EE 419/519: Industrial Control Systems

Lecture 1: Course Information and Overview

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University at Buffalo

Course Information

- **Instructor:** Luis Herrera
- **Contact Info:** 224 Davis Hall, lcherrer@buffalo.edu , 716 645-1150
- **Class Times:** Tu/Th 12:45 pm – 2:00 pm
- **Class Location:** O'Brian 209
- **Office Hours*:** TBA (will send email when decided)
- **TAs/SAs:** TBD
- **Website:** UBLearns blackboard (will upload blank notes prior to class), **please use them to follow along**

Course Description

- Control theory is used in a wide variety of applications, including robotics, power systems, aerospace, etc.

  This course will provide the fundamental knowledge for the analysis and design of control of dynamic systems.

  It will cover modeling techniques using Laplace and time domain methods, state space representation, controllability, observability, static and dynamic feedback design, and linear quadratic regulator.

Grading Policy

- **Homework (40%)**
  - The homework can be considered small projects (4-5 total)
  - Most will use Matlab, Simulink may also be used
  - HW can be hand-written although extra credit will be given if you use Latex

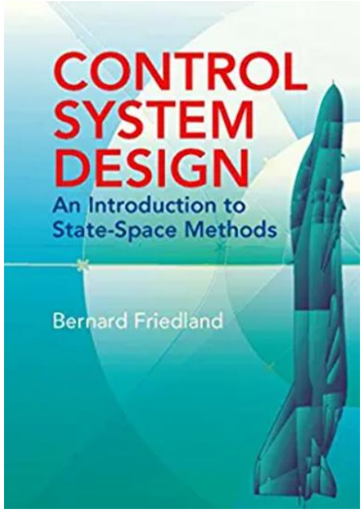
- **Quizzes (10%):** approximately 7-10, 20 mins quizzes

- **Midterm (25%):**

- **Final Exam (25%)**

Course Materials

- **Textbook (optional):**
  - B. Friedland, "Control system design: an introduction to state-space methods," Courier Corporation, 2012.
- **Software**
  - Matlab (m-files) and Simulink
- **Other useful references:**
  - R. Dorf and R. Bishop, "Modern control systems." Pearson, 2011 **(useful for frequency domain techniques).**
  - G. Franklin, et al. Feedback control of dynamic systems. Vol. 4. Upper Saddle River, NJ: Prentice hall, 2002 (**good introduction to digital/discrete control)**
  - H. Khalil, Nonlinear Systems, 3rd Ed., Patience Hall, 2002 (**nonlinear control)**



Tentative Topics

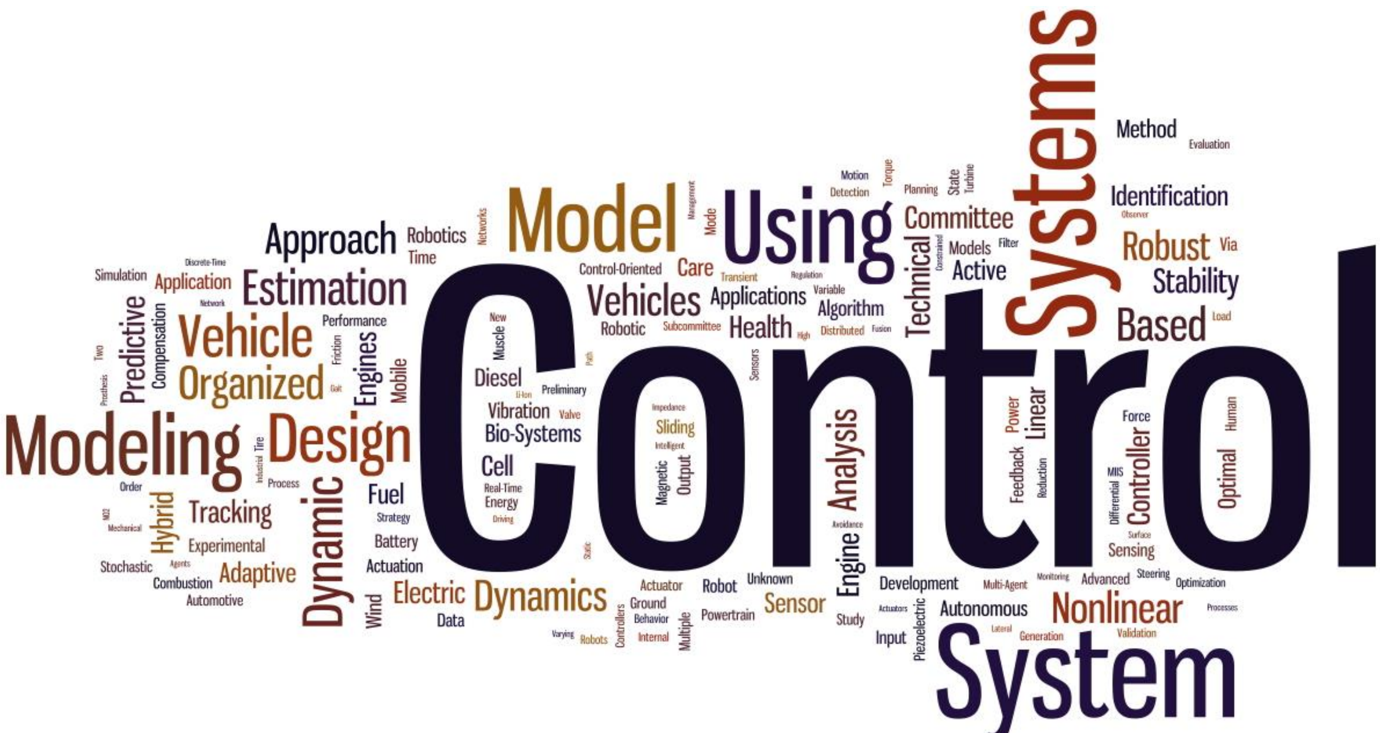
- **Introduction and Motivation**
- **Dynamic Systems Modeling**
  - Time domain (differential equations, state space)
  - Frequency domain (Laplace transform)
- **Frequency Domain Analysis**
  - Characterization of dynamic behavior
  - Stability
  - Root locus
  - Bode plots, gain margin/phase margin
  - P, PI, control
- **State Space Modeling and Solution**
  - Transfer function to state space
  - Jordan canonical form
- **Controllability and State Feedback**
- **Observability and Observer Design**
- **Dynamic Feedback - Separation Principle**
- **Advanced topics (Optimal control/LQR, Kalman Filter, nonlinear control)**

Today

- We will mainly look at an overview of the topics we will cover in class
- Motivation for control systems
- Overview of applications

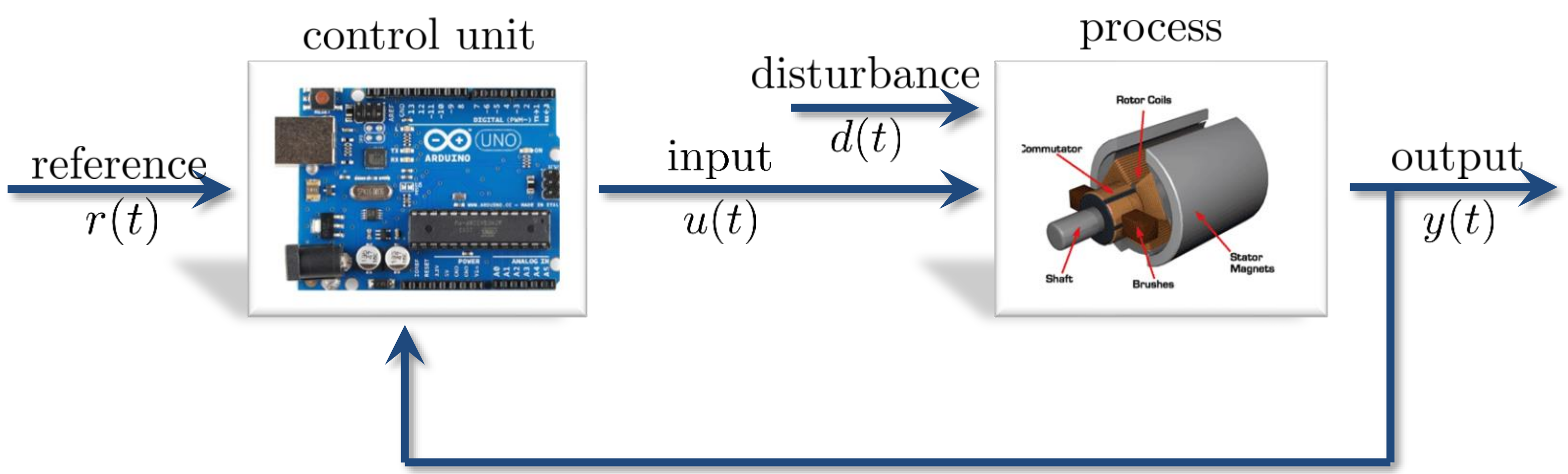
What is control systems?

- Control theory is a discipline that involves rigorous mathematical analysis
- It deals with the control of **dynamical systems**
- We will derive/obtain a mathematical model of the system and use the inputs to make the system behave in a certain way
- We will deal with **model-based control systems**



What is Control?

- Control engineering is a discipline that applies automatic control theory to design systems with desired behaviors in control environment
  - How to control the inputs $u(t)$ to the process automatically to make the output $y(t)$ track the given reference $r(t)$?
  - How to exploit the emeasurements of $y(t)$ to track the reference $r(t)$ in spite of disturbances $d(t)$ acting on the process?



A. Bemporad, Lectures on automatic control, 2011

Example 1: Cruise Control

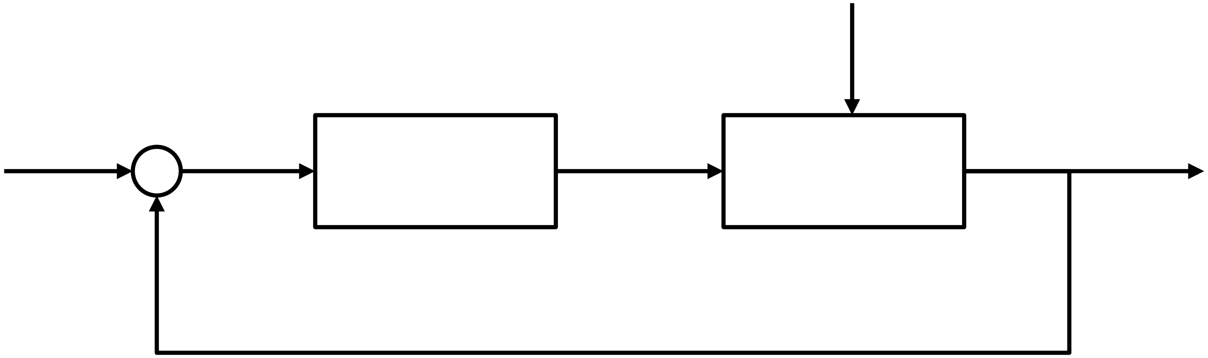
- One of the most common examples of control is **cruise control**
- Cruise control automatically adjusts the speed of the vehicle to a desired reference
- How does it work?

Example 2: Temperature Control

- How does a thermostat control the temperature to a desired value?
- Suppose that we would like to **cool** a room to 75^o F

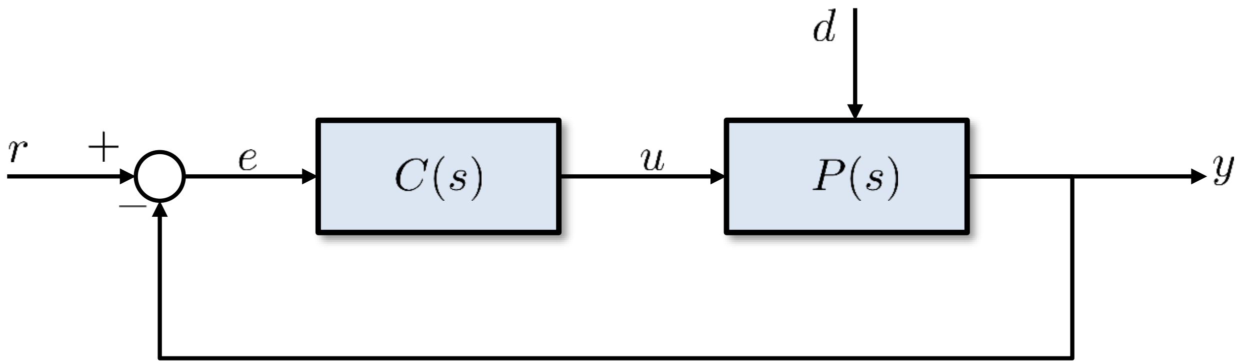
Components of a Feedback Control System

- What is typically involved in a feedback control system?



Goals of Control Systems

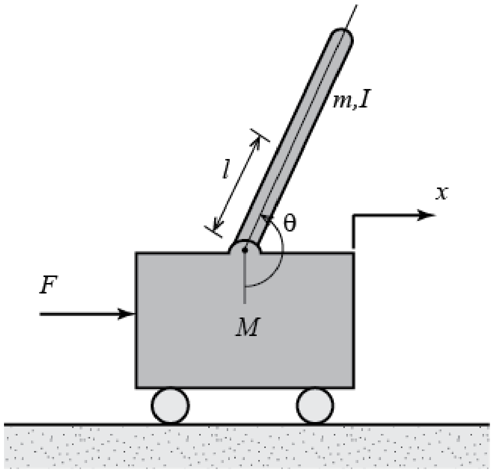
- There are many reasons to design a controller:
  - **Stabilize** the system (system may be unstable)
  - **Regulation/tracking** of output (s) to a reference (s)
  - Mitigate the impact of disturbances (**disturbance rejection**)



Why is control needed?

- Some systems are naturally **unstable**, can we think of any?

  - Inverted pendulum



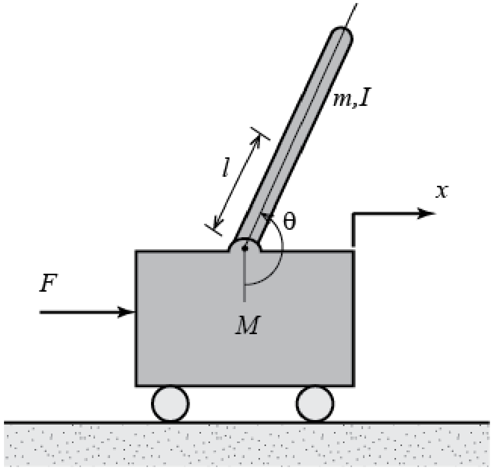
$$(M+m)\ddot{x} + b\dot{x} + ml\ddot{\theta}\cos(\theta) - ml\dot{\theta}^2\sin(\theta) = F$$

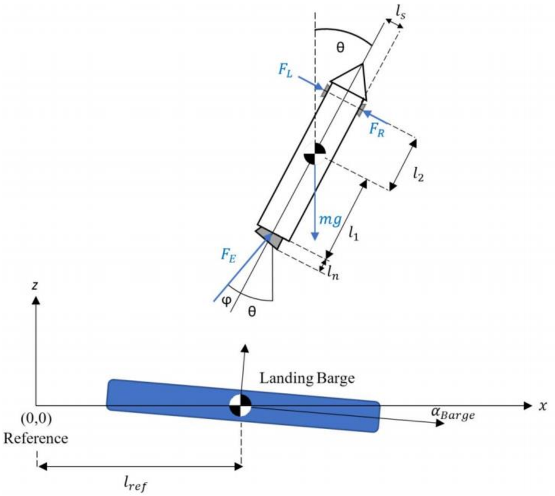
$$(I+ml^2)\ddot{\theta} + mgl\sin(\theta) = -ml\ddot{x}\cos(\theta)$$

  - Are there any real world applications of this?

Why is control needed?

- Some systems are naturally **unstable**, can we think of any?
- Inverted pendulum dynamics/control are very similar to a rocket



Why is control needed?

- Similarly, some airplanes are inherently **unstable**

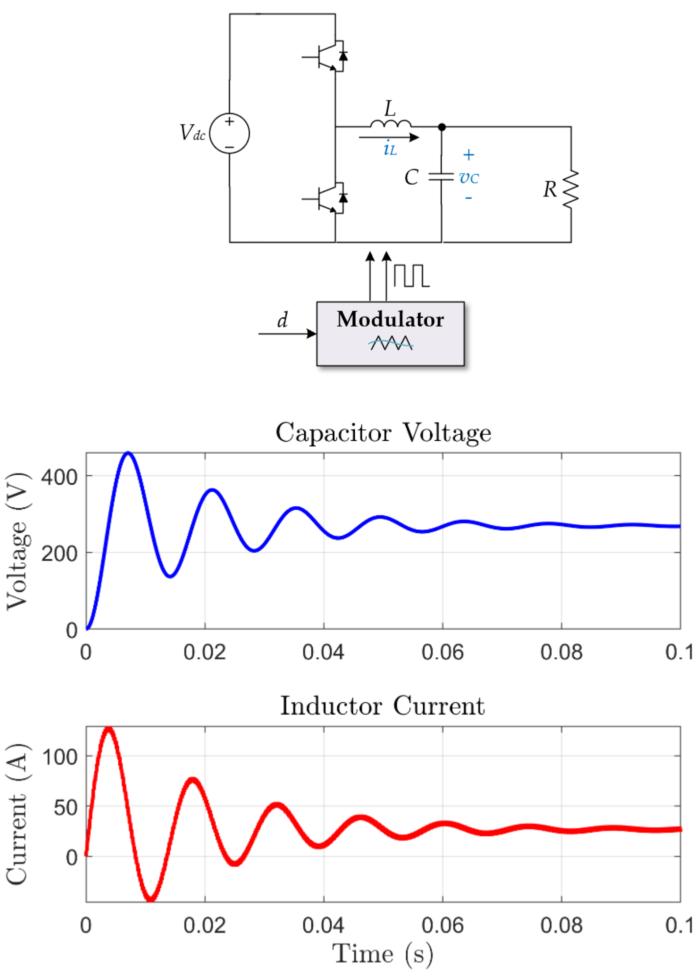
X-29

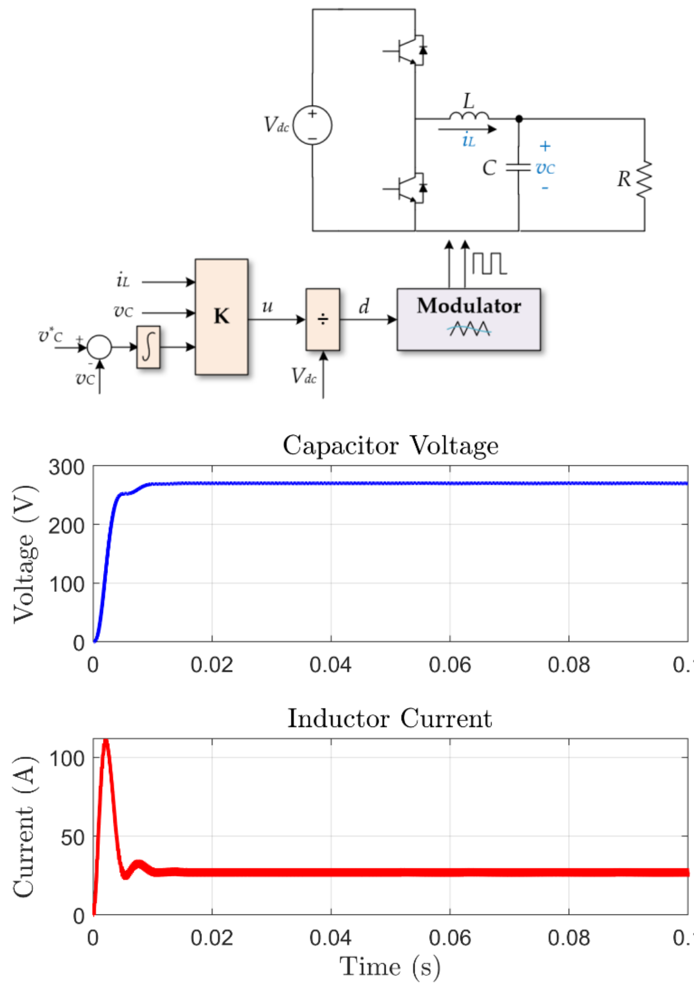
F-117

F-16

Why is control needed?

- Generally, we mainly want to achieve better performance (e.g. faster regulation, less overshoot/undershoot)



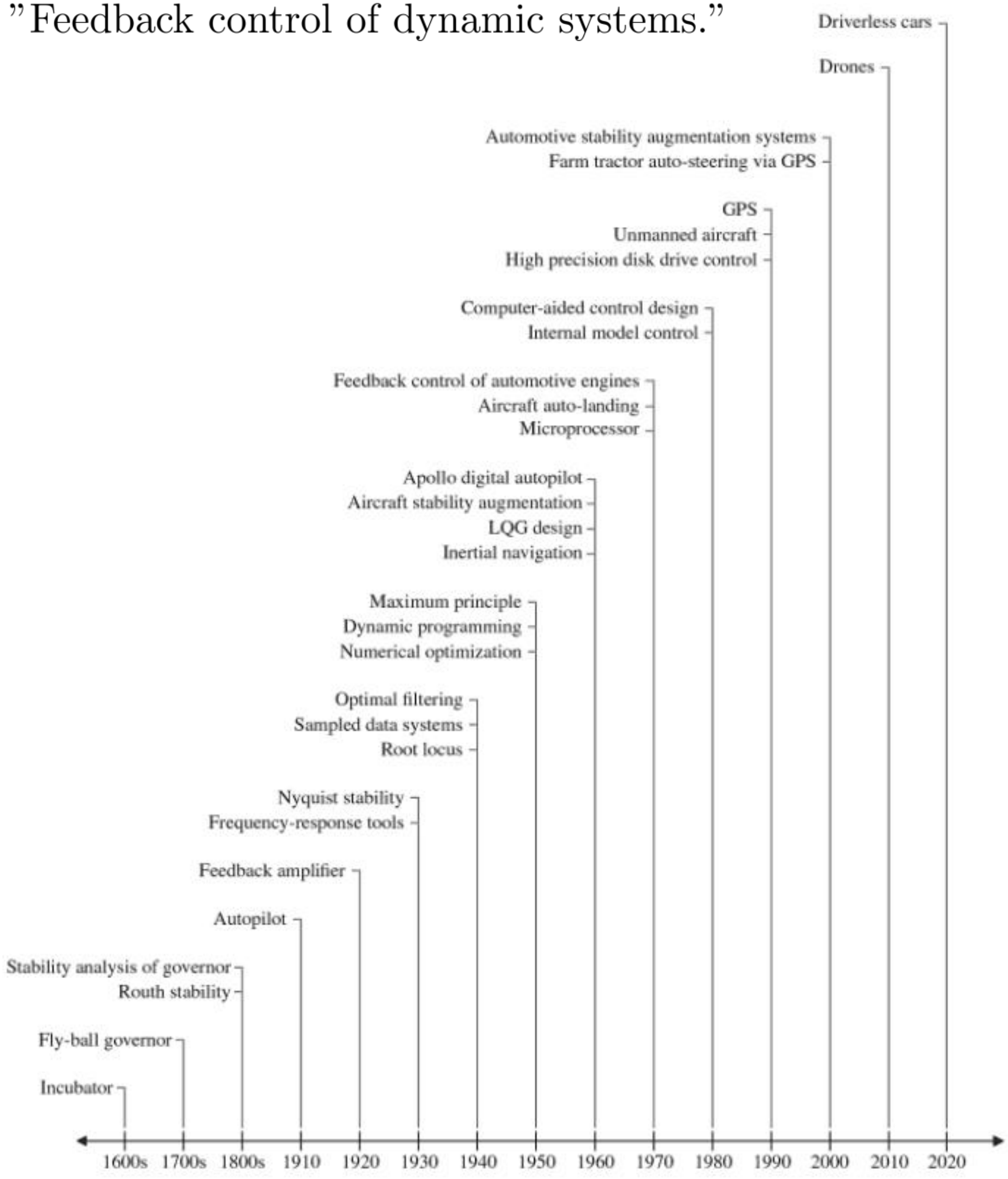


Applications of Control Systems

- Control theory/systems are found almost everywhere
  - Robotics
  - Automotive
  - Aeronautics and aerospace
  - Power systems and power electronics
  - Spacecraft
  - ⋮

History of Control Systems

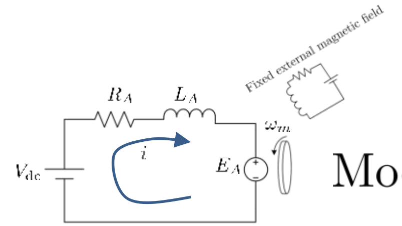
- Good overview by G. Franklin, "Feedback control of dynamic systems."



Classical vs Modern Control Systems

- Frequency (Laplace) domain analysis of feedback systems falls under **classical control**
- Time domain, in particular state space techniques, are generally known as **modern control systems**

Classical control (1900s-1950s)



Modern control (1960s-present)

$$\boxed{H_1(s) = \frac{I(s)}{V_{dc}(s)} = \frac{Js + K_f}{(JL_a)s^2 + (JR_a + K_f L_a)s + (K^2 + K_f R_a)}}$$

$$\boxed{H_2(s) = \frac{\omega(s)}{V_{dc}(s)} = \frac{K}{(JL_a)s^2 + (JR_a + K_f L_a)s + (K^2 + K_f R_a)}}$$

$$\frac{di}{dt} = \frac{-R_A}{L_A} i - \frac{K}{L_A}\omega_m + \frac{1}{L_A} V_{\rm dc}$$

$$\frac{d\omega_m}{dt} = \frac{K}{J} i - \frac{K_f}{J}\omega_m - \frac{1}{J}\tau_{\rm load}$$

$$\boxed{\begin{aligned} \dot{x} &= Ax + Bu + P\tau_{\rm load} \\ y &= Cx \end{aligned}}$$

Transfer functions, SISO, frequency response methods, tracking and regulation, etc.

State space models, MIMO, Linear Algebra, etc.

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