

# Distance Learning with MATLAB & Simulink: challenges and solutions to prepare the next generation of Engineers

**Dr. Martina Sciola**

Technical Specialist Engineer for Education

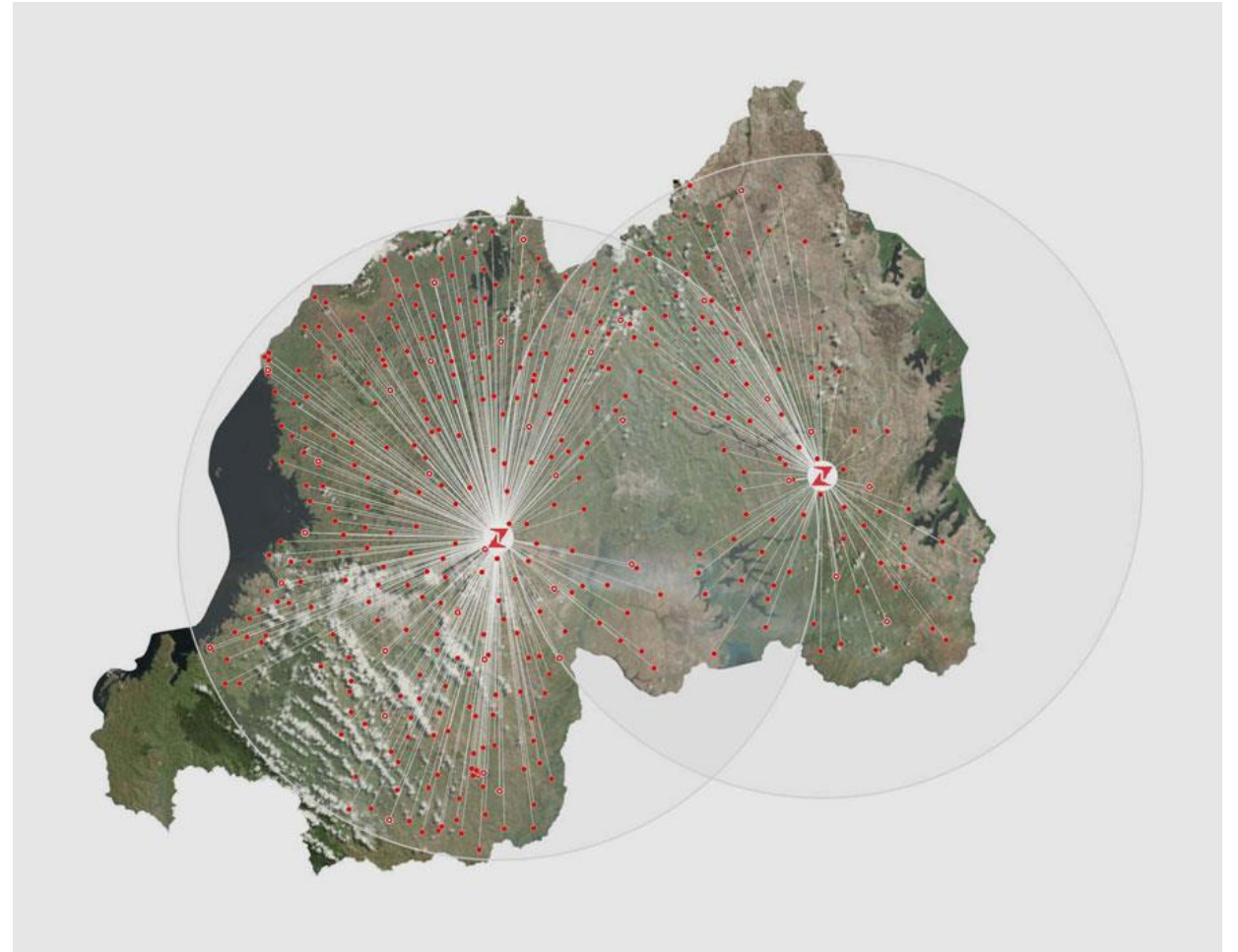
[msciola@mathworks.com](mailto:msciola@mathworks.com)

# Agenda

- Introduction
- Challenges and Needs in Teaching
- An example: Quadcopter with Pendulum
  - Modelling
  - Control Design
  - Simulation and deployment
- Resources for distance learning
- Summary and Q&A

# Let me tell you a story... **zipline**

The largest autonomous logistic network for medical supplies



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The largest autonomous logistic network for medical supplies



All images and videos on this slide are from <https://flyzipline.com/>



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The largest autonomous logistic network for medical supplies



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# What Tomorrow's Engineers and Scientists Need to Know?

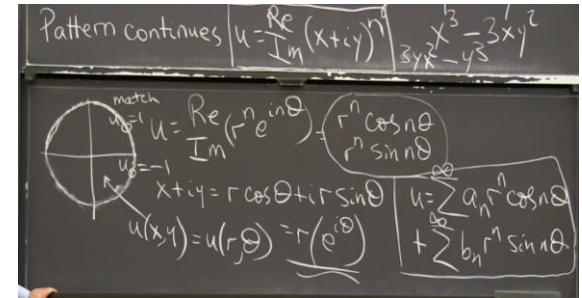
- Control, Signal Processing, Optimization, Computer Vision
- Abstraction, Modelling, and Simulation

**AND**

- Multidomain System Development

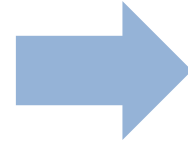
**AND**

- Distributed and Connected Systems
- Using Cloud Platforms and Big Data Processing
- AI and Data Science



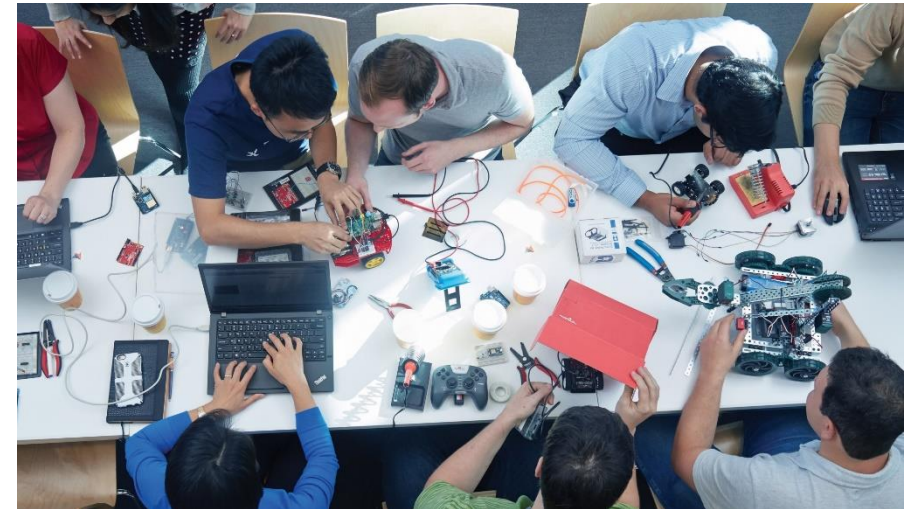
# Challenges in **Online** Teaching

- Engagement with students, keep them motivated
- Development of skills in real-problem scenarios to get ready to industry
- **Virtual Laboratories**
- **Remote classes**
- **Remote exams**



## Project-Based Learning

- Treat engineering students like engineers
- Hands-on experience of working on hardware and software
- Solve authentic problems in myriad contexts
- Increase student interest and improve learning



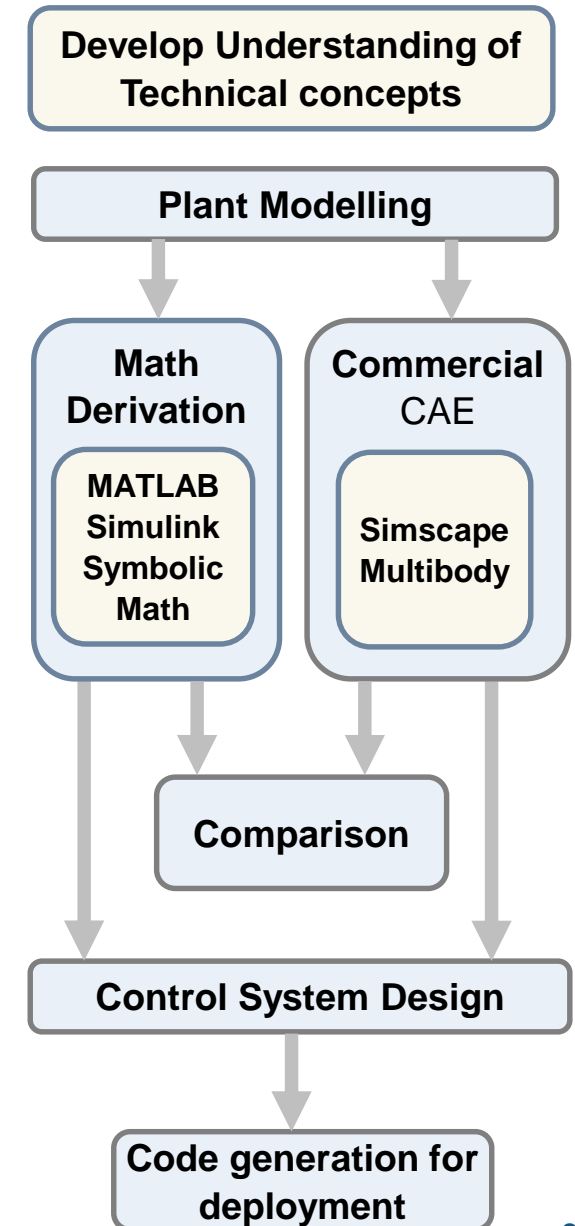
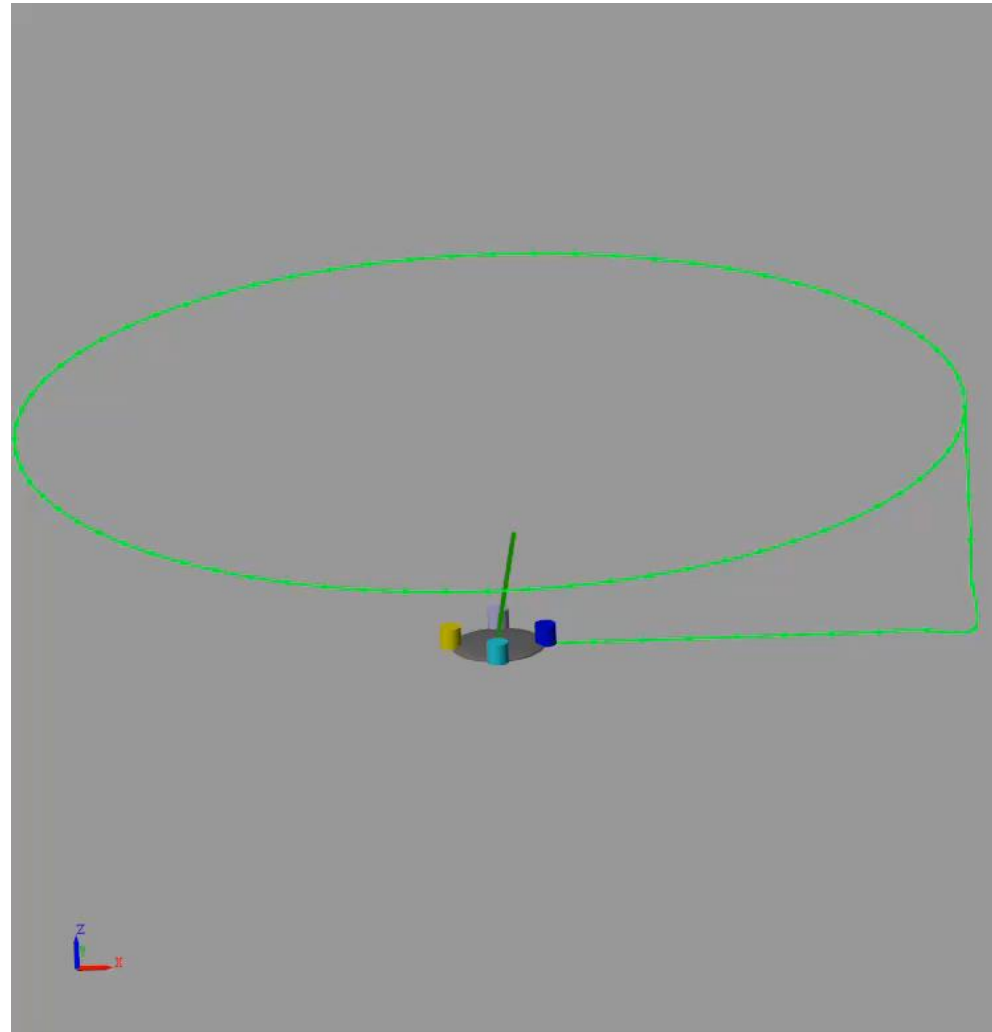


Let's consider an example...

## Quadcopter with Pendulum Simulation

### Learning Objectives

- Develops Computational Thinking for complex systems
- Enables comparisons of theory and simulation
- Principles of control and path planning



# How can students ramp up/refresh their MATLAB and Simulink skills?

<https://matlabacademy.mathworks.com/>

## Getting Started

<p><b>MATLAB Onramp</b> FREE</p> <p>Get started quickly with the basics of MATLAB.</p> <p><a href="#">Launch</a> <a href="#">Details</a></p>	<p><b>Simulink Onramp</b> FREE</p> <p>Get started quickly with the basics of Simulink.</p> <p><a href="#">Details</a></p>	<p><b>Machine Learning Onramp</b> NEW FREE</p> <p>Learn the basics of practical machine learning methods for classification problems.</p> <p><a href="#">Launch</a> <a href="#">Details</a></p>	<p><b>Deep Learning Onramp</b> FREE</p> <p>Get started quickly using deep learning methods to perform image recognition.</p> <p><a href="#">Launch</a> <a href="#">Details</a></p>	<p><b>Stateflow Onramp</b> NEW FREE</p> <p>Learn the basics of creating, editing, and simulating state machines in Stateflow.</p> <p><a href="#">Details</a></p>
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Online Self-Paced Interactive Training  
~2 h each

## Core MATLAB

<p><b>MATLAB Fundamentals</b></p> <p>Learn core MATLAB functionality for data analysis, modeling, and programming.</p> <p><a href="#">Launch</a> <a href="#">Details</a></p>	<p><b>MATLAB for Data Processing and Visualization</b></p> <p>Create custom visualizations and automate your data analysis tasks.</p> <p><a href="#">Launch</a> <a href="#">Details</a></p>	<p><b>MATLAB Programming Techniques</b></p> <p>Improve the robustness, flexibility, and efficiency of your MATLAB code.</p> <p><a href="#">Launch</a> <a href="#">Details</a></p>
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## Data Science

<p><b>Machine Learning with MATLAB</b></p> <p>Explore data and build predictive models.</p> <p><a href="#">Launch</a> <a href="#">Details</a></p>	<p><b>Deep Learning with MATLAB</b> NEW</p> <p>Learn the theory and practice of building deep neural networks with real-life image and sequence data.</p> <p><a href="#">Launch</a> <a href="#">Details</a></p>
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~10 -15 h each

## Computational Mathematics

\*Available only to users at universities that offer campus-wide online training access.

<p><b>Introduction to Symbolic Math with MATLAB</b> NEW</p> <p>Get started quickly with an introduction to symbolic math.</p> <p><a href="#">Launch</a> <a href="#">Details</a></p>	<p><b>Solving Nonlinear Equations with MATLAB</b></p> <p>Use root finding methods to solve nonlinear equations.</p> <p><a href="#">Launch</a> <a href="#">Details</a></p>	<p><b>Solving Ordinary Differential Equations with MATLAB</b></p> <p>Use MATLAB ODE solvers to numerically solve ordinary differential equations.</p> <p><a href="#">Launch</a> <a href="#">Details</a></p>	<p><b>Introduction to Linear Algebra with MATLAB</b></p> <p>Use matrix methods to solve systems of linear equations and perform eigenvalue decomposition.</p> <p><a href="#">Launch</a> <a href="#">Details</a></p>	<p><b>Introduction to Statistical Methods with MATLAB</b></p> <p>Get started quickly with basic descriptive statistics and data fitting.</p> <p><a href="#">Launch</a> <a href="#">Details</a></p>
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View/Share Certificate

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**Course Certificate**

[View/print certificate](#)

Share certificate:

shareable link

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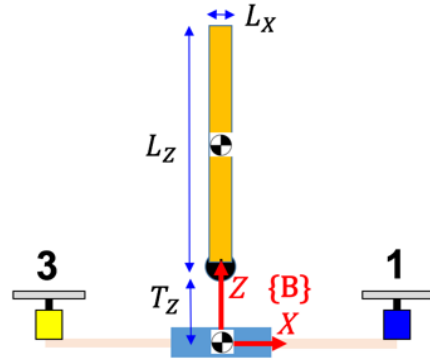
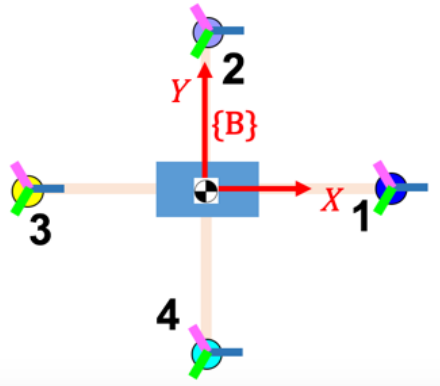
**Progress Report (includes chapter details)**

[View/print progress report](#)

Share progress report:

shareable link

# Quadcopter with Pendulum Simulation - Modelling Part 1



## Euler-Lagrange

$$\frac{d}{dt} \frac{\partial L}{\partial \dot{q}_k} - \frac{\partial L}{\partial q_k} = Q_k \quad k = 1, 2, \dots, n$$

## Generalised forces

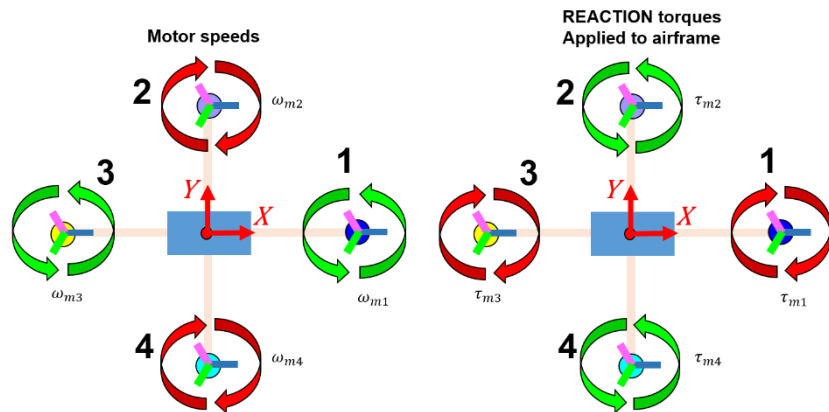
$$Q_k = \sum_{i=1}^{N_{f_{nc}}} \left( \vec{F}_i \cdot \frac{\partial \vec{v}_i}{\partial \dot{q}_k} \right) + \sum_{j=1}^{N_{\tau_{nc}}} \left( \vec{\tau}_j \cdot \frac{\partial \vec{\omega}_j}{\partial \dot{q}_k} \right)$$

## Kinetic energy

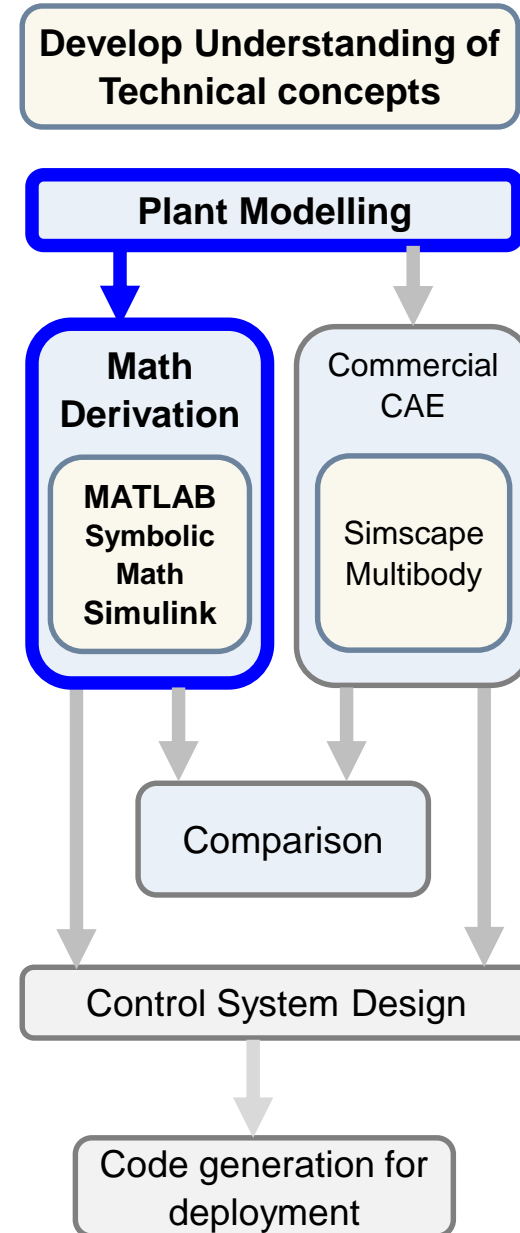
$$KE_i = \frac{1}{2} \vec{v}_{cm_i}^T \cdot m_i \cdot \vec{v}_{cm_i} + \frac{1}{2} \cdot \vec{\omega}_{B_i}^T \cdot [I_{cm_i}] \cdot \vec{\omega}_{B_i}$$

## Potential energy

$$PE_i = g \cdot m_i \cdot h_i$$



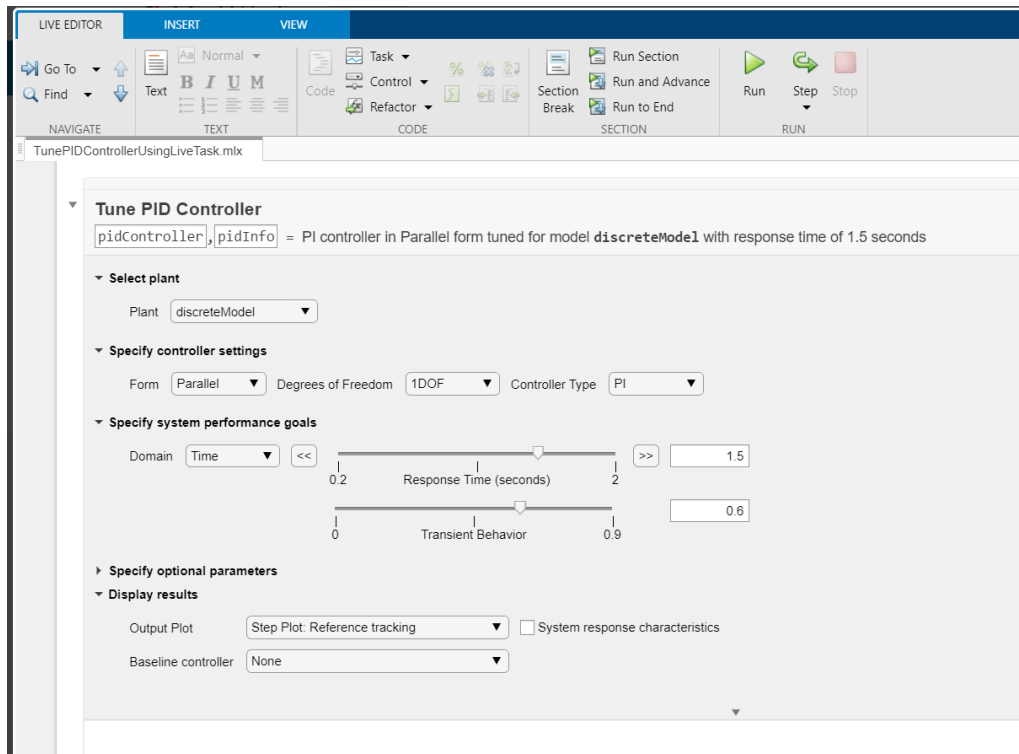
- 1 Airframe
- 4 Propeller assemblies
- 1 Pendulum



# How to keep students engaged during lectures?

## Live Scripts

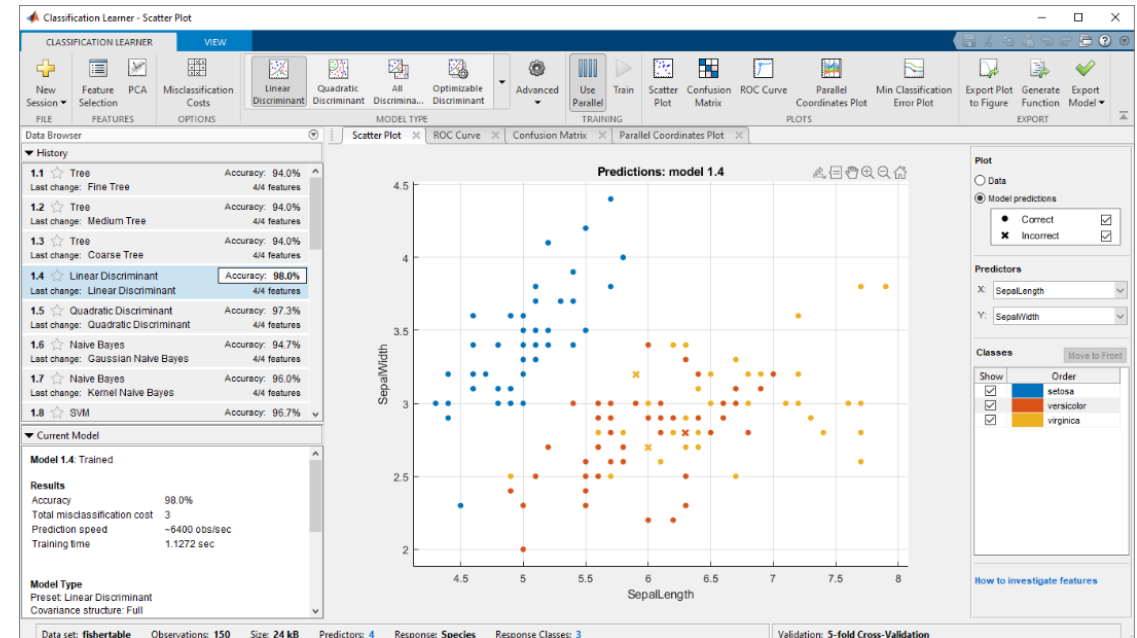
Interactive executable notebooks with code, text, figures, outputs all in a single document. Students can experiment with parameters and see the results immediately in the same document



[Tune PID Controller from Measured Plant Data](#)

## MATLAB Apps

Built-in or customised user-interfaces that allow students to interact with the material and develop an intuition before getting into the specifics of equations or algorithms.

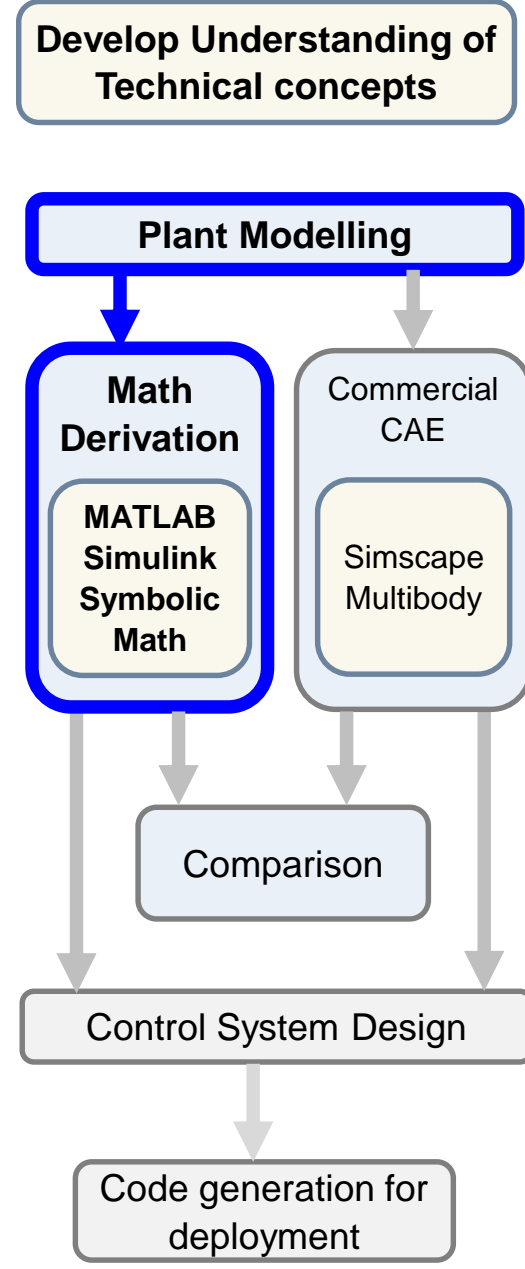
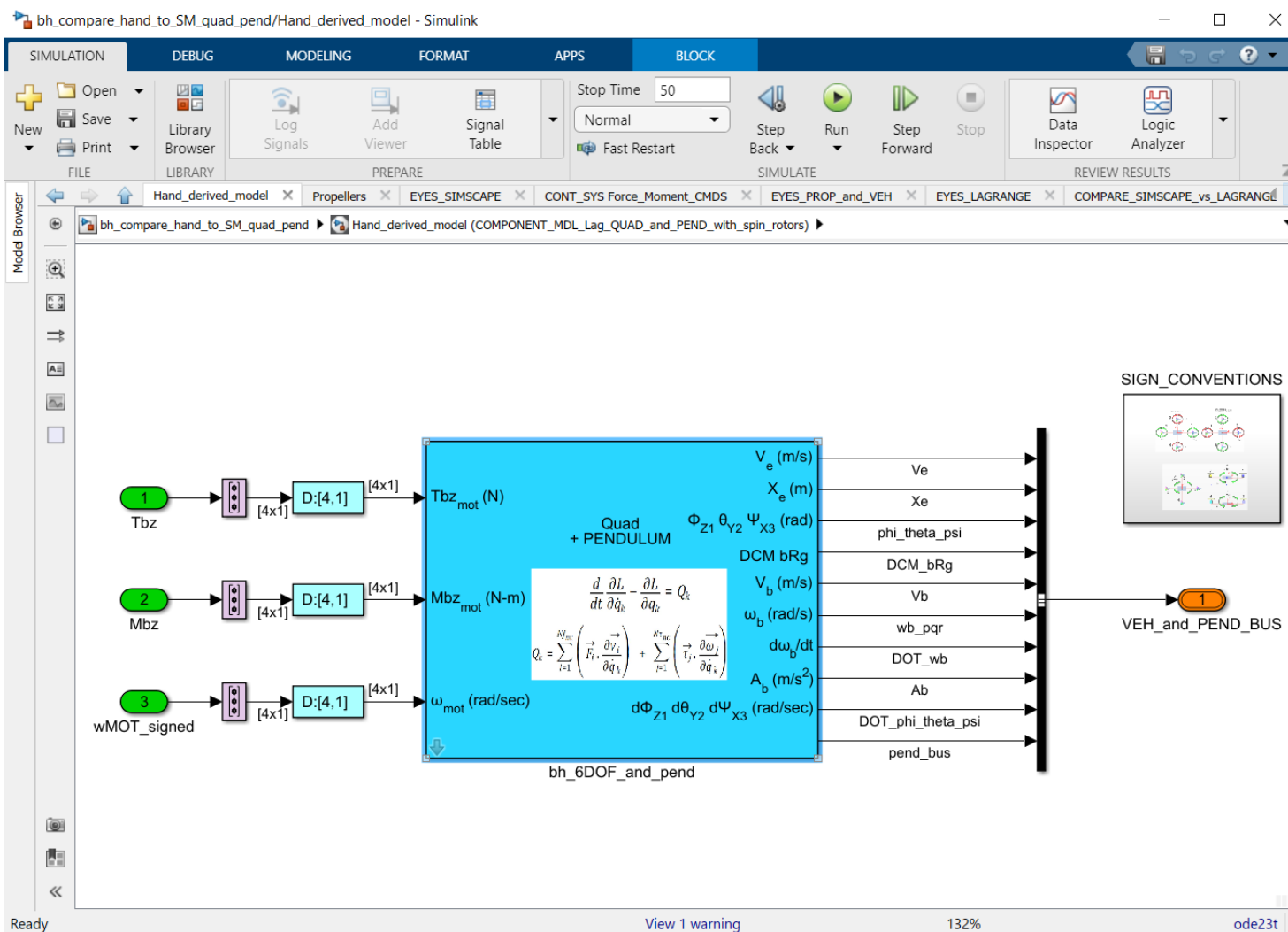


[Machine Learning model for classification](#)



# Quadcopter with Pendulum Simulation - Modelling Part 2

## Implementation of Euler-Lagrange with blocks in Simulink



# How can students can access MATLAB & Simulink remotely? How do I share the scripts and models with students?

- Students and Staff have access to MATLAB for free

## Get Campus Software

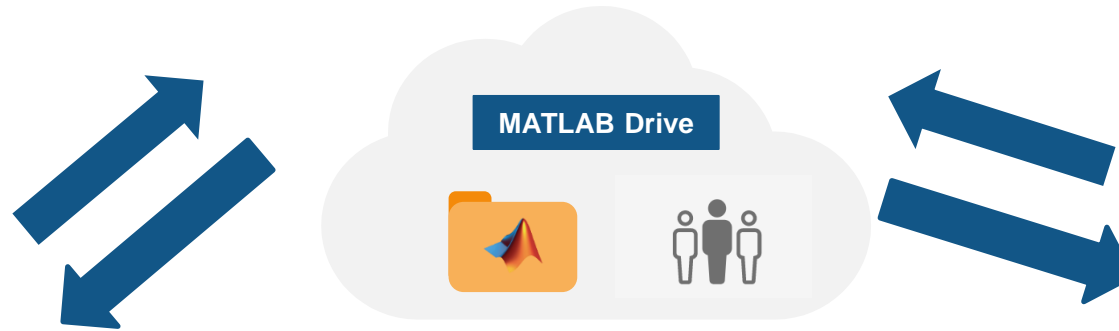
You may already have free access to MATLAB through your school.

[Check for access](#)

## Campus-Wide Licence

Download MATLAB on your PC using your University email address

Possibility to use Source Control (e.g. Git, SVN) on MATLAB Desktop



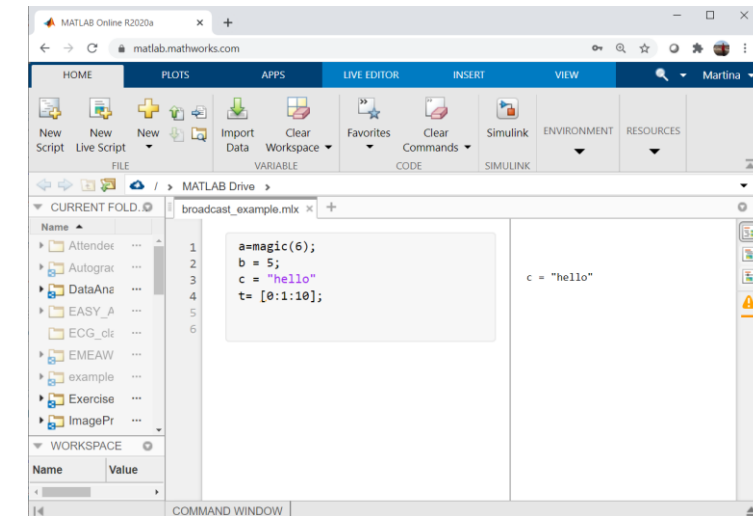
Sync and share your MATLAB code and Simulink models with [MATLAB Drive](#)



Access [MATLAB Mobile](#)

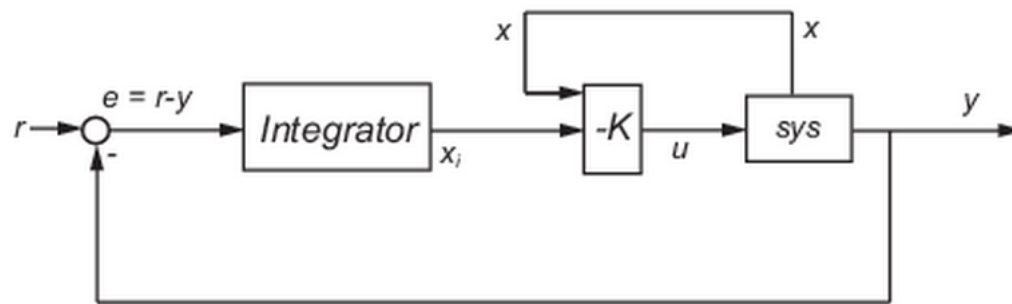


## Access [MATLAB and Simulink Online](#)



**Learn and practice anywhere, anytime!**

# Quadcopter with Pendulum Simulation - Control Design



LQI control

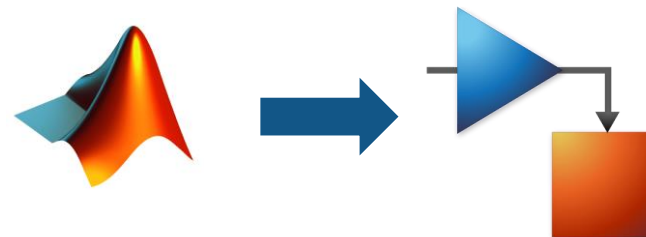
## State-space equations

$$\frac{dx}{dt} = Ax + Bu$$

$$y = Cx + Du$$

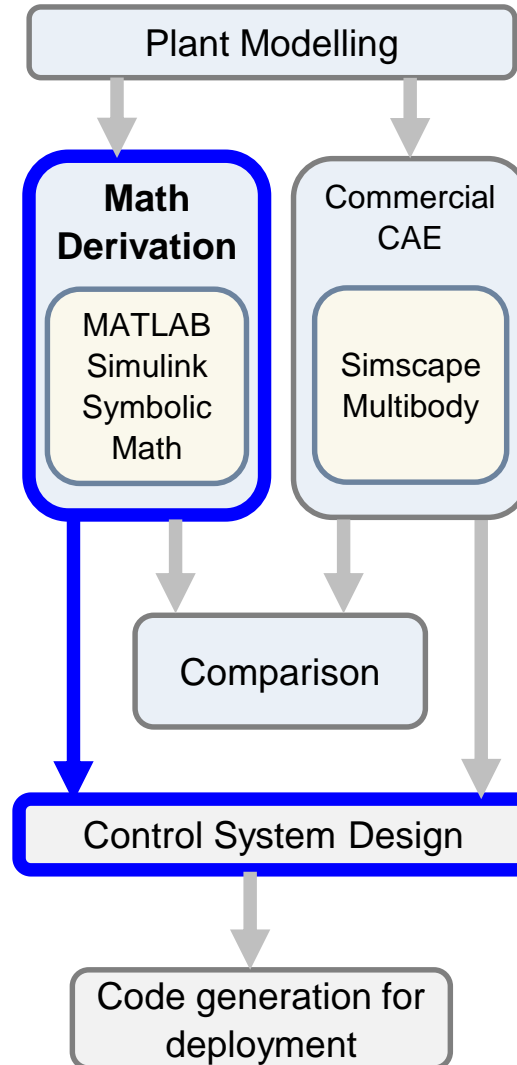
## State-feedback control

$$u = -K [x; x_i]$$



- Linearize the model
  - 4 Inputs
  - 3 Outputs
  - 18 States
- Discretise
- Set weighting matrices Q and R

Develop Understanding of Technical concepts



# How can I assess my students and build their confidence with immediate feedback?

<https://grader.mathworks.com>

[MATLAB Grader](#): a tool to save time grading MATLAB code and provide immediate feedback to students

- Creation and sharing of **MATLAB-based assignments**
- A library of **re-usable examples**
- **Autograded student solution** with custom scoring rubrics
- View **student performance analytics** at the individual and aggregate levels
- [Learning Management System Integration](#) with Campus-Wide Licence

The screenshot shows the MATLAB Grader interface for a problem titled "Design a PI Controller (DRAFT)". The interface includes a sidebar with a table of contents, a main content area with a title field and a problem description, and an assessment section at the bottom.

**Table of Contents:**

Control and Dynamics
Reorder Content
System Dynamics and Control
Linearization of a Function
System Identification
Car Suspension Step Response
Bode Magnitude Plot
Frequency Response of a Second-order System
Stability of a Feedback System
Generating the Root Locus
<b>Design a PI Controller</b>
Design of a Lead Compensator using Frequency Response
ADD PROBLEM

**Problem Description and Instructions:**

In this problem you will write a function that designs and returns a PI controller for the system illustrated below:

$$R(s) \rightarrow \oplus \rightarrow E(s) \rightarrow \left[ K_p + \frac{K_i}{s} \right] \rightarrow \left[ \frac{1}{Ts+1} \right] \rightarrow Y(s)$$

It is desired that the closed-loop poles have real part less than -a and imaginary part greater than b (or less than -b). Your function should late by adding are placed in the

**Assessment: 0 of 2 Tests Passed** [Run Pretest] [Submit]

✘ **Does the function return valid outputs for the given test inputs?** (Pretest)  
The real parts of the closed-loop poles are not less than -a.  
**Hint:** Since the closed-loop transfer function is second order, the desired closed-loop poles will be a complex-conjugate pair. Choose the desired real and imaginary parts of the closed-loop poles to place them just inside the desired region.

✘ **Does the function return valid outputs for randomized inputs?**  
The real parts of the closed-loop poles are not less than -a.



# Quadcopter with Pendulum Simulation - Modelling Part 3

Simscape Multibody: multibody simulation environment for 3D mechanical systems and integrate with hydraulic, electrical, pneumatic, and other physical systems

**Multidisciplinary** projects can speak the same language!

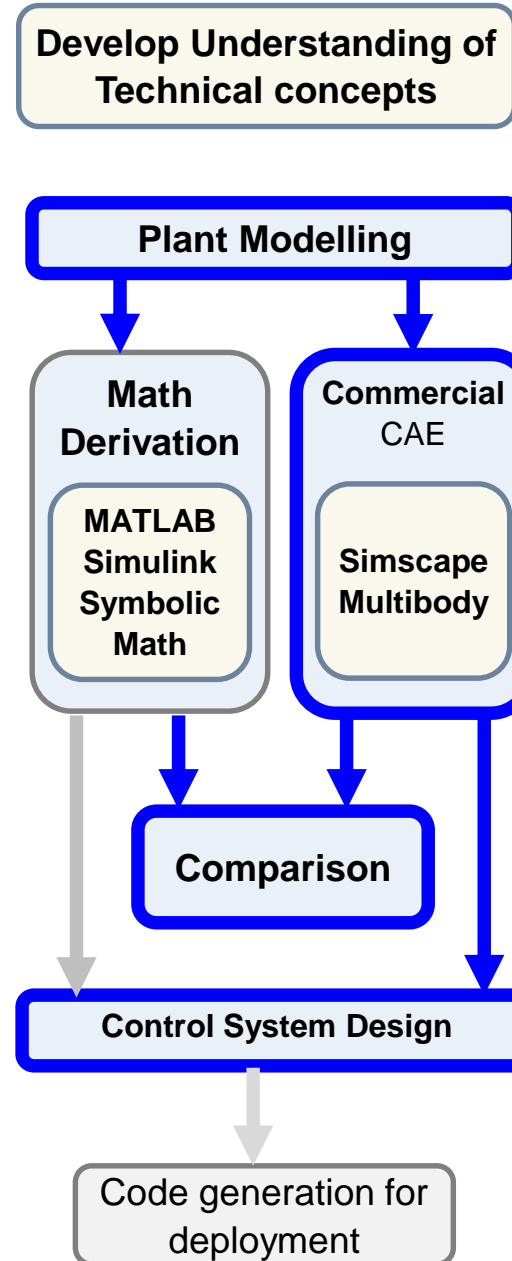


- Simulate in a virtual environment
- Test the model under indefinite number of conditions



**Industry**  
Model-Based Design

**Academia**  
Virtual and Remote Laboratory



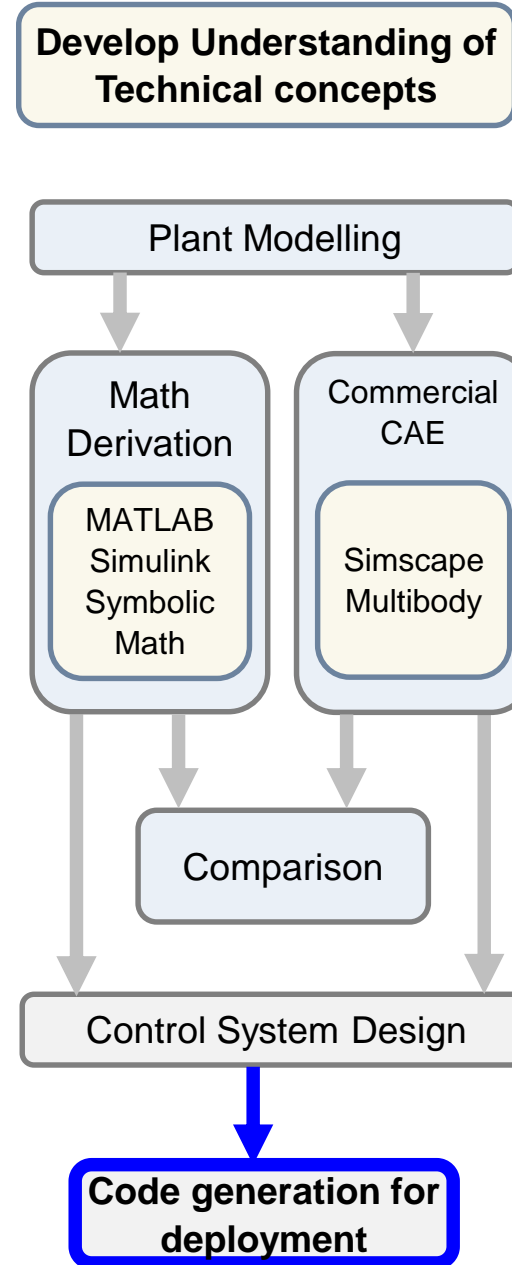
# Quadcopter – Code generation and deployment

Easily and quickly **generate code** and **deploy** it to **target hardware** with **Code Generation!**

<https://www.mathworks.com/hardware-support/home.html>



- C/C++
- HDL
- PLC
- See complete list of Code Gen Toolbox [here!](#)



**PX4 Autopilots Support from Embedded Coder**

*Automatically build and deploy flight control algorithms to the Pixhawk Autopilot using Simulink and Embedded Coder*

[Parrot Drone Support from MATLAB](#)

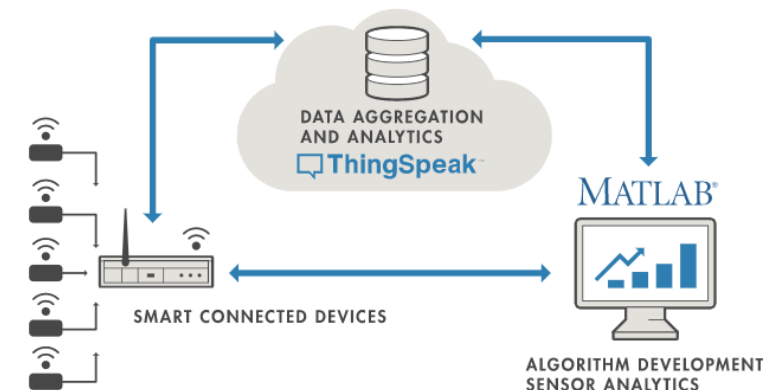
[Parrot Minidrone Support from Simulink](#)

# How to include data collection experience in remote teaching?

- Low-cost hardware at home (i.e. Arduino, Raspberry PI)
- Share protected Simulink models, where students provide inputs and gather output without having access to the details of the model
- [Thingspeak](#): IoT analytics platform service that allows you to aggregate, visualize and analyze live data streams in the cloud.

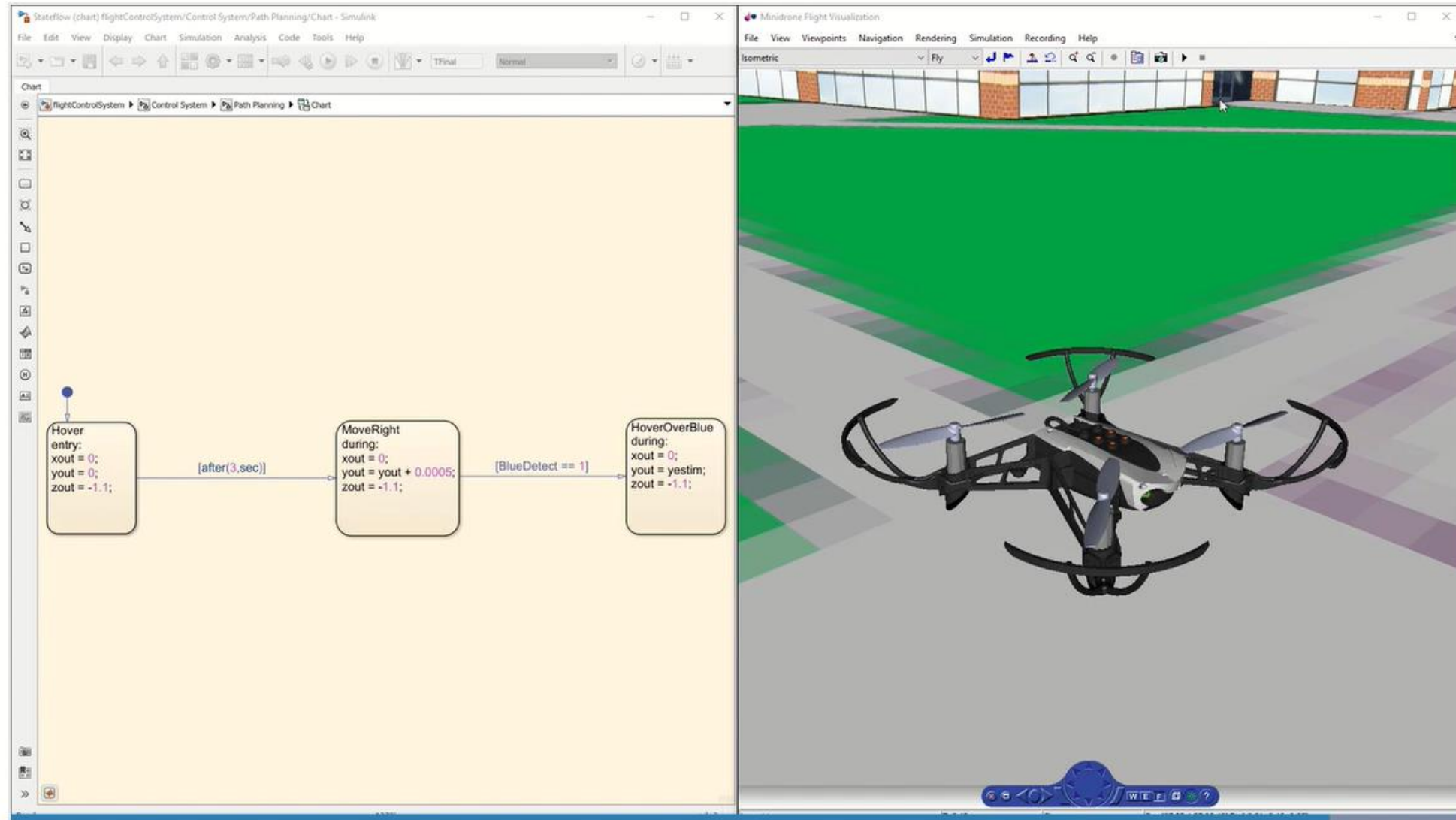


[Experience from Prof. Yossi Chait at University of Massachusetts Amherst](#)



# Virtual Laboratories with MATLAB and Simulink

## Path Planning and Motion Control with State Machines using [Stateflow](#)



The image displays two side-by-side windows from a MATLAB/Simulink environment. The left window, titled 'Stateflow (chart) flightControlSystem/Control System/Path Planning/Chart - Simulink', shows a Stateflow chart with three states:

- Hover** (entry):  $x_{out} = 0;$ ,  $y_{out} = 0;$ ,  $z_{out} = -1.1;$
- MoveRight** (during):  $x_{out} = 0;$ ,  $y_{out} = y_{out} + 0.0005;$ ,  $z_{out} = -1.1;$
- HoverOverBlue** (during):  $x_{out} = 0;$ ,  $y_{out} = y_{estim};$ ,  $z_{out} = -1.1;$

Transitions between states are defined as follows:

- From **Hover** to **MoveRight**: triggered by `[after(3,sec)]`.
- From **MoveRight** to **HoverOverBlue**: triggered by `[BlueDetect == 1]`.

The right window, titled 'Minidrone Flight Visualization', shows a 3D rendering of a quadcopter drone in a virtual environment. The drone is positioned on a green field with a grey path. The environment includes a brick wall and a blue sky. The drone's position and orientation are controlled by the Stateflow chart.

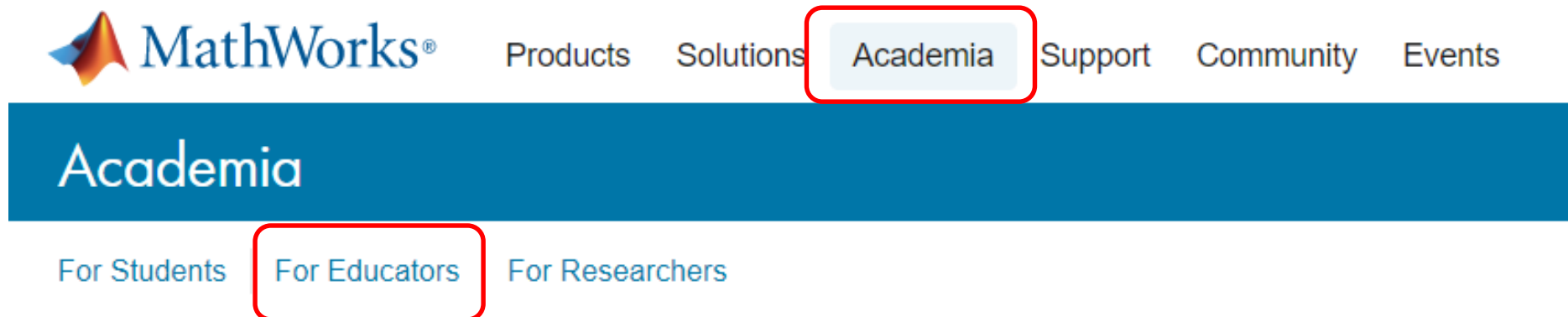


# Resources for Distance Learning

- ✓ [Self-Paced Online Trainings](#): browser-based interactive courses with immediate feedback
- ✓ [MATLAB Online/Simulink Online](#): use MATLAB and Simulink from the browser
- ✓ [MATLAB Mobile](#): use MATLAB from your smartphone
- ✓ [MATLAB Drive](#): sync and share your projects
- ✓ [MATLAB Grader](#): autograde MATLAB code and provide immediate feedback
- ✓ [Thingspeak](#): IoT platform to visualise and analyse data
- ✓ [Distance Learning Community](#): discover how academics are preparing for remote teaching

## Other Teaching Resources

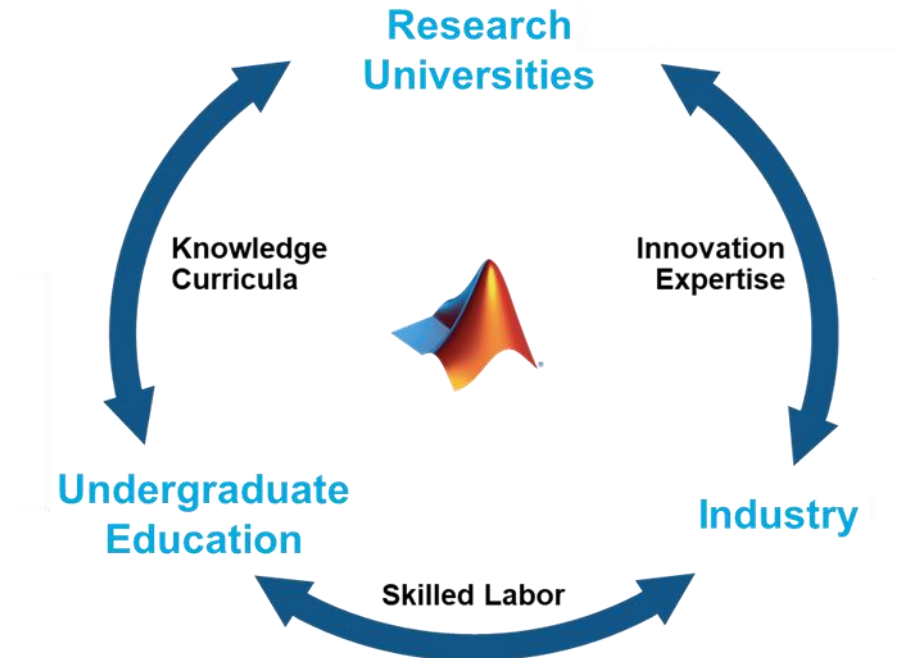
- ✓ [Live Scripts](#): interactive scripts with code, images, text, etc.
- ✓ [MATLAB Apps](#): interactive graphic application for technical computing tasks
- ✓ [Courseware](#): repository of downloadable teaching material from academics
- ✓ [Control Tutorials](#): tutorials and curriculum on system dynamics and control



<https://www.mathworks.com/academia.html>

## Key Takeaways

- Digital Transformation is revolutionizing the industry
- New graduates will be expected to address more complex and multidisciplinary challenges
- Experience with tools and workflows used in industry make students more hireable



# THANKS FOR YOUR ATTENTION

## Any questions?

[https://www.mathworks.com/support/contact\\_us](https://www.mathworks.com/support/contact_us)



**Dr. Martina Sciola**

Technical Specialist Engineer for Education

[msciola@mathworks.com](mailto:msciola@mathworks.com)

Academia Team in Italia

**Dr. Stefano Olivieri**

[solivier@mathworks.com](mailto:solivier@mathworks.com)



**Dr. Francesca Marini**

[fmarini@mathworks.com](mailto:fmarini@mathworks.com)



# Quadcopter with Pendulum Simulation - Control Design

Develop Understanding of Technical concepts

Trim, Linearise and design a Control system for the **Lagrangian** quadcopter and **PENDULUM** model:

Double click to LOAD vehicle and PENDULUM parameters

Plant Modelling

**Math Derivation**  
 MATLAB  
 Simulink  
 Symbolic  
 Math

Commercial CAE  
 Simscape  
 Multibody

Comparison

**Control System Design**

Code generation for deployment