

Resources for Instructors Teaching Controls Courses and Labs

Craig Buhr, Ph.D.
Controls Design Products
MathWorks

Melda Ulusoy, Ph.D.
Controls Product Marketing
MathWorks

Key takeaways

- We help students learn fundamental concepts; acquire MATLAB and Simulink skills
- We help educators preparing course materials and curriculum
- We make it easy to do real-life projects and access to MATLAB and Simulink from everywhere



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ASSESSMENT



GETTING HELP



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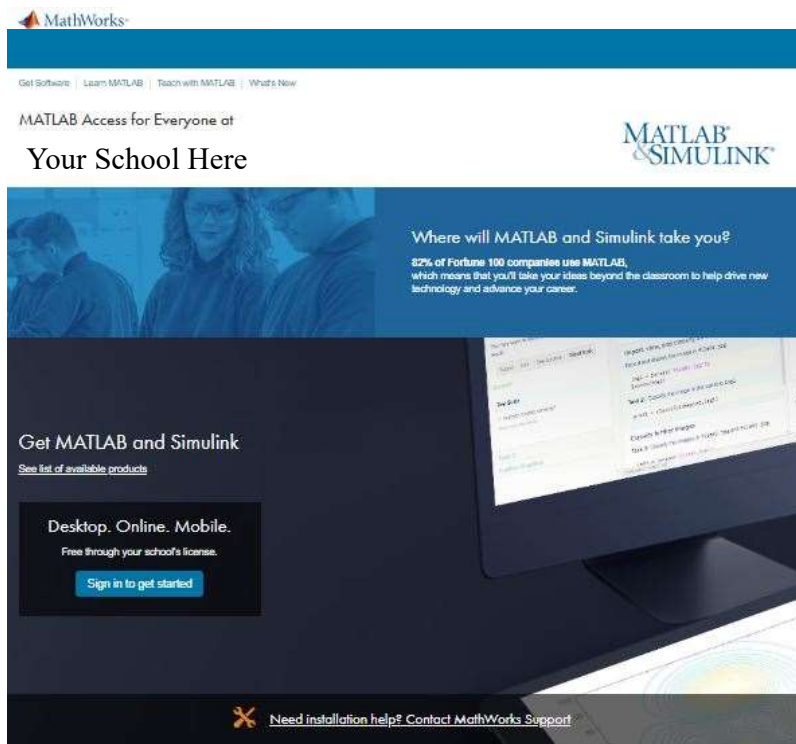
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Campus Wide License



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 [Need installation help? Contact MathWorks Support](#)

<https://www.mathworks.com/academia/tah-support-program/eligibility.html>

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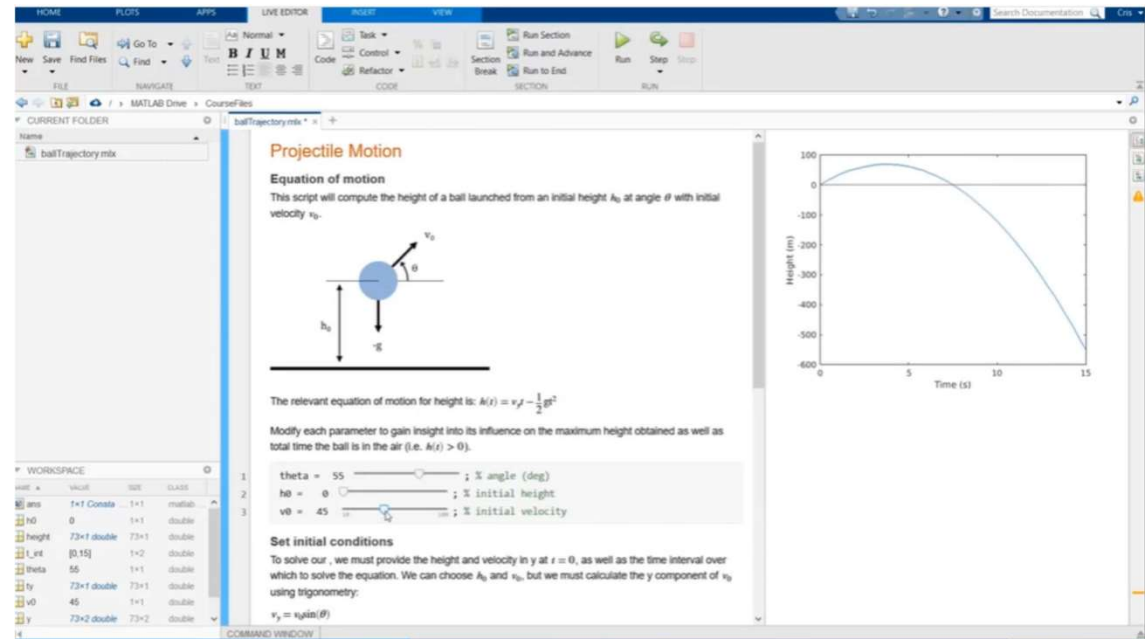
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GETTING HELP

Access MATLAB and Simulink from any standard web browser with MATLAB and Simulink Online

- No downloads or installations required
- Always run latest version of MATLAB and Simulink
- Collaborate with others through online sharing and publishing
- Store, manage, and access your files anywhere



<https://www.mathworks.com/products/matlab-online.html>



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Free Self-Paced Interactive Tutorials for Students



MATLAB Onramp

Get started quickly with the basics of MATLAB.



Simulink Onramp

Get started quickly with the basics of Simulink.



Control Design Onramp with Simulink

Get started quickly with the basics of feedback control design in Simulink.



Reinforcement Learning Onramp

An interactive introduction to reinforcement learning methods for control problems.



Machine Learning Onramp

An interactive introduction to practical machine learning methods for classification problems.



Deep Learning Onramp

Get started quickly using deep learning methods to perform image recognition.



Stateflow Onramp

Learn the basics of creating, editing, and simulating state machines in Stateflow.



Simscape Onramp

Learn the basics of simulating physical systems in Simscape.



Signal Processing Onramp

An interactive introduction to practical signal processing.



Image Processing Onramp

Learn the basics of practical image processing.

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

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MATLAB Onramp

Self-Paced Online Courses
MU

[Home](#) | [My Courses](#)

MATLAB Onramp

2%

Resume course

[Share](#) | [Certificate](#) | [Settings](#)

> **Course Description**

Modules

- ✔ > [Course Overview](#) 5 min | 100%
- > [Commands](#) 20 min
- > [MATLAB Desktop and Editor](#) 10 min
- > [Vectors and Matrices](#) 15 min
- > [Indexing into and Modifying Arrays](#) 15 min
- > [Array Calculations](#) 5 min
- > [Calling Functions](#) 5 min
- > [Obtaining Help](#) 5 min

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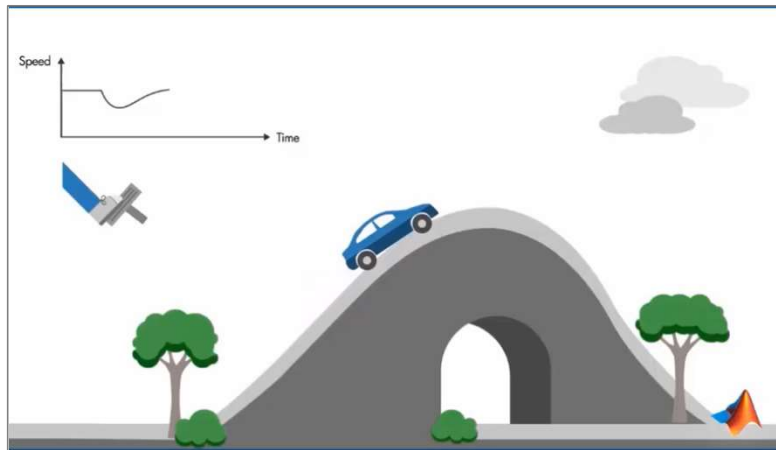
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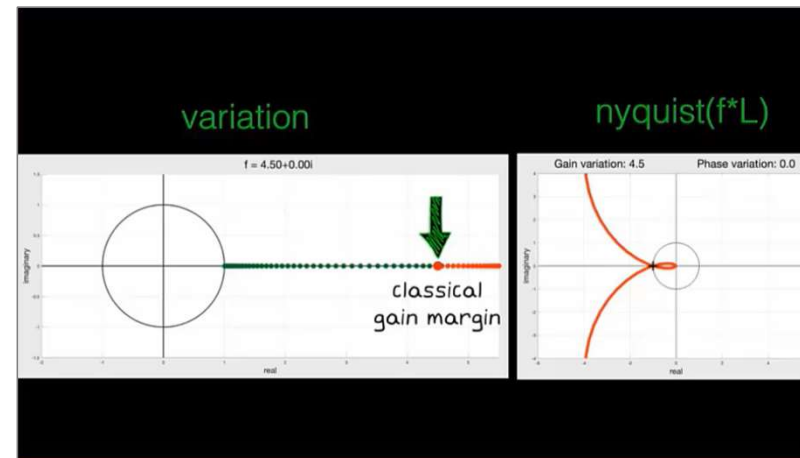
MATLAB Tech Talks: Educational Videos for Students

Use free educational videos to supplement your teaching of controls concepts

- Series of short videos
- Help students gain intuition into complex controls concepts



<https://www.youtube.com/c/matlab/videos>



<https://www.mathworks.com/videos/tech-talks/controls.html>

MATLAB Tech Talks Library

- › Learning-Based Control
- › Robust Control
- › Fuzzy Logic
- › Model Predictive Control
- › Reinforcement Learning
- › Machine Learning
- › Deep Learning
- › Motor Control
- › Kalman Filters
- › PID Control
- › Bode Plots
- › Introduction to Controls
- › Trimming and Linearization
- › Sensor Fusion and Tracking
- › Autonomous Navigation
- › Discrete-Event Simulation
- › Drone Control and Simulation

<https://www.mathworks.com/videos/tech-talks>

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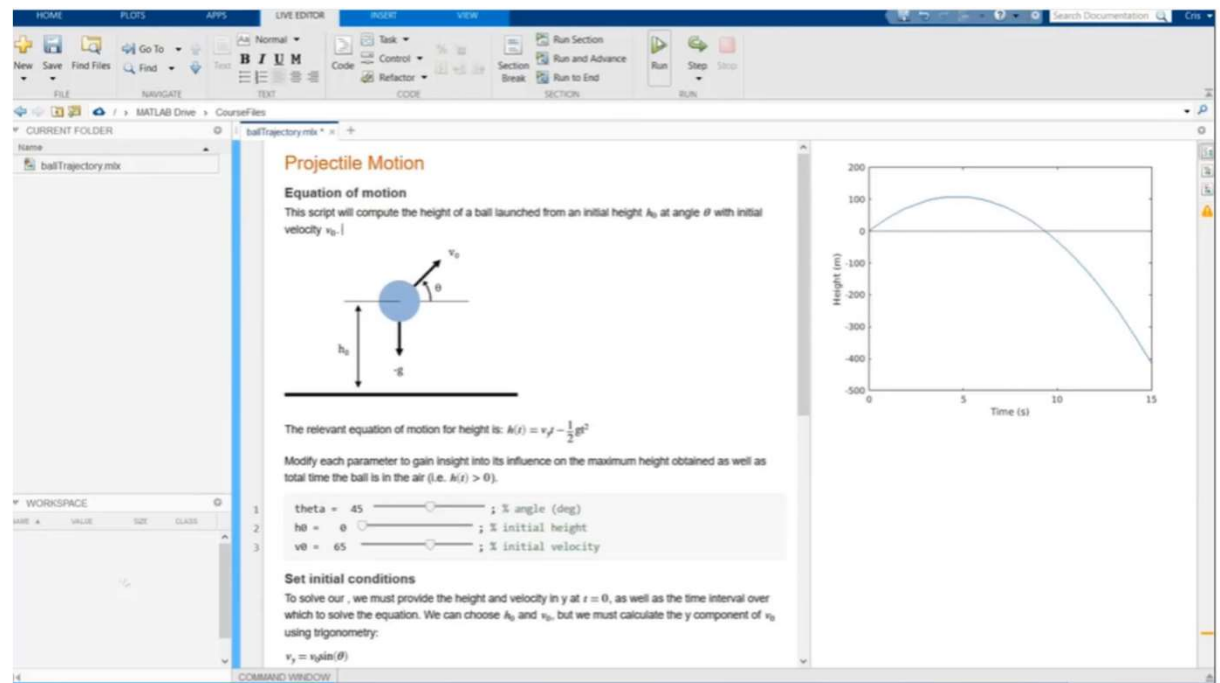
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GETTING HELP

Teach with Interactive Live Scripts

Create engaging lectures that combine

- Code
- Interactive controls
- Outputs
- Visualizations
- Formatted text



<https://www.mathworks.com/products/matlab/live-editor.html>

Interactive Live Script Control Tutorials for MATLAB and Simulink

<https://www.mathworks.com/campaigns/products/control-tutorials.html>

Introduction: Root Locus Controller Design

In this tutorial, we will introduce the root locus, show how to create it using MATLAB, and demonstrate how to design feedback controllers that satisfy certain performance criteria through the use of the root locus.

Key MATLAB commands used in this tutorial are: `feedback`, `rlocus`, `step`, `controlSystem`.

Run Live Script Version in MATLAB Online

Run live script example in your browser without installing MATLAB

Contents

- Closed-Loop Poles
- Plotting the Root Locus of a Transfer Function
- Choosing a Value of K from the Root Locus
- Closed-Loop Response
- Using Control System Designer for Root Locus Design

Closed-Loop Poles

Root Locus Concept

The root locus of a feedback system is a plot of the locations (locus) of all possible closed-loop poles with some parameter, often a proportional gain K , varied between 0 and ∞ . The figure below shows a unity-feedback architecture, but the procedure is identical for any open-loop transfer function $H(s)$, even if some elements of the open-loop transfer function are in the feedback path.

Let us consider the given unity-feedback system with:

$$H(s) = \frac{Y(s)}{U(s)} = \frac{s+2}{s^2+2s+3}$$

The following live script first plots the open-loop poles and zeros with blue X's and O's, respectively. Then as you move the slider to vary the value of the proportional gain K , it adds points to the figure representing the system's closed poles for each specific value of K . As you plot more and more values of the parameter, you can imagine connecting the dots to generate a continuous graph. Such a figure containing the closed-loop poles for all values of K from 0 to ∞ is a root locus plot. If you would like to clear the figure, you can choose the selection "reset figure" from the drop-down menu. If you then return to the "hold figure" selection, you can again see the different closed-loop pole locations as K is varied with the slider.

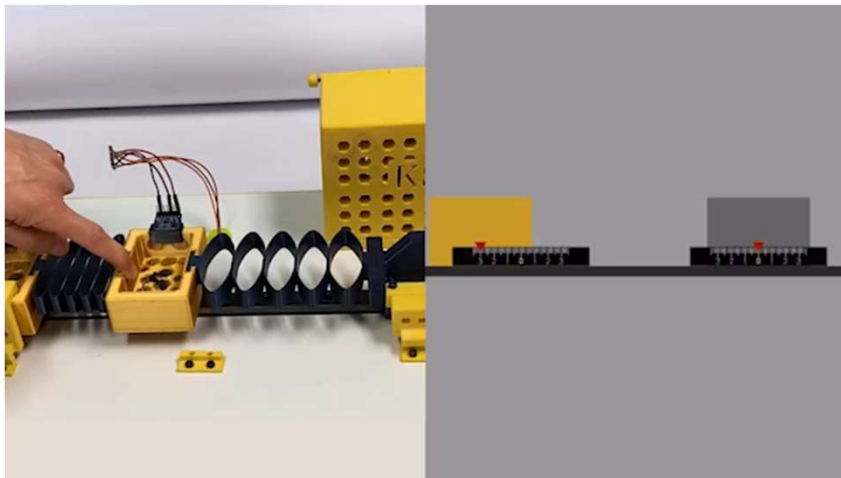
Project-Based Learning: Virtual Labs

Vibration and Controls Labs using Simscape

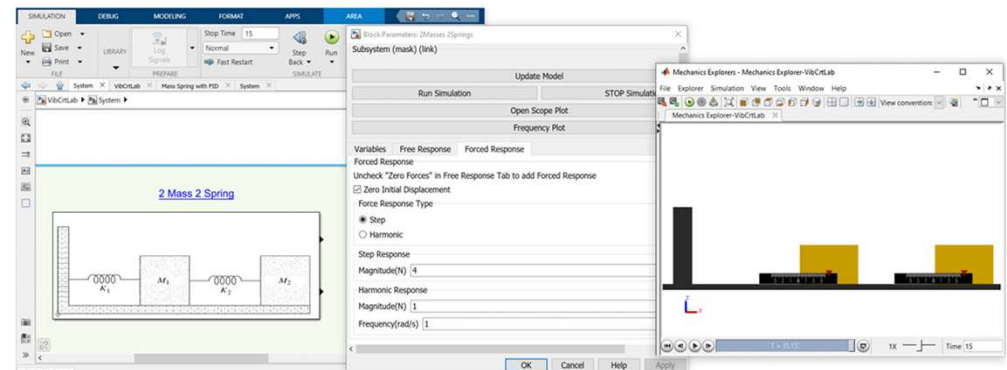
- Students can adjust the parameters of the virtual dynamic system such as mass-spring-damper and view system response in 3D
- Virtual labs can be downloaded at <http://facultyweb.kennesaw.edu/atekes/GUI%20Program.php>



Prof. Ayse Tekes,
Kennesaw State
University



Mass-spring system lab equipment (on the left) and the simulation (on the right)



Virtual labs for vibration and control analysis in Simscape

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GETTING HELP

Project-Based Learning using Low-Cost Hardware

Hardware Support Packages for MATLAB and Simulink

- Connect MATLAB and Simulink to hardware platforms for project-based learning
- Over 150 support packages, for Arduino, Raspberry Pi, LEGO Mindstorm, Parrot minidrones, iPhone, webcams, Kinect and more



<http://www.mathworks.com/hardware>

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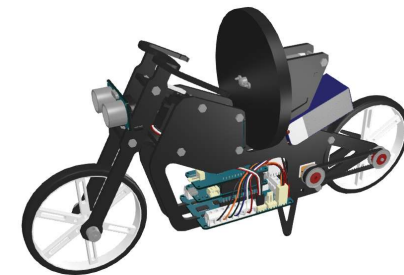
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GETTING HELP

Project-Based Learning using Arduino Engineering Kit

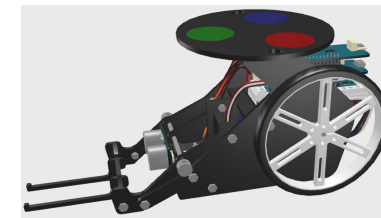
Self-balancing motorcycle

- Maneuvers itself on varying terrain and remains upright using a flywheel for balance
- Concepts: Controls, IMU sensing, filter design, system modeling, simulation



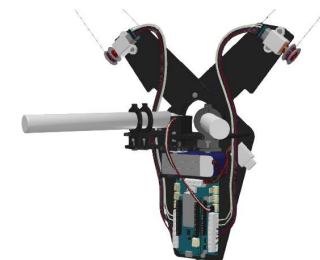
Mobile rover

- Navigates between reference points, locates and moves objects with a forklift
- Concepts: Robotics, system modeling, simulation, controls, object tracking, localization



Drawing robot

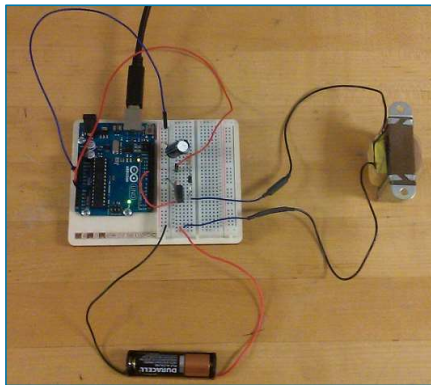
- Takes a reference drawing and duplicates it on a whiteboard
- Concepts: Image acquisition & processing, optimization, kinematics



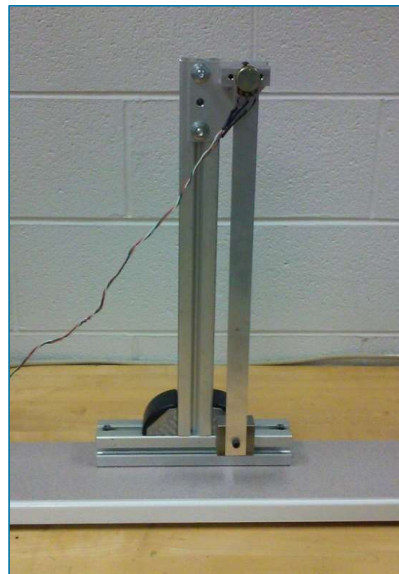
<https://www.mathworks.com/campaigns/products/arduino-kit.html>

Project-Based Learning using Low-Cost Hardware

- **Simple and Inexpensive Hardware Experiments for the System Dynamics and Controls Curriculum (ACC 2015 Sponsored Special Session)**
 - Professor Rick Hill, University of Detroit Mercy



Electrical Circuits



Mechanical Systems



Electromechanical Systems



Thermal Systems

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Project-Based Learning using Low-Cost Hardware

CONTROL TUTORIALS FOR MATLAB & SIMULINK

INTRODUCTION CRUISE CONTROL MOTOR SPEED MOTOR POSITION SUSPENSION INVERTED PENDULUM AIRCRAFT RITCH BALL & BEAM

TIPS ABOUT BASICS **HARDWARE** INDEX NEXT ▶

Hardware-Based Activities

Below you will find an extensive list of hardware-based activities that instructors and individuals can employ to learn the concepts behind the modeling, controller design, and controller implementation for dynamic systems. The activities as outlined employ an Arduino board (Uno, Mega 2560, etc.) interfaced with a host computer running MATLAB/Simulink, though the essence of the various activities can be achieved with alternative hardware and software platforms.

(Image: A laptop displaying a Simulink model connected to an Arduino board via a USB cable.)

Most of the activities employ the **ArduinoIO** package, though you can also use the standard **Arduino Hardware Support Package**. Both packages are freely available with the standard MATLAB/Simulink license. Details on these packages and their installation can be found by following the link below.

- [ArduinoIO Package Installation and Introduction](#)

Contents

- RC Circuit
- LRC Circuit
- Simple Pendulum
- Light bulb
- Boost Converter Circuit
- DC Motor

Overview

- RC circuit
- LRC circuit
- Pendulum
- Lightbulb
- BoostConverter
- DC motor

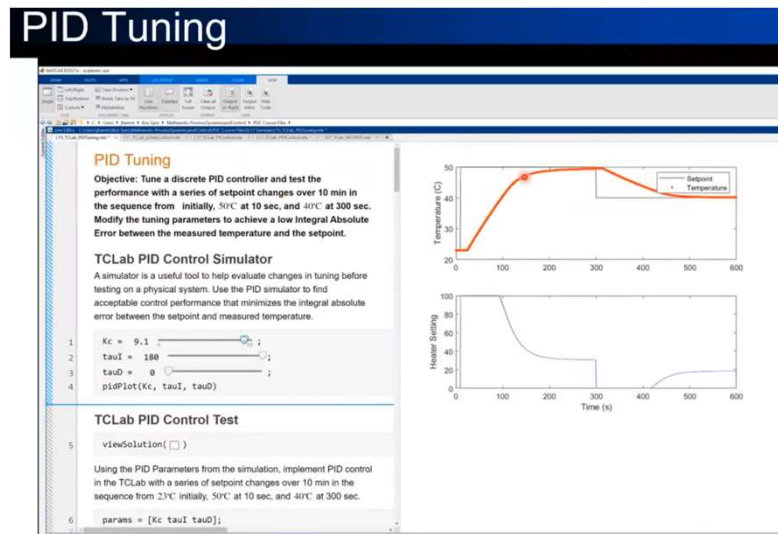
Prof. Bill Messner at Carnegie Mellon and Prof. Dawn Tilbury at MathWorks in 2011, Prof. Messner, Assoc. Prof. Rick Hill redesigned the web interface and updated all of the tutorials to

Project-Based Learning using Low-Cost Hardware

- **Hands-on Process Control Experiments with the Arduino-Based TCLab**
 - Interactive live script-based modules (35) include
 - Theory: Lesson
 - Simulation: Assignment
 - Labs: Temperature control
 - Modules available at: <https://github.com/APMonitor/mdc>



Prof. John Hedengren,
Brigham Young
University



Project-Based Learning using Low-Cost Hardware

■ Teaching Feedback Control Systems with one Palm-size Drone for Each Student

- Lectures teach design, simulation, code generation with Simulink
- Problem sets let students practice at home
- Palm size make them easy to carry
- Safe and reliable
- Hardware Support package for Parrot Minidrone



Prof. Sertac Karaman,
MIT

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Virtual Control Laboratory developed by MathWorks

- Virtual controls labs introduce basic controls concepts – feedback control
- Students implement and test controllers in Simulink and visualize dynamics of systems such as a DC motor, rotary and inverted pendulums
- Labs available on GitHub
<https://github.com/MathWorks-Teaching-Resources/Virtual-Controls-Laboratory>





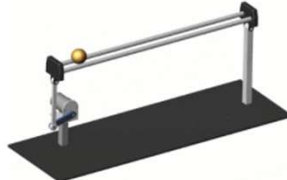
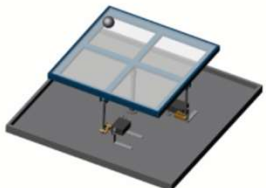


MathWorks Teaching Resources

mathworks.github.io

<https://mathworks.com/academia/ed...>

Virtual Mechanisms

<p>Cruise control CruiseControl.slx</p> 	<p>DC motor DCMotorControl.slx</p> 	<p>Inverted pendulum InvertedPendulum.slx</p> 
<p>Rotary pendulum RotaryPendulum.slx</p> 	<p>Ball and beam BallAndBeam.slx</p> 	<p>Ball and plate BallAndPlate.slx</p> 

ACCESS

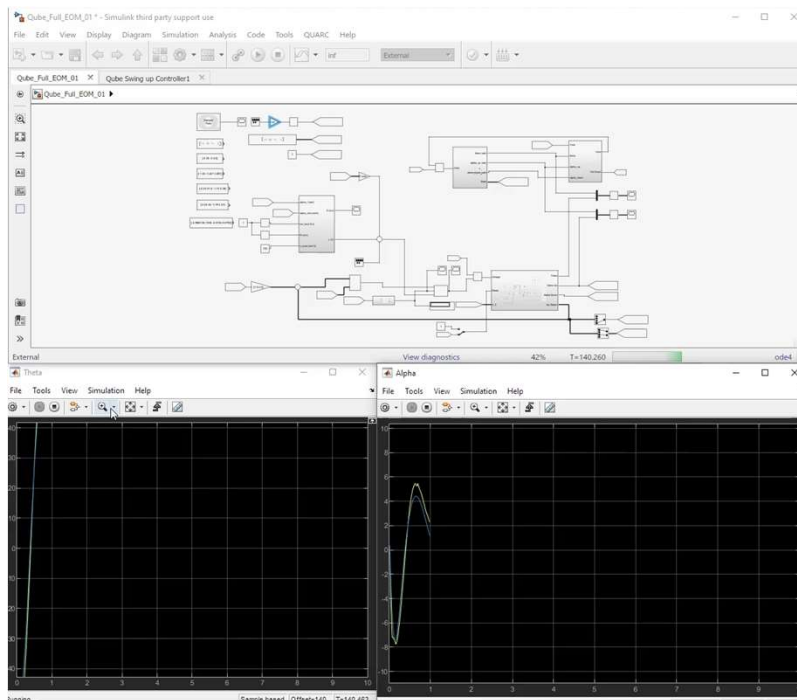
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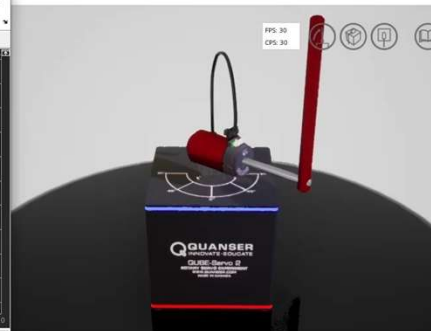
GETTING HELP

Teaching Control with Quanser Hardware and Interactive Labs

Quanser Qube Servo



Hardware Lab



Virtual Lab



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GETTING HELP

Autograde code with MATLAB Grader

- Create online private courses and assignments
- Students execute MATLAB code on the web
- Control the visibility of the test suites from students
- Visualize solution results using MATLAB graphics
- Solution map informatics for instructors
- Download all student attempts and report on grading data

<https://www.mathworks.com/products/matlab-grader.html>

The screenshot displays the MATLAB Grader interface. On the left is a 'CONTENTS' sidebar with a list of topics including 'Frequency Response of a Second-order System', 'Stability of a Feedback System', 'Generating the Root Locus', 'Design a PI Controller', and 'Design of a Lead Compensator using Frequency Response'. The main area shows 'Problem Description and Instructions' for a task involving a second-order system. It includes a plot of the step response $y(t)$ versus time t , with labels for y_{max} , y_{ss} , t_p , and $\%M_p$. Below the plot, it states: 'The step response data of the second order system has been provided to you as the variables t, y, and yss where: y is the vector of output data, t is the vector of corresponding times, yss is the output's steady-state value'. At the bottom, a 'Solution Map' is shown as a scatter plot of 'Size' (y-axis, 0-80) versus 'Order of Arrival' (x-axis, 0-60). The legend indicates: Non-Search Incorrect (grey), Non-Search Correct (light grey), Non-Search Leading (light grey), Incorrect (red), Correct (green), and Leading (blue).

MATLAB Grader – Student Feedback

- **Optimal Control and Dynamic Programming with MATLAB**
 - Professor Duarte Guerreiro Tomé Antunes TU/Eindhoven
 - 150 students
- **Benefits**
 - Significantly improved learning outcomes
 - Enabled the teaching assistants to spend more time working directly with students
 - Motivated the students by providing immediate feedback on their work
 - Identified what concepts students were learning well and where they needed help

MATLAB Grader Melda Utusoy ▾

CONTENTS Close Courses & Content LMS Integration Documentation & Support ▾

Frequency Response of a Second-order System

Stability of a Feedback System

Generating the Root Locus

Design a PI Controller

Design of a Lead Compensator using Frequency Response

ADD PROBLEM

ADD GROUP

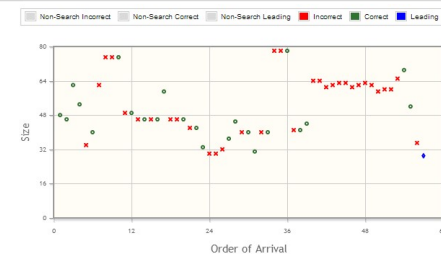
Collaborate with Instructors

Problem Description and Instructions ⓘ

In this problem you will write a script to identify the transfer function parameters of a standard, underdamped, second-order system (2 complex poles, no zeros) based on its unit step response as illustrated below:

The step response data of the second order system has been provided to you as the variables t , y , and y_{ss} where:

- y is the vector of output data
- t is the vector of corresponding times.
- y_{ss} is the output's steady-state value



MATLAB Grader – Student Feedback

Student Feedback

Student feedback on Cody Coursework was overwhelmingly positive. Here is a sample of the responses we received:

“The fact that you can get immediate feedback (or confirmation) on a quite complicated piece of code is really neat, and without it, debugging your own code would really be a mess. It also motivated me to get 100% score on all the MATLAB assignments.” Joost P.

“Cody Coursework is a great platform. It gives me more confidence about my solution rather than waiting for the instructor evaluation.” Manoj P.

“My experience with Cody Coursework was very positive. The green checkboxes are an extra motivation to get a high grade.” Koen B.

“The most useful feature of Cody Coursework was the ability to check our solutions against various test cases, which helped in debugging our code and formulating it in a much more generalized manner.” Amrith V

“I like that you receive feedback immediately, which makes it much easier to find problems in your code... I learned a lot from the MATLAB assignments in a relative short period.” Ruud S.



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Distance Learning Community

Distance Learning Community


[MATLAB Central](#) | [Home](#) | [Explore](#) | [Contribute](#) | [My Activity](#)


Online Teaching with MATLAB and Simulink

Whether you are transitioning a classroom course to a hybrid model, developing virtual labs, or launching a fully online program, MathWorks can help you foster active learning no matter where it takes place.

[» Learn more](#)

Tip of the Week

DT [Tip of the Week – View version history for problem content in MATLAB Grader](#) 0

Latest Activity by Div Tiwari on 17 Sept 2021 at 19:22

Tags: [tip_of_the_week](#), [matlab_grader](#), [distance_learning](#) replies

[» View all tips](#)

Discussions

[Start a discussion](#)

DT [Tip of the Week – View version history for problem content in MATLAB Grader](#) 0

Latest Activity by Div Tiwari on 17 Sept 2021 at 19:22

Tags: [tip_of_the_week](#), [matlab_grader](#), [distance_learning](#) replies

DT [Tip of the Week - Use Live Editor on iOS and Android devices with MATLAB Mobile](#) 0

Latest Activity by Div Tiwari on 10 Sept 2021



Welcome to the Distance Learning Community

Moderator:
[Jiro Doko](#)

This is a world-wide community for educators who are teaching remotely or online using MathWorks tools. It houses resources, such as articles, code examples, and videos, as well as an area where community members can ask questions or hold discussions around best practices in distance learning.

[Share](#) [Tweet](#) [Share](#)

Additional Resources

- [MATLAB Online](#)
- [MATLAB Drive](#)
- [MATLAB Mobile](#)
- [Online Training](#)
- [MATLAB Grader](#)

<https://www.mathworks.com/matlabcentral/topics/distance-learning.html>

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Curriculum Materials developed by MathWorks and Educators from Leading Universities

Featured Courseware

Explore interactive teaching content and examples developed by MathWorks and educators from leading universities.

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

Virtual Labs



MECHANICAL AND ELECTRICAL ENGINEERING

Robo Ninja Warrior

Paul Ruvolo, Olin College

Module that teaches math, physics, and engineering and applying them to programming a mobile robot

Includes: Code, Assignments



MECHANICAL AND ELECTRICAL ENGINEERING

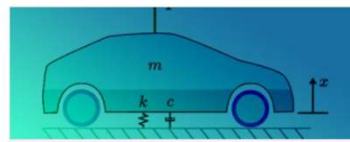
GUI for Vibrations and Control Theory

Ayşe Tekes, Kennesaw State University

Virtual equipment for conceptual laboratory demonstrations of dynamics, vibrations, and control theory

Includes: Models

Interactive Examples



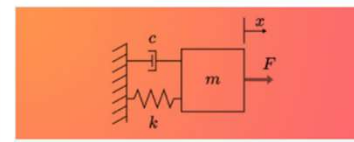
MECHANICAL, AEROSPACE, AND CIVIL ENGINEERING

Mass-Spring-Damper Systems

MathWorks

MATLAB live scripts and Simulink models that explore mass-spring-damper systems

Includes: Code, Models, Assignments



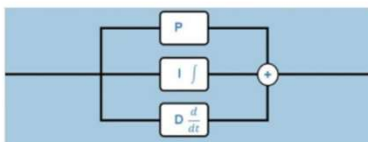
MECHANICAL, ELECTRICAL, AND AEROSPACE ENGINEERING

Control Tutorials for MATLAB and Simulink

Richard Hill, University of Detroit Mercy

Live script examples using MATLAB for the analysis and design of automatic control systems

Includes: Code



MECHANICAL AND ELECTRICAL ENGINEERING

Duino-Based Learning



MECHANICAL AND ELECTRICAL ENGINEERING

Modeling, Analysis, and Control of



MECHANICAL, ELECTRICAL, AND AEROSPACE ENGINEERING



MECHANICAL AND ELECTRICAL ENGINEERING

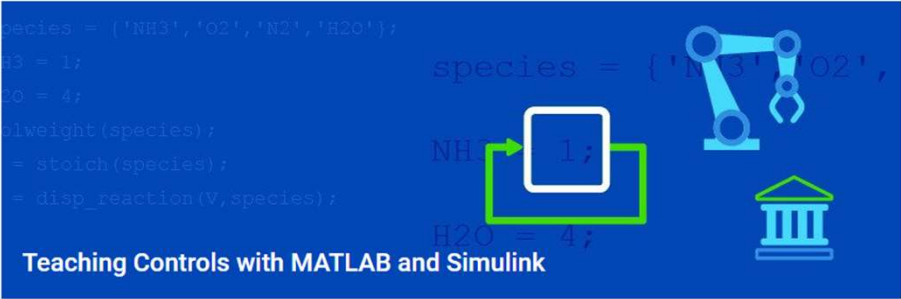
Transfer Function Analysis of Dynamic

Controls Resources for Instructors

- Course curricula
- Virtual labs
- Educational videos
- Textbooks
- Onramps

Search MathWorks.com
Educators

Teach with MATLAB and Simulink | Curriculum Resources ▾ | Online Teaching ▾ | Campus-Wide License ▾



Teaching Controls with MATLAB and Simulink

Educators teach controls with MATLAB and Simulink by drawing on available course modules, onramp tutorials, and code examples.

Apps provided with Control System Toolbox let users interactively design and analyze control systems as well as graphically tune PID controllers and lead/lag compensators using root locus, Bode diagrams, and Nichols charts. Educators can use MATLAB live scripts to create lectures that combine explanatory text, mathematical equations, code, and results. Live Editor tasks that can be inserted into live scripts let students perform control design tasks, such as tuning PID controllers, interactively.

Below is a sampling of course curricula, textbooks, educational videos, code examples, online labs, and additional tools for teaching controls with MATLAB and Simulink.

<https://www.mathworks.com/academia/courseware/teaching-controls-with-matlab-and-simulink.html>


Virtual Labs and Projects with MATLAB and Simulink

Educators

Teach with MATLAB and Simulink ▾
Curriculum Resources ▾
Online Teaching ▾
Campus-Wide License ▾

Online Laboratories

Use MATLAB and Simulink to teach virtual or remote labs, or teach with hardware kits. As the format of lab activities varies between topics, MATLAB and Simulink contain tools to support your instruction by deploying apps, streaming data from your [hardware](#), and utilizing [mobile devices](#).




Virtual

Simulates a process, test, apparatus, or other activity.

Examples:

- [Air Track Collisions Lab for Physics](#)
- [Quanser Interactive Labs](#)




Remote

Campus-based hardware is accessed, viewed, or operated.

Examples:

- [Analyzing vehicle traffic with ThingSpeak](#)
- [Robotarium remote-access robotics lab](#)



Hardware at Home

Students use kits or mobile devices, or collect data.

Examples:

- [Arduino Engineering Kit](#)
- [Classifying images using deep learning with MATLAB Mobile](#)

<https://www.mathworks.com/academia/online-teaching/virtual-labs.html>

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Contact us for questions on MathWorks controls teaching resources

- Melda Ulusoy
mulusoy@mathworks.com
- Craig Buhr
cbuhr@mathworks.com