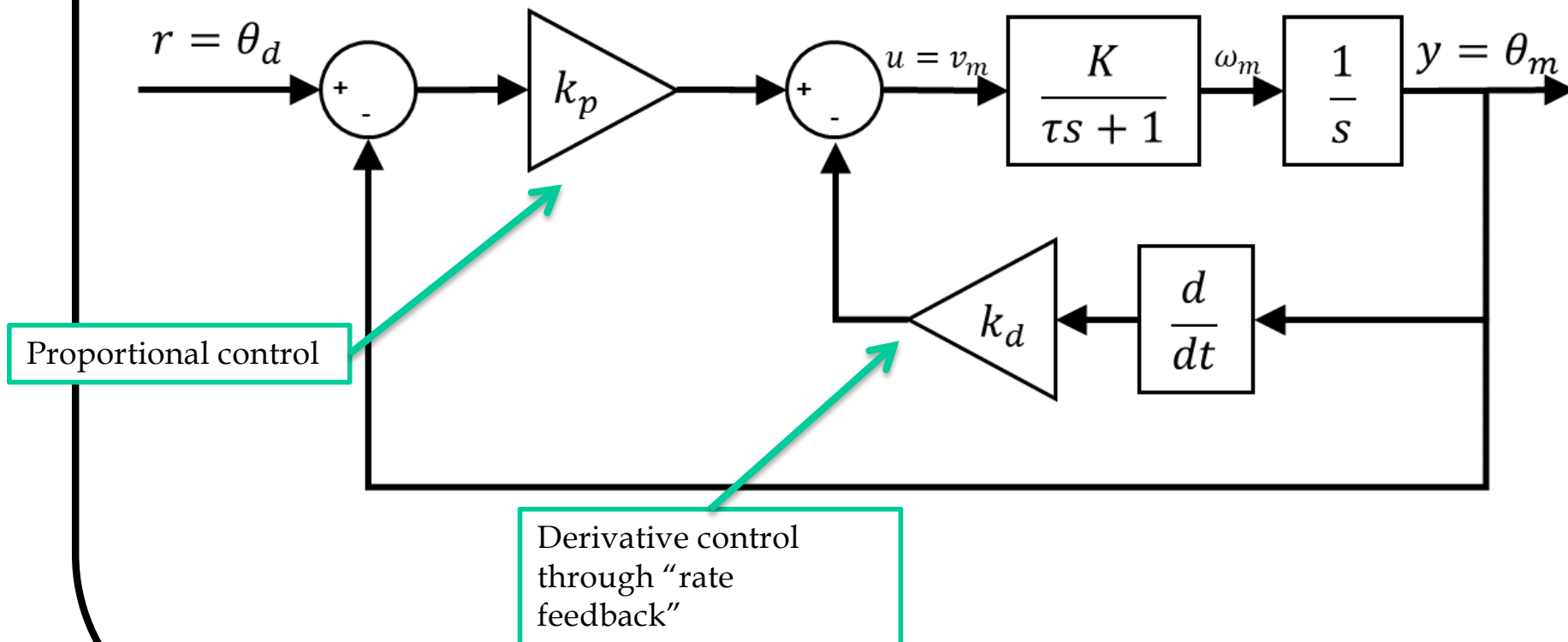
P and PD control
by pole
placement

QUARC

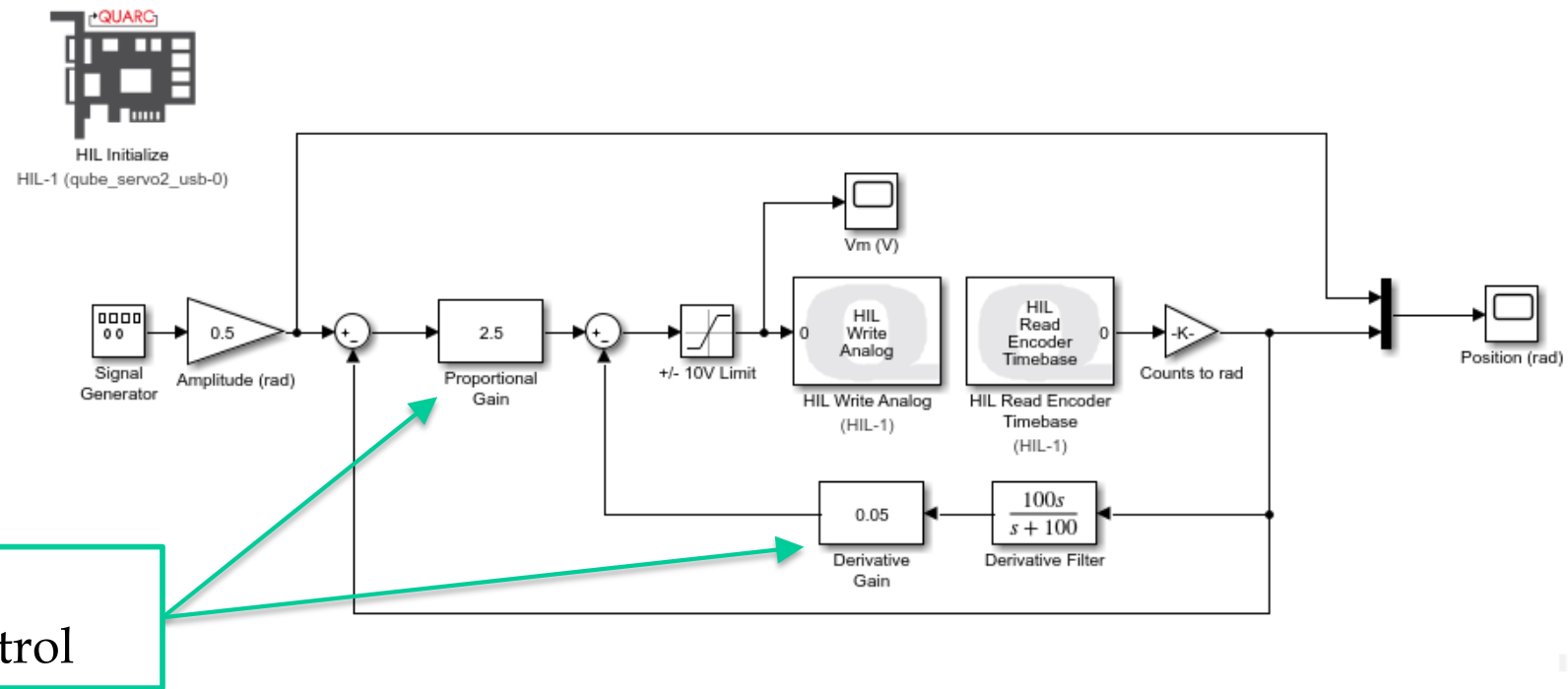
- QUARC is a Rapid Control Prototyping Software made by Quanser for Matlab/Simulink
- Generates real-time code from a Simulink diagram



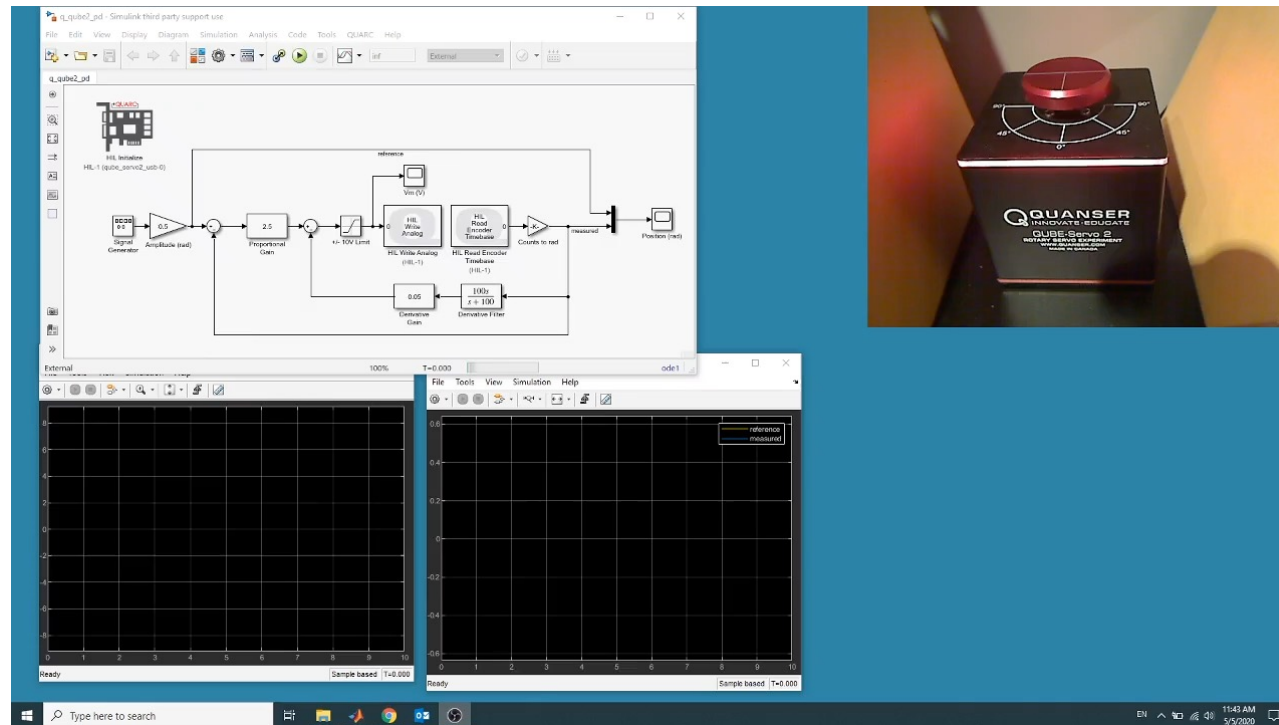
PD control of motor angular position



PD control implementation



PD control of motor angular position



Lab 2 - State-feedback control of QUBE rotary inverted pendulum



Modeling

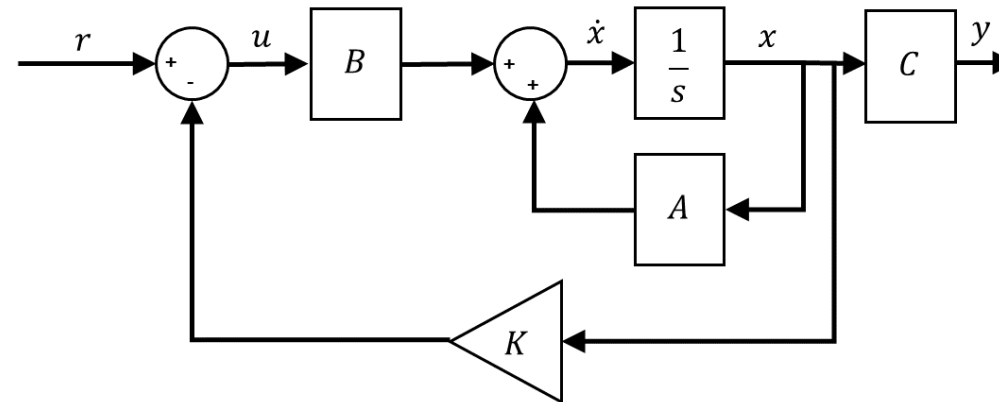
State-Space
Modeling
from physic laws

Control Design

LQR balance
control

Swing-up control

State-feedback LQR control of the inverted pendulum

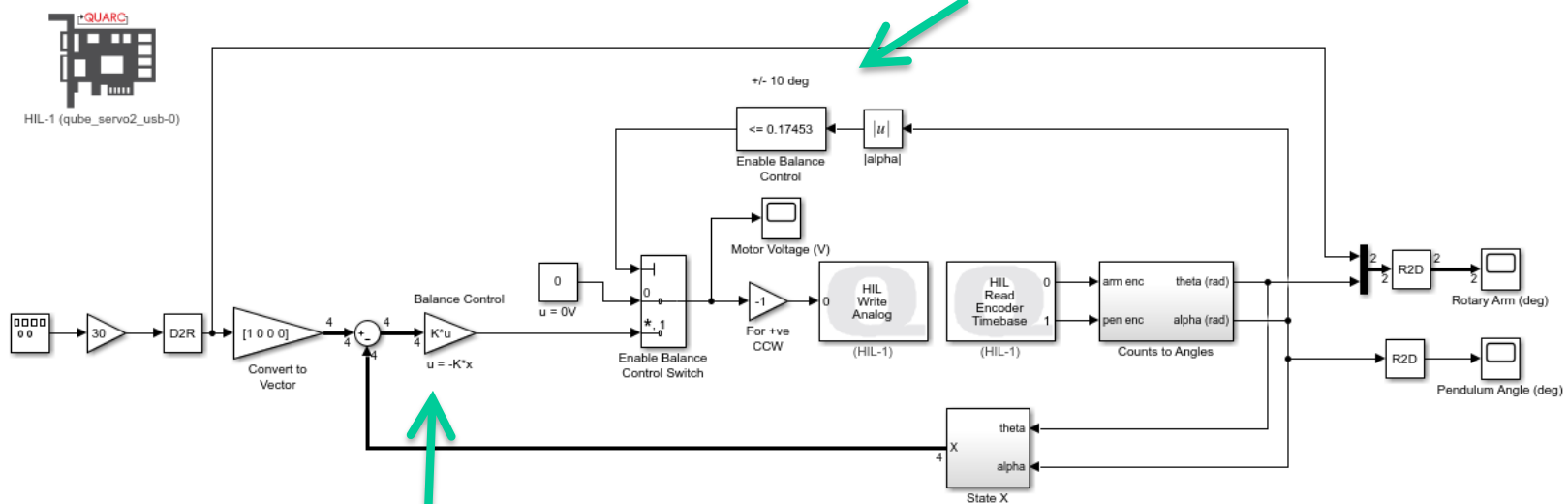


Use state-feedback LQR control to balance pendulum



LQR control implementation

Engage when +/- 10 deg about vertical



State-feedback control

Pendulum swing-up by nonlinear energy control

- Swinging up a pendulum can be done analytically using a **nonlinear control**

Use dynamics of pendulum to swing it up automatically!

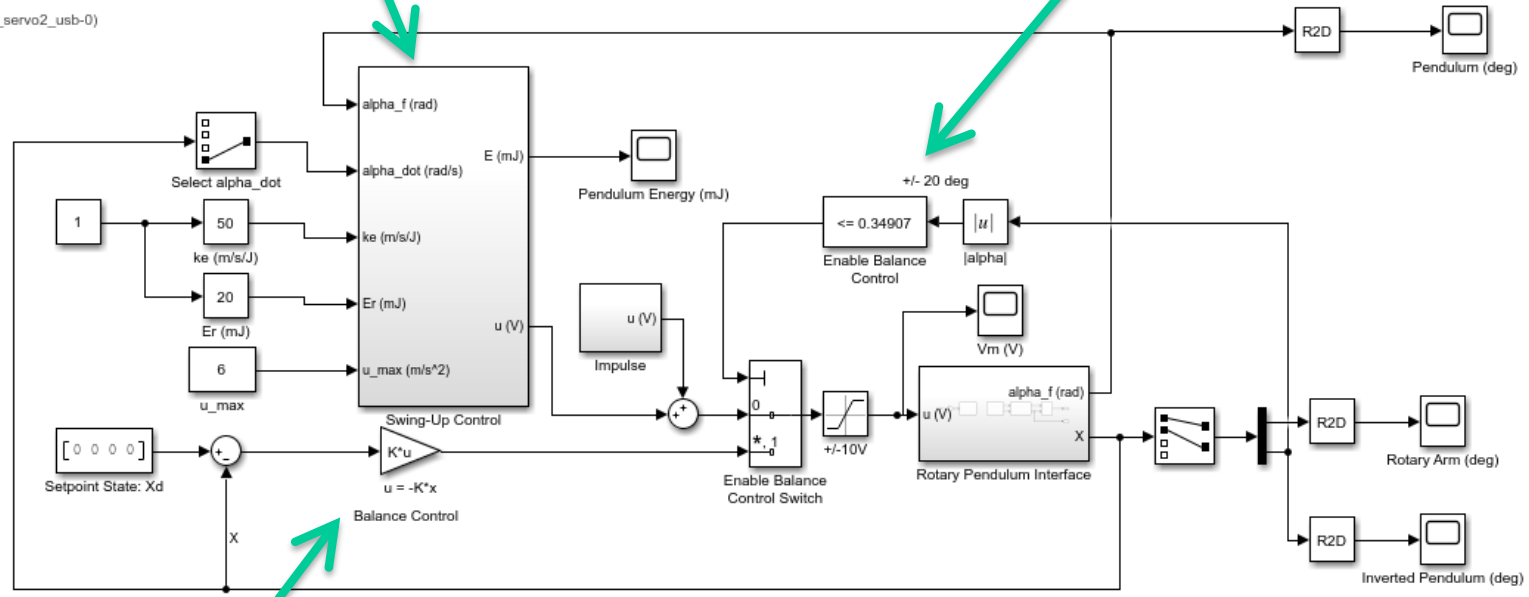


Pendulum swing-up + balance implementation



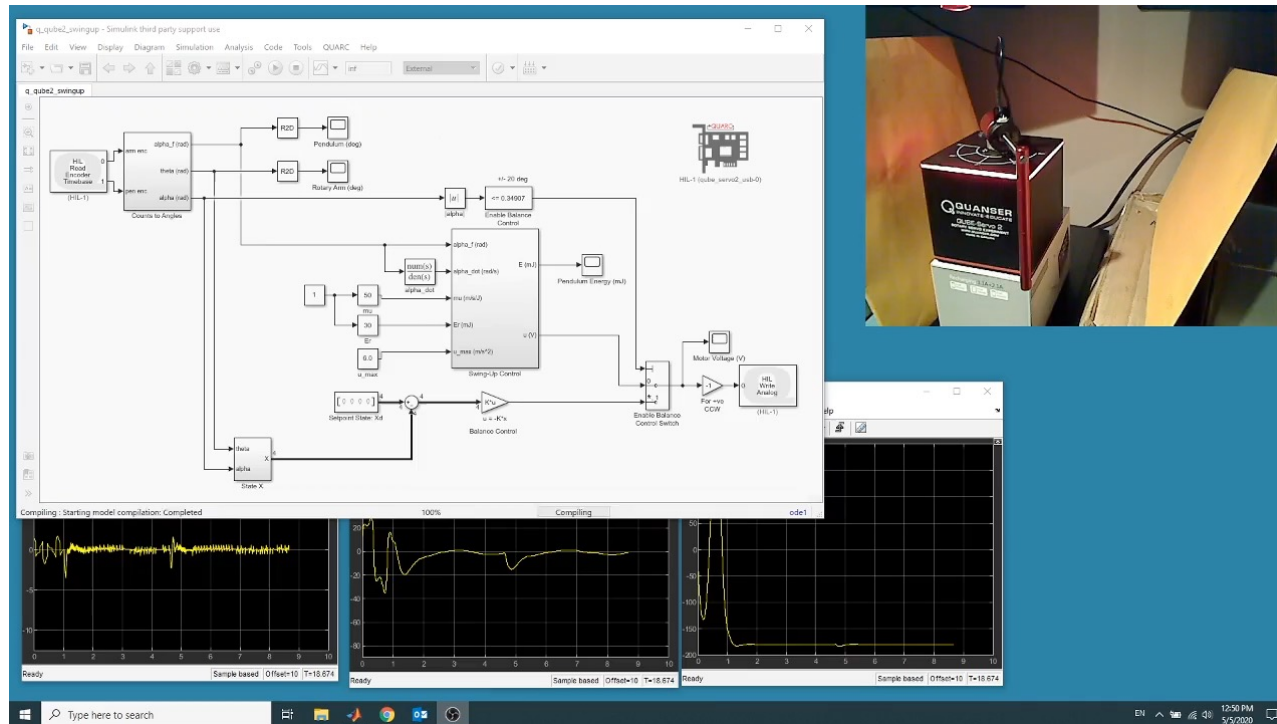
Swing-up control

Switch to balance model when +/- 20 deg



State-feedback balance control

Swing-up and balance control of the QUBE Servo-2 inverted pendulum



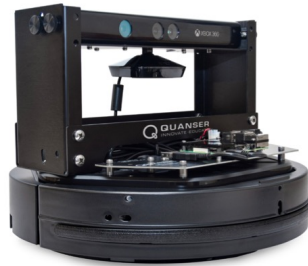
Lab 2 - Image-based control of the Ball & Beam with the QUBE-Servo 2

Balance control of two QUBE-servo 2

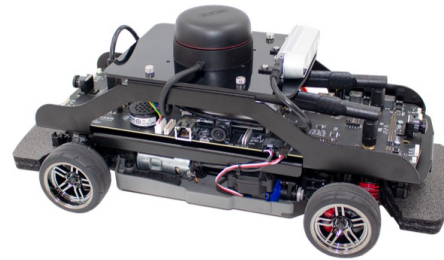


Mobile robots used during the remaining 6 labs

The Qbot



The Qcar



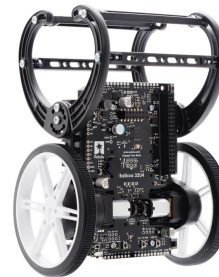
The 3pi+



The Tello drone



The Balboa



The Zumo

