Modern Control

ECE 463 - Modern Control

Jake Glower - Lecture #0

Please visit Bison Academy for corresponding
lecture notes, homework sets, and solutions

Feedback

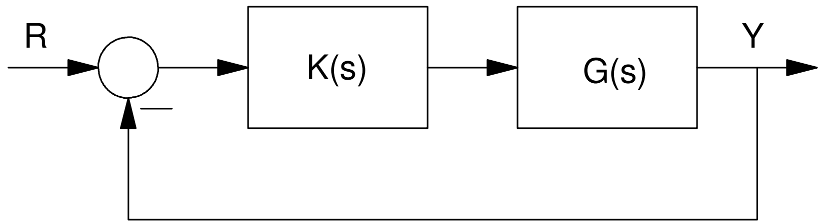
Feedback is very useful

- Instead of specifying the input, you specify the desired output
- It can improve the response of a system
- It can turn an unstable system into a stable system (closed-loop)

ECE 461: Classic Control

One solution: Use output feedback

- G(s) is the plant
- K(s) is a pre-filter, making a poorly behaving system behave like a well-behaved system



Tools for finding K(s)

- Root Locus
- Nichols Charts
- Bode Plots

Sometimes, classic control works very well

- Controlling DC motors
- Controlling temperature
- Controlling water flow

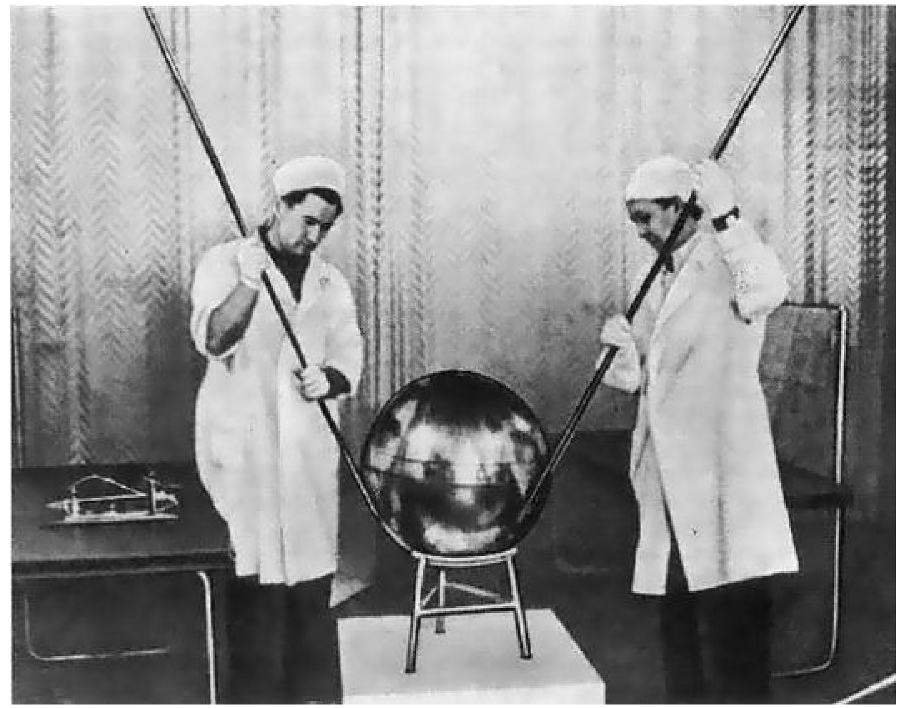
Sometimes, Classic Control doesn't

- Rockets
- Systems with multiple unstable poles

Sputnik & Modern Control

https://theinvisibleagent.files.wordpress.com/2011/09/sputnik3.jpg

While NASA was struggling to get a rocket into space, the Soviet Union placed a satellite into orbit in 1957



This was a major shock to the U.S.

- Russia was ahead of the U.S.

This led to researchers looking at Soviet technical journals to learn how the Soviets stabilize their rockets

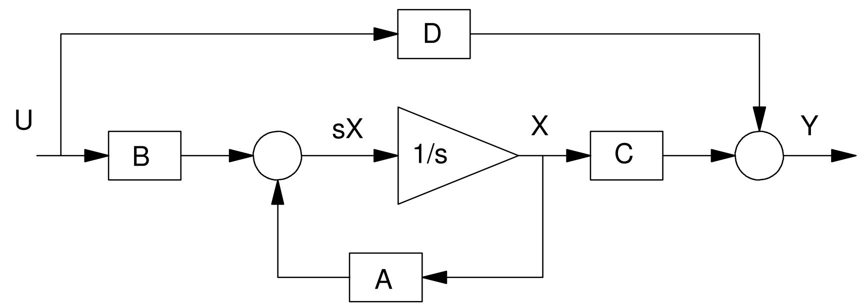
- The techniques used is termed "Modern Control"

Modern Control (ECE 463/663)

- A matrix approach to designing feedback control systems

Let X define the energy in the system

- X = [position, velocity, ...]
- potential energy, kinetic energy, ...



If you specify how the energy moves around, you've specified the dynamics

$$sX = AX + BU$$

$$Y = CD + DU$$

Modern vs. Classical Control

The transfer function from U to Y is

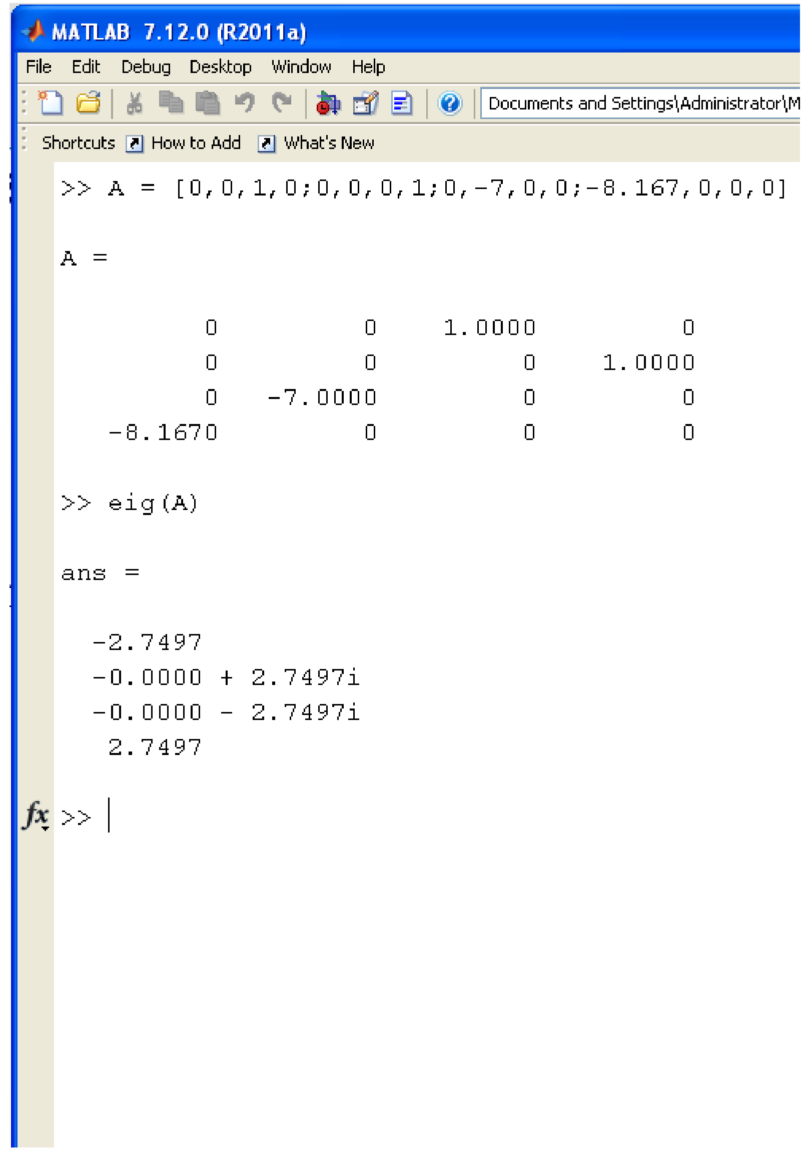
$$Y = \left(C(sI - A)^{-1} B + D \right) U$$

$$G(s) = C(sI - A)^{-1} B + D$$

The eigenvalues of A are all important

- Eigenvalues = Poles
- Negative definite = stable
- Positive real = unstable
- Complex = oscillatory

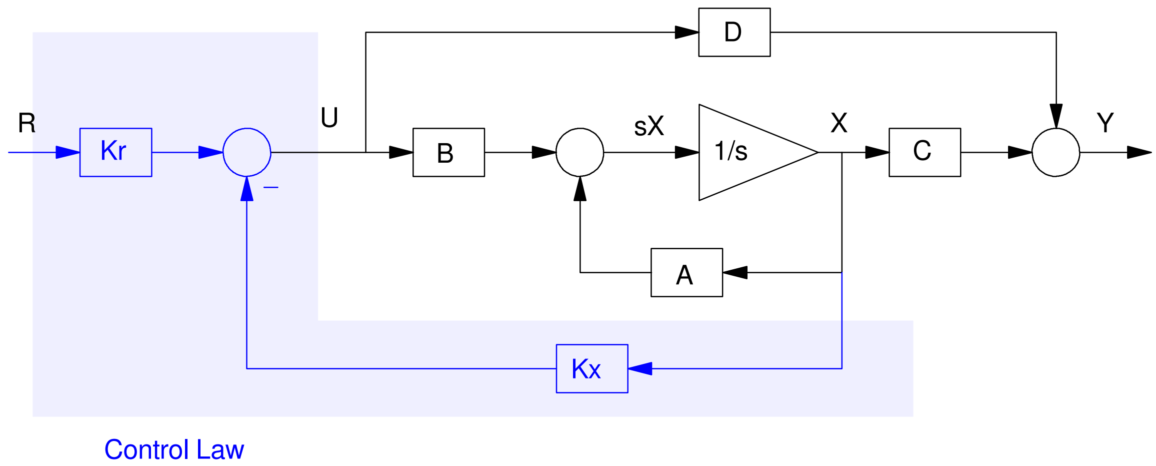
If you can shift the eigenvalues of A, you can change how the system behaves



Full State Feedback

A is an NxN matrix

- It has N eigenvalues
- It has N poles



If you define U as

$$U = -K_x X + K_r R$$

the dynamics become

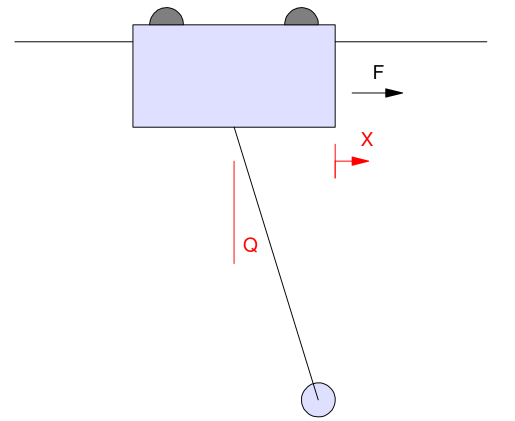
$$sX = (A - BK_x)X + BK_r R$$

$$Y = CX + DU$$

With Kx, you have N degrees of freedom to place the N closed-loop eigenvalues.

How do you determine the system dynamics?

- Week 1-5 (Test #1)
- LaGrangian formulation

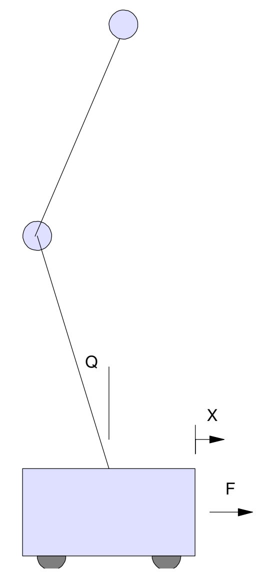


Define the energy in the system

$$L = KE - PE$$

Define how the energy moves about the system

Linearize to determine the state-space model

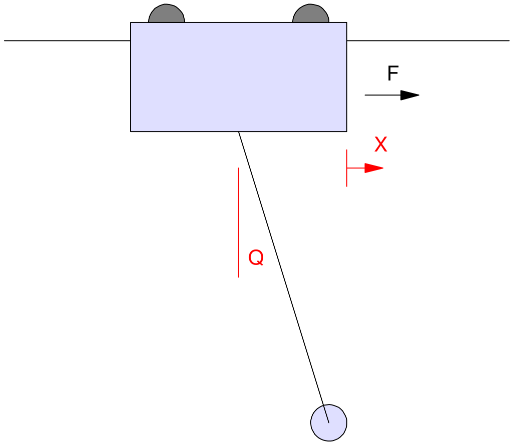


Works for both linear and nonlinear systems

Systems we look at in ECE 463

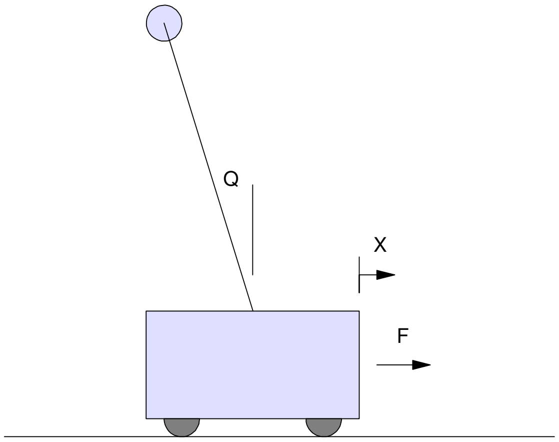
Gantry System

$$x = \left(\frac{2(s+j3)(s-j3)}{s^2(s+j4)(s-j4)}\right)F$$



Cart and Pendulum

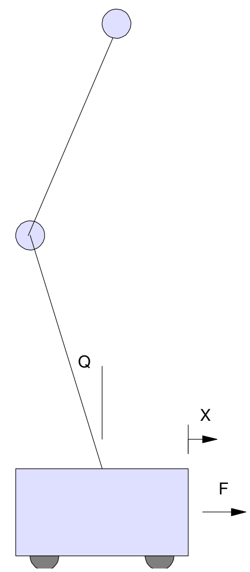
$$x = \left(\frac{2(s+3)(s-3)}{s^2(s+4)(s-4)}\right)F$$



Systems we look at in ECE 463

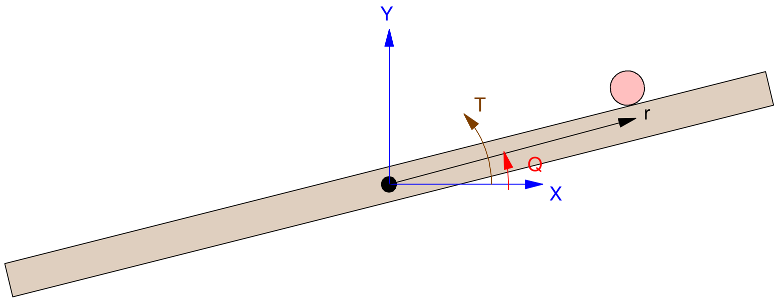
Double Pendulum

$$x = \left(\frac{(s+3.5 \pm j1.5)(s-3.5 \pm j1.5)}{s^2 (s+4.5 \pm j1.5)(s-4.5 \pm j1.5)} \right) F$$



Ball and Beam

$$r = \left(\frac{10}{(s+3)(s-3)(s+j3)(s-j3)} \right) T$$



Problem: How do you determine Kx?

Pole Placement

- **Weeks 6 - 9 & Test #2**

- Bass Gura
- Kx contains N terms
- (A - B Kx) has N eigenvalues
- N equations and N unknowns

Good:

- Complete freedom
- Can place poles anywhere

Bad:

- Complete freedom
- Where *should* you place the poles

Optimal Control

- **Weeks 10-14 & Test #3**

- Based upon Calculus of Variations
- Define a cost function
- $J = f(\text{energy}) + g(\text{input}^2)$
- Determine Kx to minimize J

Good:

- Places all poles in their optimal spot

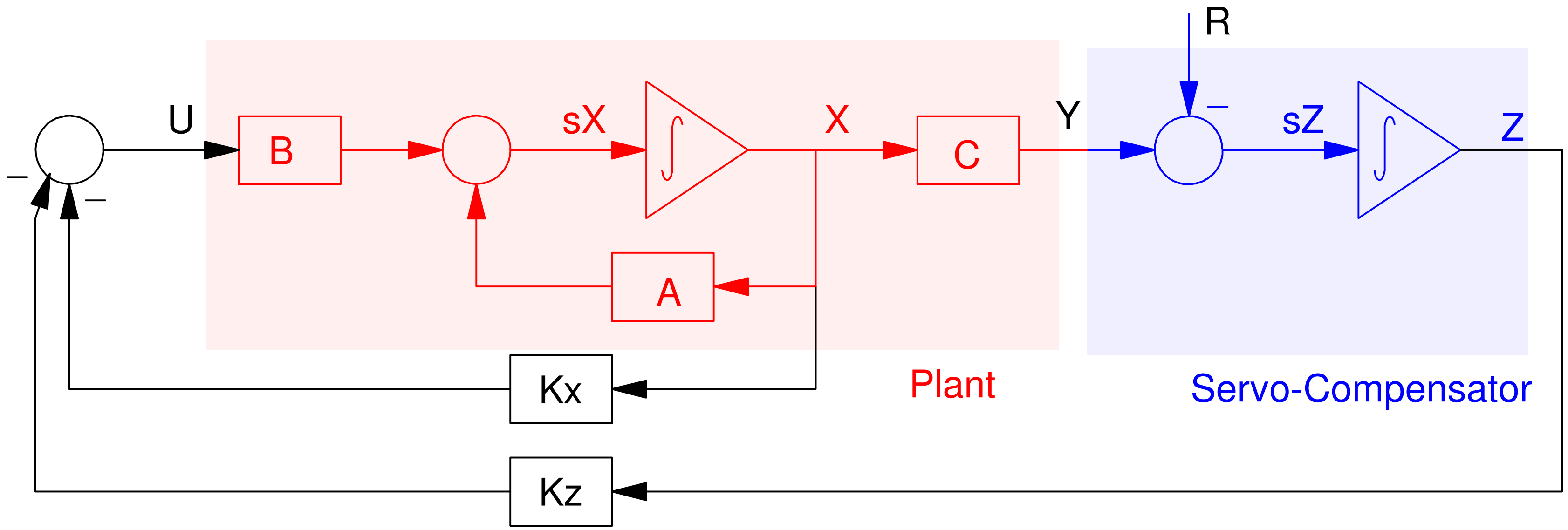
Bad:

- Cost function is arbitrary
- I'd prefer "good control" over "optimal control"
- It's a tool to find Kx

Problem: How to you track a constant set point?

- ECE 461: Make it a type-1 system
- ECE 463: Add a servo compensator

Also allows you to track multiple sine waves

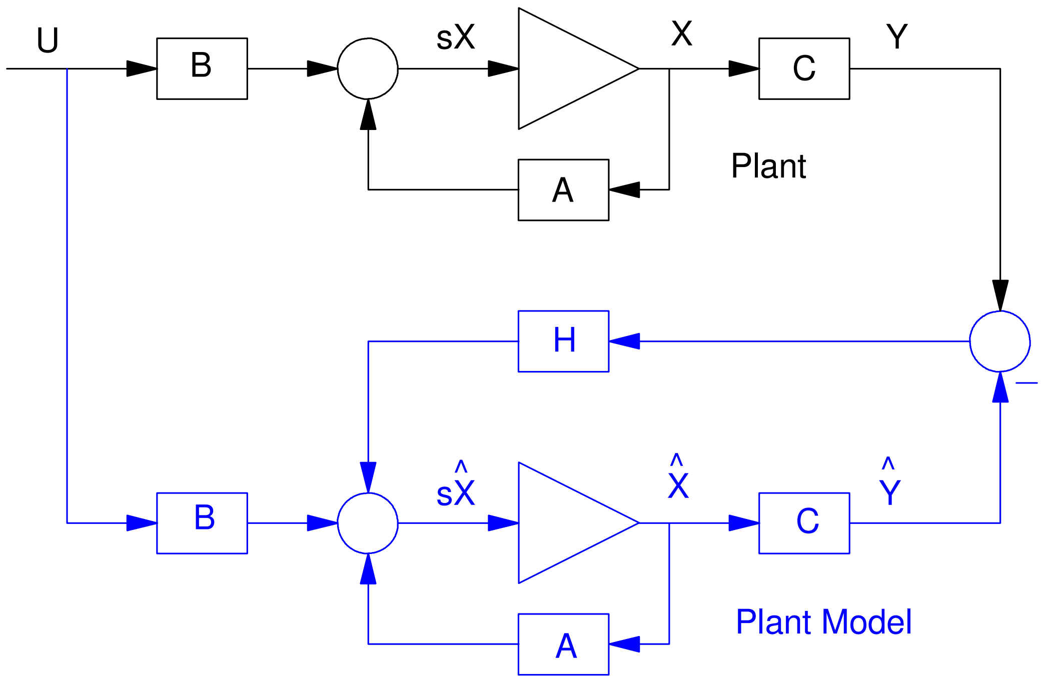


Problem: What if you can't measure *all* of the states?

- Kx contains N terms
- You need to know all N states in X

If you can't measure the states, estimate them from the input and output

- Full-Order Observer



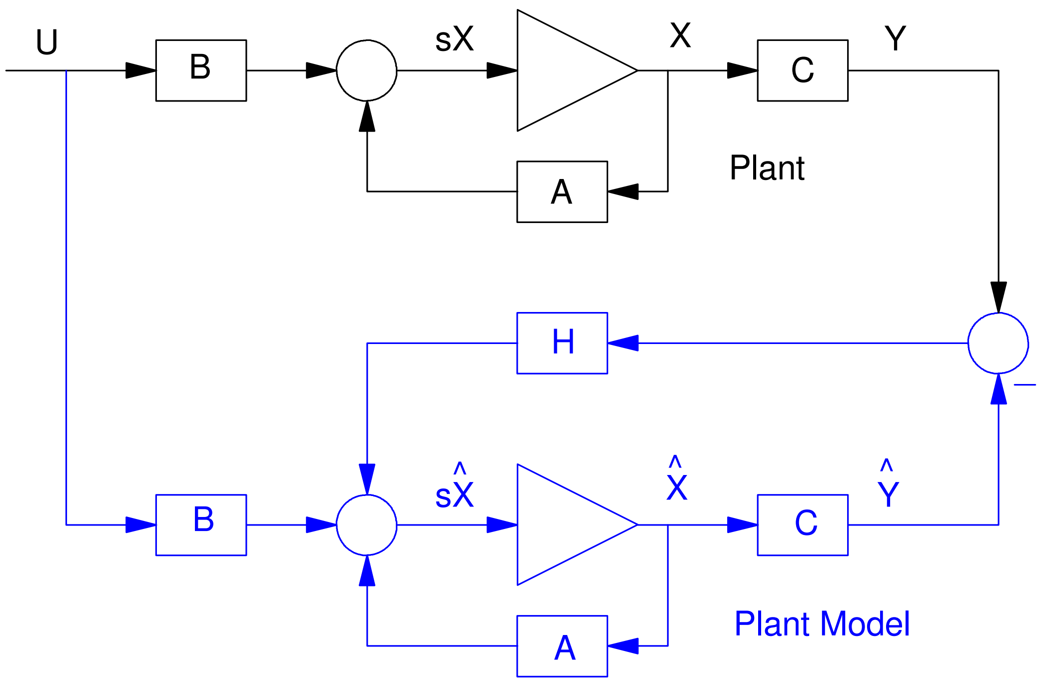
Problem: How do you choose H?

Option #1: Pole Placement

- Bass Gura

Option #2: Optimal Control

- Produces a Kalman Filter
- Optimal H given sensor noise and input noise



ECE 463/663 Web Site

- www.BisonAcademy.com

Syllabus is posted

- Daily lecture topics

All lecture notes are posted

- pdf format

Videos of all lectures are linked

- YouTube videos

Homework Sets are posted

- Solutions posted after due date

BISON ACADEMY

Courses taught in the Department of Electrical and Computer Engineering North Dakota State University

ECE 463/663: Modern Control

Syllabus - Spring 2021

Syllabus - HW & Solutions - Resources - Comments

Instructor: Jacob Glower
Contact Info: jacob_glower@yahoo.com (where to email your homework solutions)
Class Times: MWF 10am, In-Person and on Zoom

Please send homework solutions to Jacob_Glower@yahoo.com with header HWx ECE 463
(or hardcopy or submit on blackboard)

	Date	Topic	Lecture (YouTube)	Code & Handouts	Homework Email solutions to Jacob_glower@yahoo.com Subject: ECE463/663 HWx
M	Jan 11	Holiday	0		HW #1
W	Jan 13	Syllabus MATLAB Review Slides #1	1 Matlab Review		
F	Jan 15	LaPlace Transforms Slides #2	2 LaPlace Xform	2nd Order Approximations Step Responses	
M	Jan 18	Holiday			HW #2
W	Jan 20	State Space Slides #3	3 State Space		
F	Jan 22	Eigenvalues and Eigenvectors Slides #4	4 Eigenvalues	Heat	
M	Jan 25	Canonical Forms & Similarity Transforms Slides #5	5 Canonical Forms		HW #3
W	Jan 27	LaGrangian Dynamics Slides #6	6 LaGrangian Dynamics	Ball	
F	Jan 29	Cart and Pendulum System Slides #7	7	Gantry Gantry Display Gantry Dynamics - Cart Cart Display Cart Dynamics	
M	Feb 1	Ball and Beam System Slides #8	8 Ball and Beam	Beam BeamDisplay BeamDynamics	HW #4
W	Feb 3	Dynamics of a 2-Link Robot Slides #9	9 2-Link Robot	FreeFall 2-Link Dynamics	
F	Feb 5	Dynamics of a Double	10 Double	Gantry2	

Homework Sets & Solutions

Last 4 years posted

- Serves as a reference if you need help with the homework
- Systems and dynamics are different, but the procedure will be similar

Also has sample tests and solutions

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ECE 463/663: Modern Control

Homework and Solutions

Syllabus - HW & Solutions - Resources - Comments

Spring 2019	Spring 2018	Spring 2017	Spring 2016
1: Dominant Poles Solution #1	1: Dominant Poles Solution #1	1: Dominant Poles Solution #1	1: LaPlace Transforms Solution #1
2: State Space Solution #2	2: State Space Solution #2	2: State Space Solution #2	2: Modeling in State Space Solution #2
3: Canonocal Forms Solution #3	3: Canonical Forms Solution #3	3: Canonical Forms Solution #3	3: Canonical Forms Solution #3
4: LaGrangian Dynamics Solution #4	4: LaGrangian Dynamics Solution #4	4: LaGrangian Dynamics Solution #4	4: LaGrangian Dynamics Solution #4
Test #1 Test #1 Solution	Test #1 Test #1 Solution	Test #1	5: Controllability and Observability Solution #5
5: Pole Placement Solution #5	5: Pole Placement Solution #5	5: Pole Placement Solution #5	6: Pole Placement Solution #6
6: Servo Compensators Solution #6	6: Servo Compensators Solution #6	6: Servo Compensators Solution #6	7: Servo Compensators Solution #7
7: Linear Observers Solution #7	7: Observers Solution #7	7: Linear Observers Solution #7	8: Observers Solution #8
Test #2 Solution A : Solution B	Test #2 Test #2 Solution	Test #2 Solutions: A Level □- B Level □- C Level	9: Calculus of Variation Solution #9
8: Calculus of Variations Solution #8	8: Calculus of Variations Solution #8	8: Calculus of Variations Solution #8	10: LQG Control Solution #10
9: Optimal Control Solution #9	9: Optimal Control Solution #9	9: LQG Control Solution #9	11: Kalman Filters

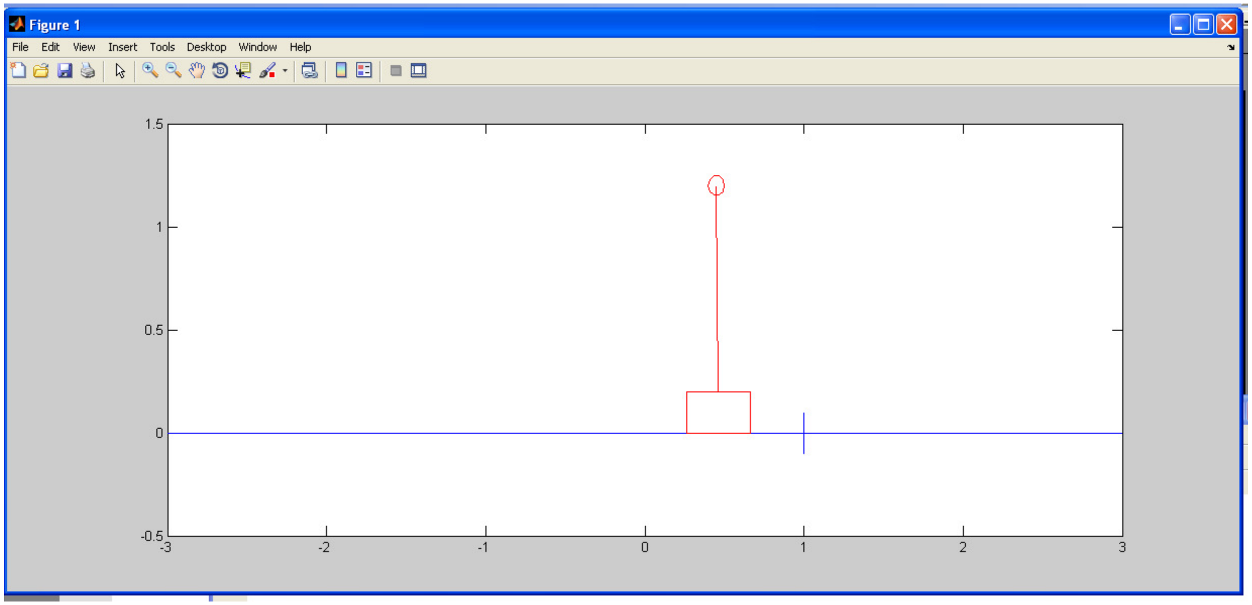
ECE 463: Modern Control

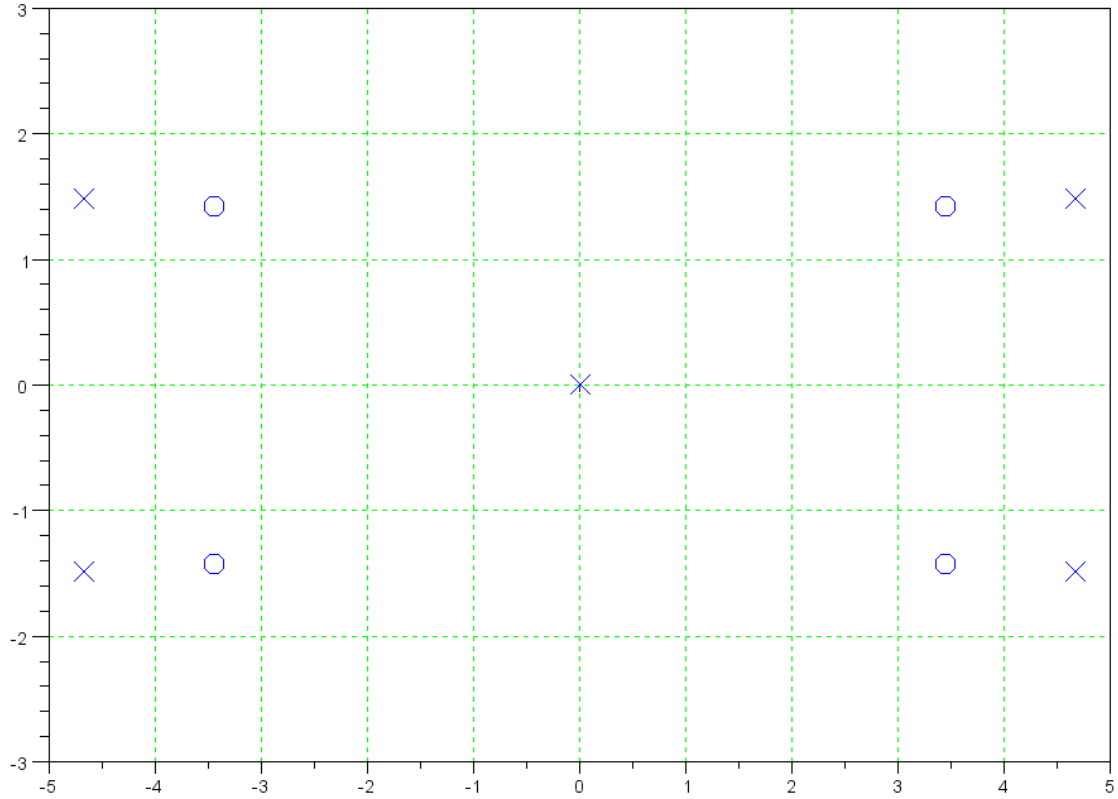
Fun class were we use Matlab extensively

- Simulating nonlinear dynamic systems
- Manipulating NxN matrices

Heavy use of matrix algebra

- We cover what you'll use in this class
- Math 129 is the main class we use

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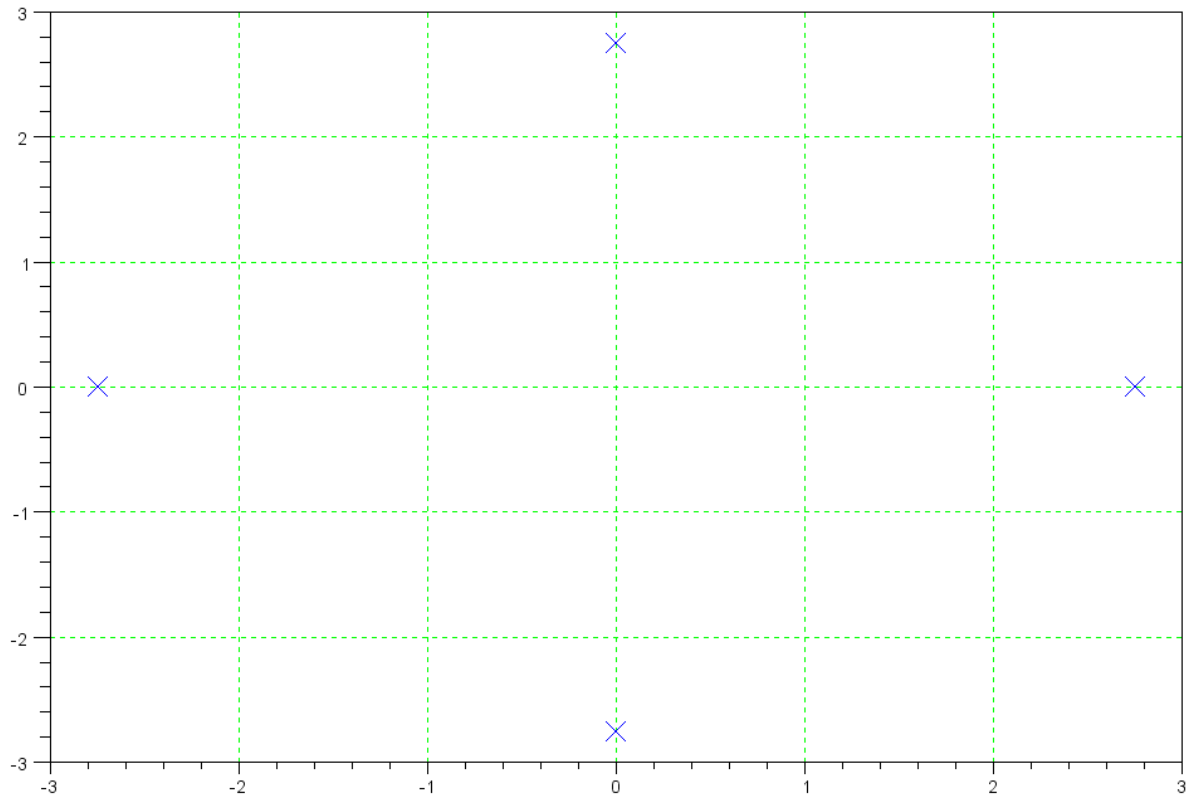
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