INTRODUCTION TO PROCESS CONTROL

Course Overview

UNIVERSITY OF WATERLOO

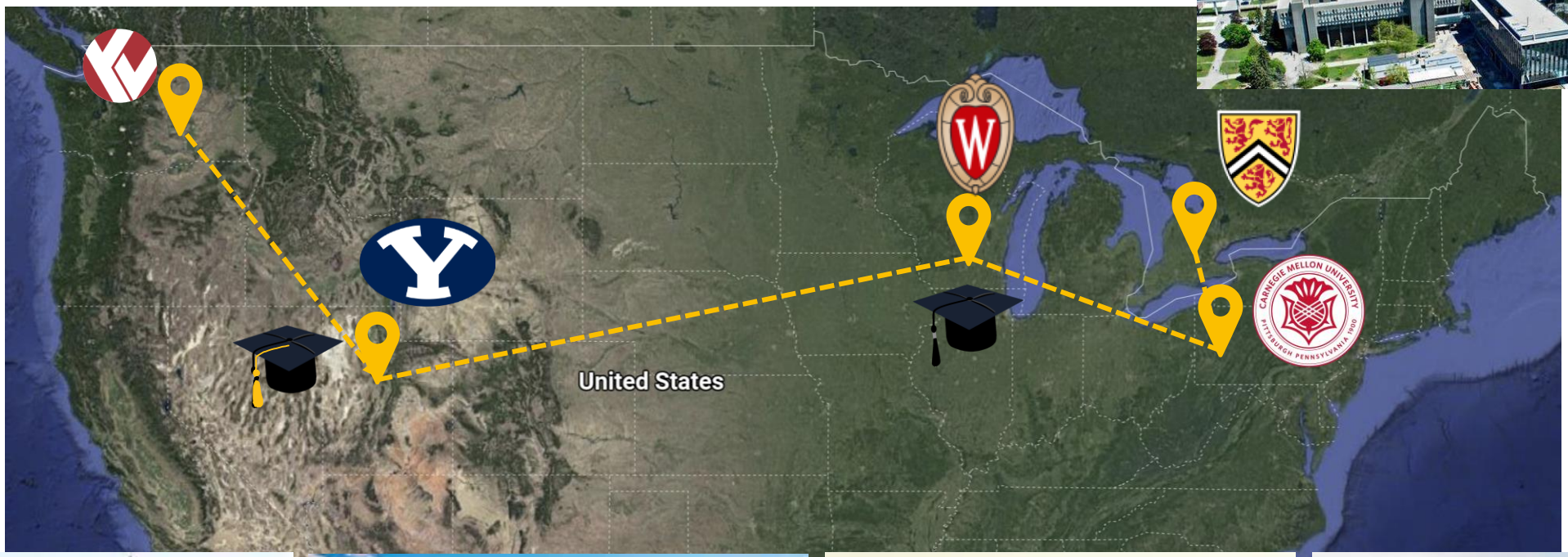
ABOUT THE INSTRUCTOR

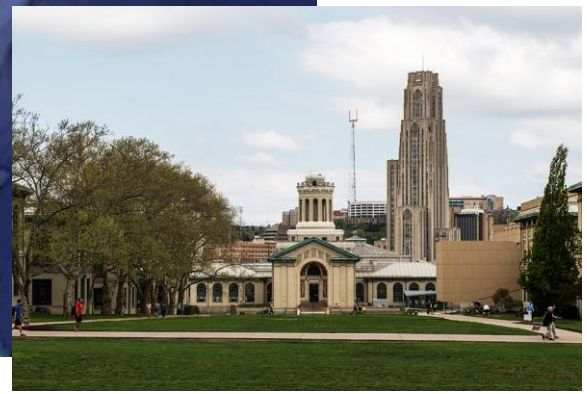
The who

ABOUT ME

- Grew up “mostly” in Washington state
- Oldest of 3 brothers
- Enjoy snow skiing, scuba diving, swimming, flying planes, guitar playing, & good food
- Lived in Perú for 2 years
- Married in 2017
- Proud father of Phineas

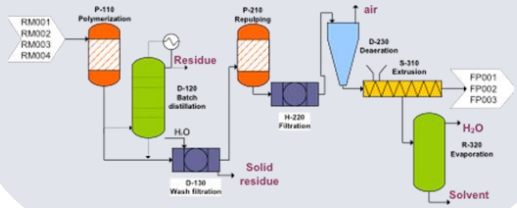
MY ACADEMIC JOURNEY



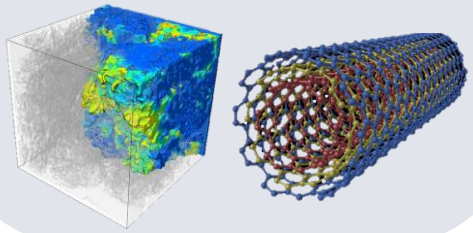


MY RESEARCH: PROCESS SYSTEMS ENGINEERING

Chemical Processes

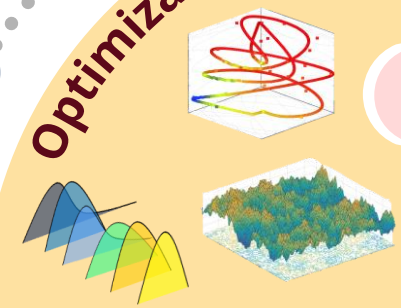


Material Science

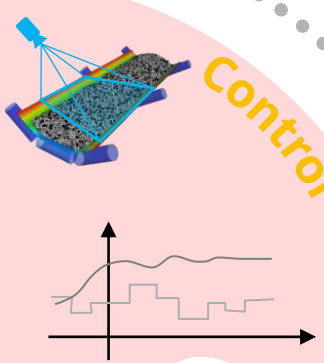


Energy Systems

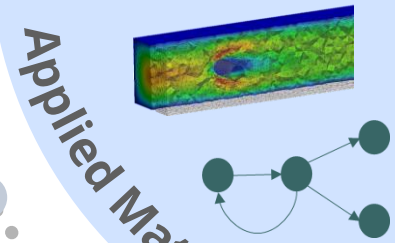
Optimization



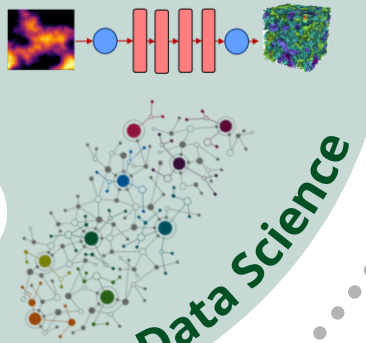
Control



Applied Mathematics

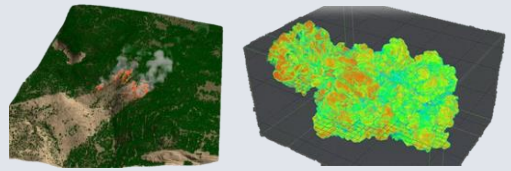


Data Science

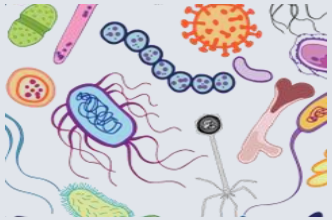


Sustainability

Environmental Science



Biological Systems



julia

python™

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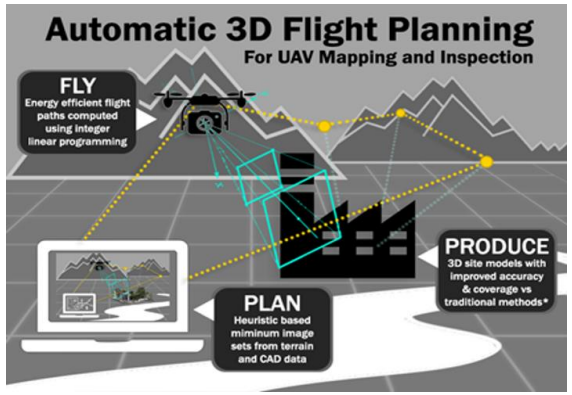
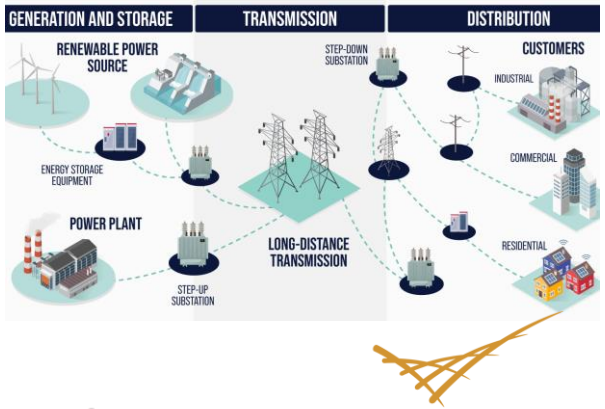
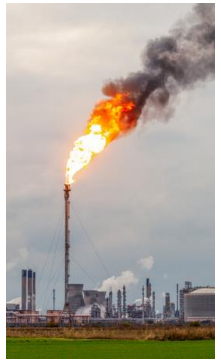
PROCESS CONTROL (AUTOMATION) EXPERIENCE

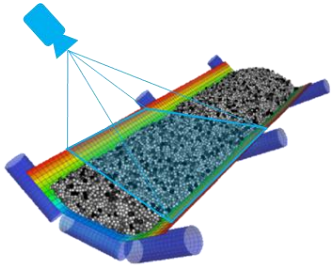


Automated drone inspection for infrastructure monitoring



Robust power grid control and design

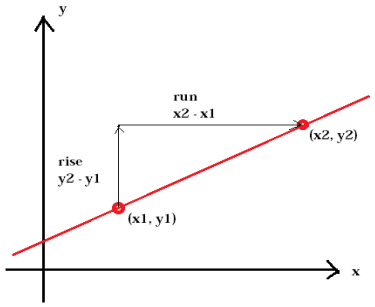




Computer vision aided process control

Controlling treatment of evacuation from wildfires and building fires

TEACHING PHILOSOPHY



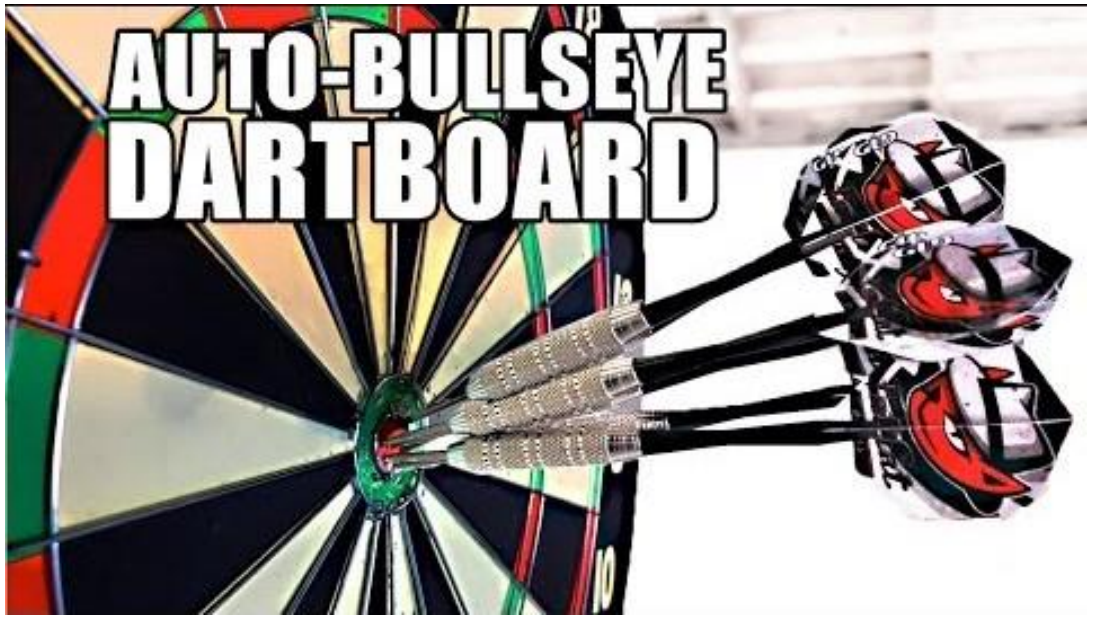
- Growth mindset
  - Mastering a subject is a matter of **effort**
  - Aptitude for a subject is **not innate**
- Active learning
  - True learning requires “struggling with the material”
  - **Deliberate practice**
- Accountability
  - An **individual is ultimately responsible** for their learning

PROCESS CONTROL OVERVIEW

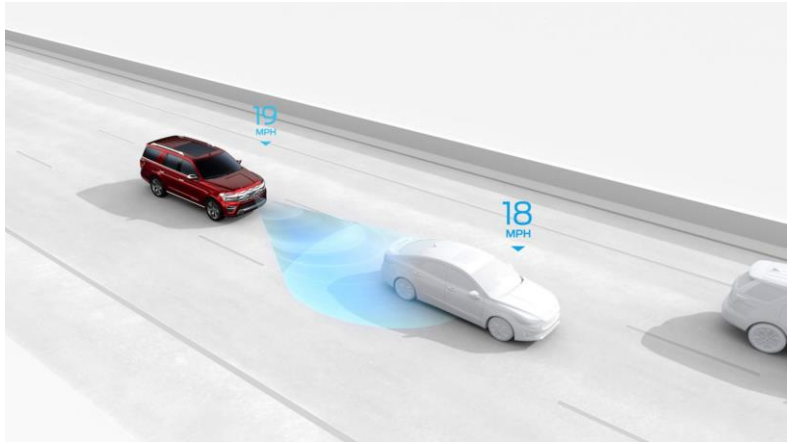
The what and why

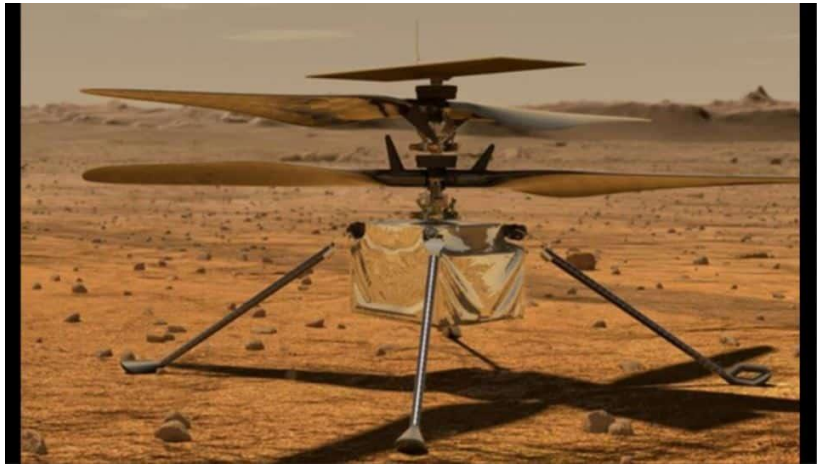
WHAT IS AUTOMATION?

- Technology to manipulate a process/system without direct continued human input based predetermined criteria



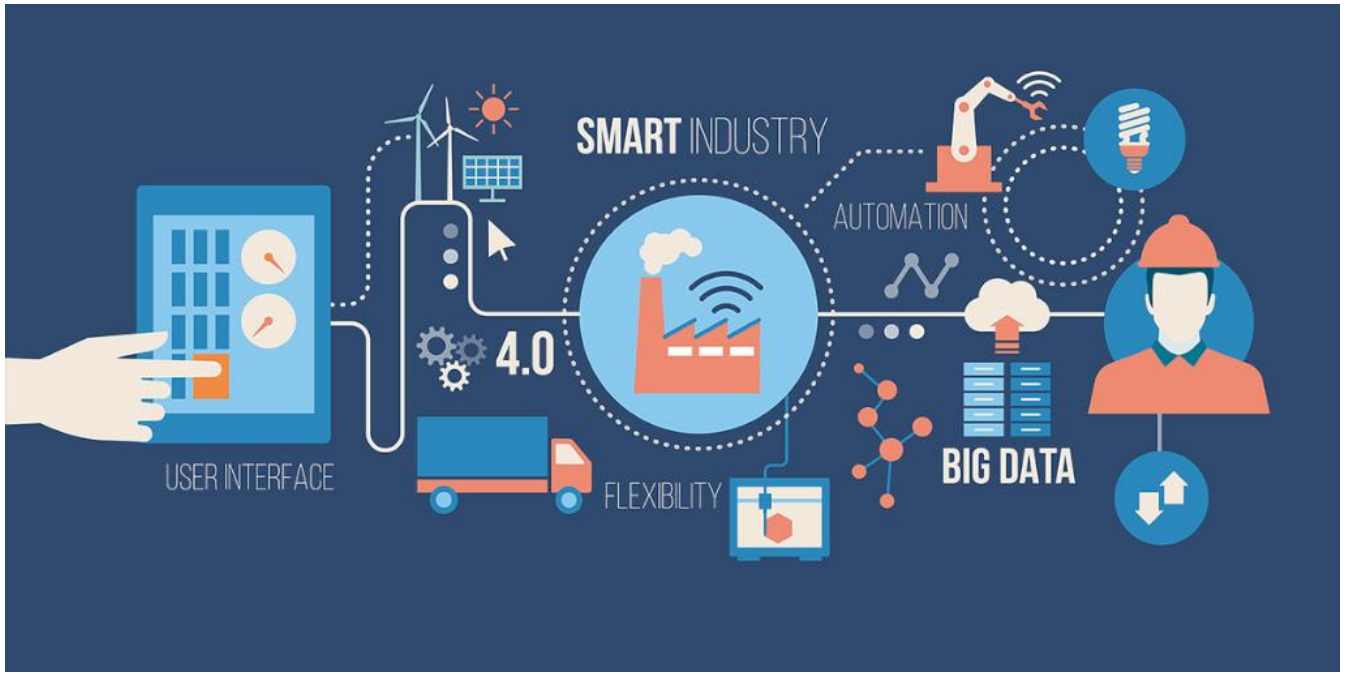
APPLICATIONS





WHAT IS PROCESS CONTROL?

- Use on automation on process systems to maintain desired performance
- Achieve better performance than manual control in terms of
  - Safety
  - Consistency
  - Economy



AUTOMATION AND SAFETY

- Automation can (should) increase safety

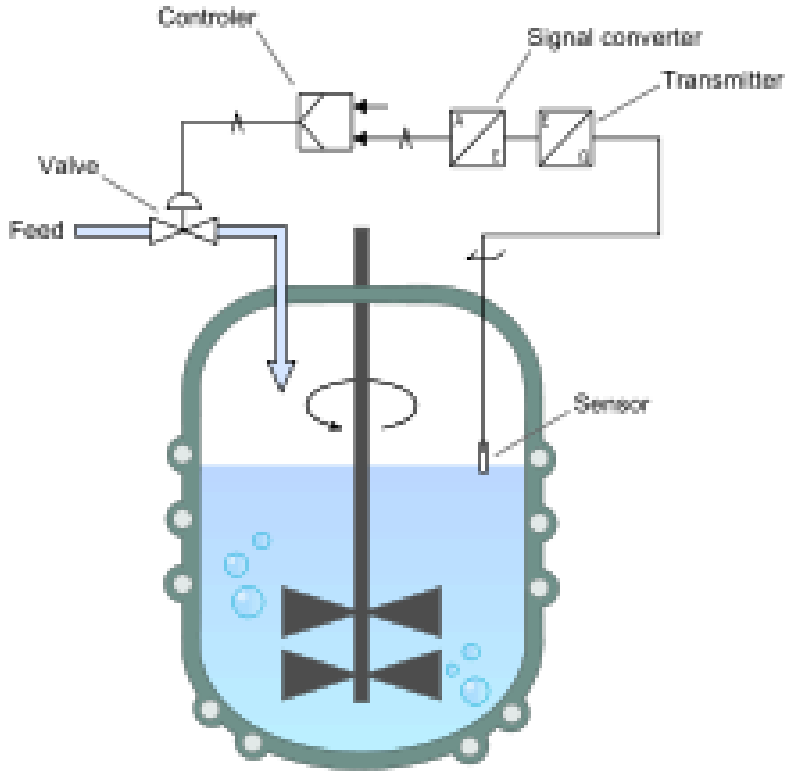
- However, flawed control designs can induce catastrophic consequences

BASIC COMPONENTS OF CONTROL

- System
  - The platform undergoing dynamic behavior
- Sensors
  - Measure quantities to be controlled (PV or MV)
- Actuators
  - The system inputs we can manipulate (OP)
- Controller
  - Automates the use of actuators based on sensor data

DYNAMIC SYSTEMS

- Control theory is all about time-varied behavior
- Inputs
  - Fixed variables
  - Disturbances
  - Manipulated variables (OPs)
- Outputs
  - States
  - Process/controlled variables (PVs)



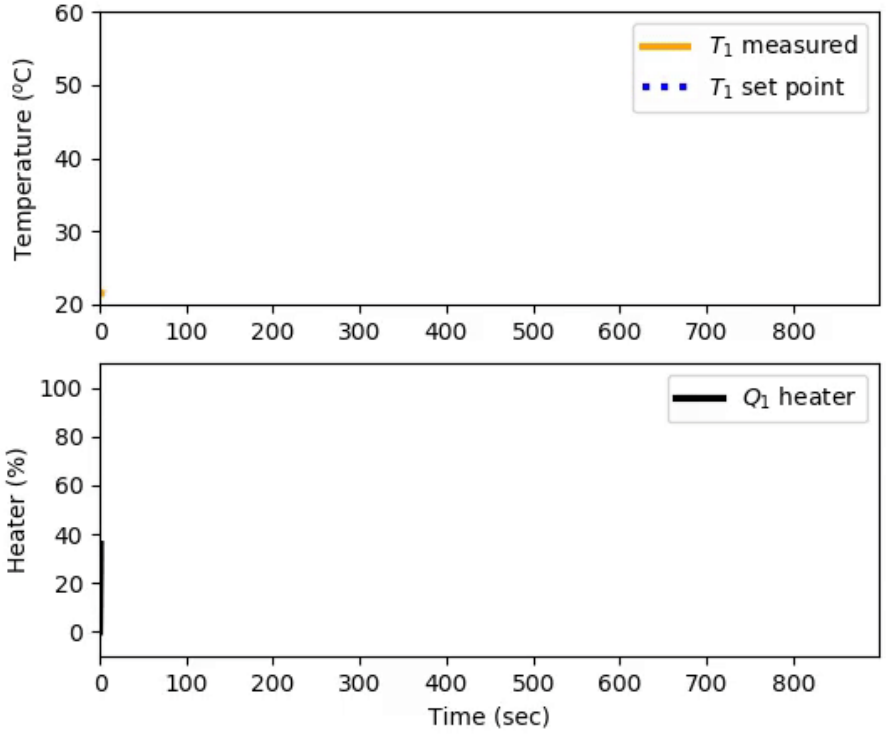
CORE ENGINEERING STEPS

- Dynamic modeling
  - 1st principles model and/or data
  - Reduced model
- Controller design
  - Choose architecture
  - Tune the parameters
- Refinement and analysis

$$\frac{dc_A V}{dt} = \sum c_{A_{in}} \dot{V}_{in} - \sum c_{A_{out}} \dot{V}_{out} + r_A V$$

$$\tau_p \frac{dy(t)}{dt} = -y(t) + K_p u\,(t - \theta_p)$$

$$u(t) = \mathrm{KP}\, e(t) + \mathrm{KI} \int_0^t e(t)dt + \mathrm{KD} \frac{de(t)}{dt}$$



COURSE OVERVIEW

The how, when, and where

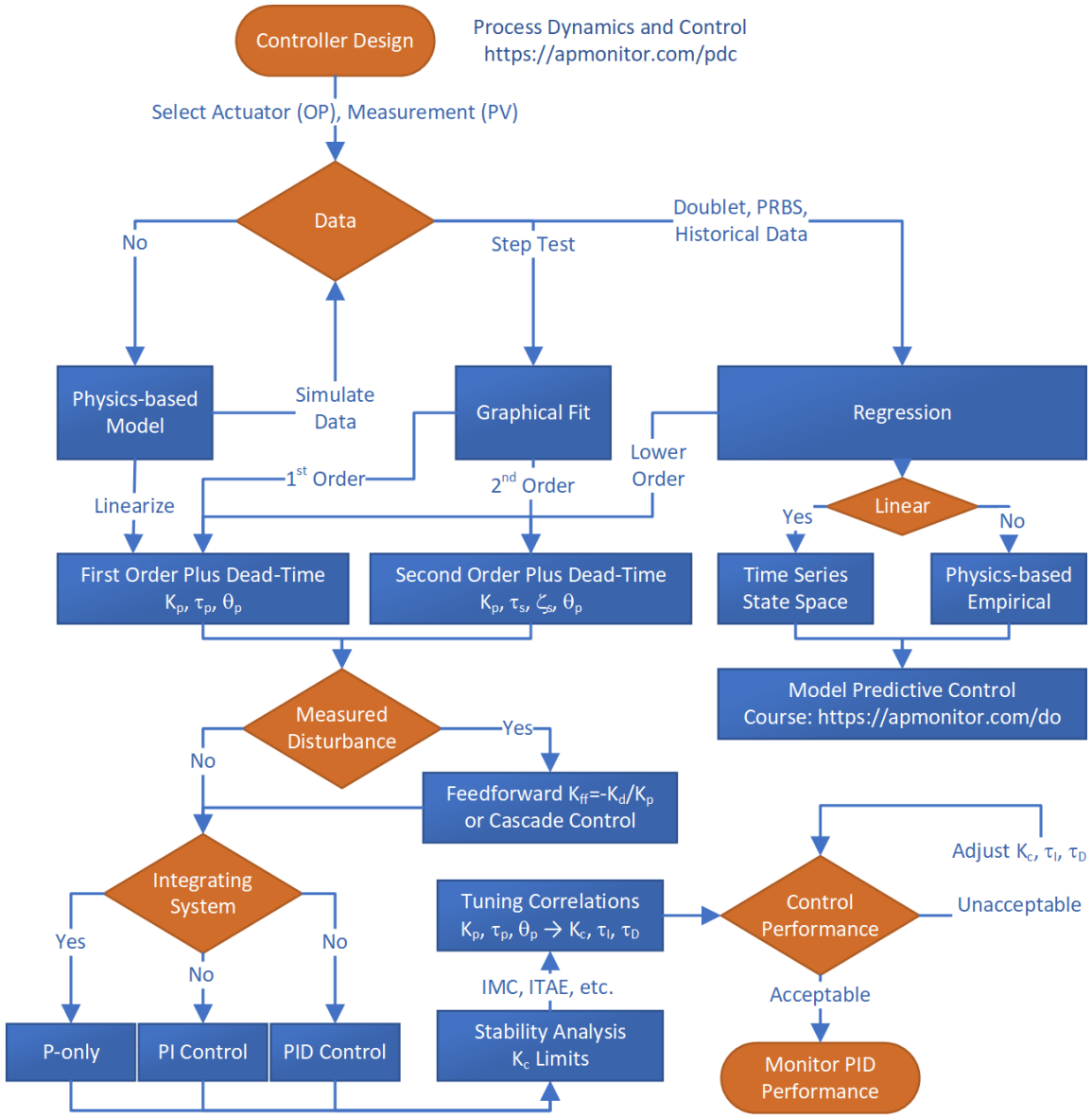
INSTRUCTOR AND TEACHING ASSISTANT

- *Instructor:* Joshua Pulsipher
- *Office:* E6-5008
- *Office hours:* Fridays 11am-12pm
- Contact
  - *Email:* pulsipher@uwaterloo.ca
  - Office hours
  - Before/after class
- Availability
  - Regular business hours (~8:30-5:00 M-F)

- *TA:* Shayesteh Dolatabadi
- *Office:* E6-3114
- *Office hours:* Fridays 1:30 - 2:20 pm in E6-4002
- Contact
  - *Email:* shayesteh.dolatabadi@uwaterloo.ca
  - Office hours
  - Tutorials
- Availability
  - Limited availability outside of the above

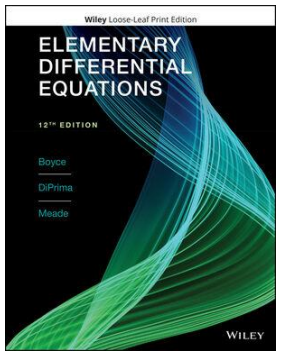
LEARNING OUTCOMES

- Model dynamic ChE systems
- Design/tune PID controllers
- Familiar w/ advanced techniques
- See syllabus for full list
- Note: This is an introductory course
- Want to learn more?
  - ChE 522, ChE 524
  - Undergraduate research



PREREQUISITE KNOWLEDGE*

- Computer programming
  - Competent with the basics of python
- Differential equations and linear algebra
  - Solving ODEs
  - Laplace transforms
  - Matrix operations, computing eigenvalues
- Modeling ChE process units
  - Derive 1st principle models for common units



$$\frac{dc_A V}{dt} = \sum c_{A_{in}} \dot{V}_{in} - \sum c_{A_{out}} \dot{V}_{out} + r_A V$$

*Not an exhaustive list

ASSESSMENT WEIGHTING

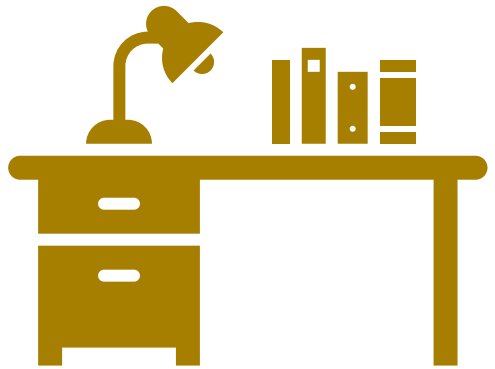
- Quizzes/Assignments (10%)
- Temperature control lab report (10%)
- Tests 1-3 (35%)
- Project oral and written report (20%)
- Final exam (25%)

TYPICAL COURSE STRUCTURE OVER A WEEK

- Monday
  - Previous week's assignment due at start of class (turned in online via Learn)
  - 2 back-to-back lectures (PowerPoint-based due to physical limitations, also some Python)
  - Quiz opens after class and is due at 11:59pm
- Wednesday
  - 1 lecture and 1 tutorial (PowerPoint-based with some Python exercises)
  - Quiz opens after class and is due at 11:59pm
- Fridays
  - Office hours

QUIZZES AND ASSIGNMENTS (10%)

- Quizzes
  - Due at 11:59pm after each class period
  - Low stakes review of lecture content
  - Lowest two scores dropped
  - Each quiz can be taken twice via Learn
- Assignments (i.e., homework)
  - Typically, due Mondays at 1:30pm via Learn
  - Self-assessed
  - DO NOT check your answers before you finish



TESTS AND FINAL

- Tests (35%)
  - 3 tests (1 for each module)
  - In class tests with 60-minute limit
  - Closed-book, 1 page (only one side) of notes are allowed
- Final (25%)
  - Summative assessment
  - Closed-book, 1 page (only one side) of notes are allowed
  - 2.5 hour time limit
  - Location and time TBA

MODULE 1: DYNAMIC MODELING

- Tentative schedule

	Date	Time	Label	Topic	Review Quiz	Due Deliverable(s)
Module 1: Dynamic Modeling	8-Jan	1:30 PM	Lecture 1	Course introduction	Quiz 1	--
	8-Jan	2:30 PM	Lecture 2	Transient balances		--
	10-Jan	1:30 PM	Tutorial 1	Python review	Quiz 2	--
	10-Jan	2:30 PM	Lecture 3	Simulating dynamic models		--
	15-Jan	1:30 PM	Lecture 4	Linearizing balance equations	Quiz 3	Assignment 1
	15-Jan	2:30 PM	Lecture 5	FOPDT Models		
	17-Jan	1:30 PM	Lecture 6	Parameter regression	Quiz 4	--
	17-Jan	2:30 PM	Tutorial 2	Test Review	--	--
	22-Jan	1:30 PM	Test 1	Test on Module 1	--	Assignment 2

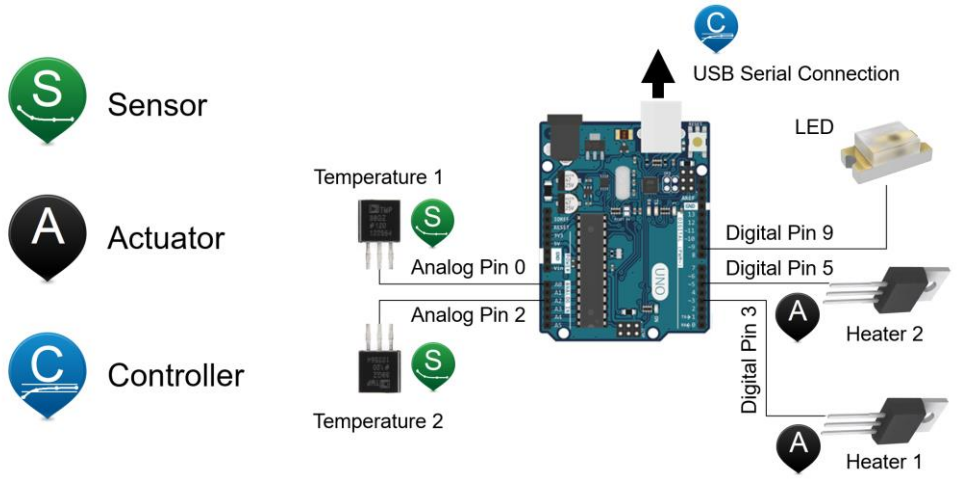
MODULE 2: CONTROLLER DESIGN

- Tentative schedule

	Date	Time	Label	Topic	Review Quiz	Due Deliverable(s)
Module 2: Controller Design	24-Jan	1:30 PM	Lecture 7	Control design	Quiz 5	--
	24-Jan	2:30 PM	Lecture 8	P-only controllers		--
	29-Jan	1:30 PM	Lecture 9	PI controllers	Quiz 6	Assignment 3
	29-Jan	2:30 PM	Tutorial 3	Case study: level control		
	31-Jan	1:30 PM	Lecture 10	PID controllers	Quiz 7	--
	31-Jan	2:30 PM	Tutorial 4	Case study: nonlinear system control		--
	5-Feb	1:30 PM	Lecture 11	Valve design	Quiz 8	Assignment 4
	5-Feb	2:30 PM	Lecture 12	Disturbances		
	7-Feb	1:30 PM	Lecture 13	Sensors	Quiz 9	--
	7-Feb	2:30 PM	Tutorial 5	Test Review	--	--
	12-Feb	1:30 PM	Test 2	Test on Module 2	--	Assignment 5

TEMPERATURE CONTROL LAB (10%)

- Have 2 weeks to complete it between Modules 2 and 3
- Implement an effective dual temperature controller for the TCLab kit
- Work in teams of two
- Deliverable is a **concise 2-page report**
- Obtain hands-on experience with control
- Refine report skills needed for course project



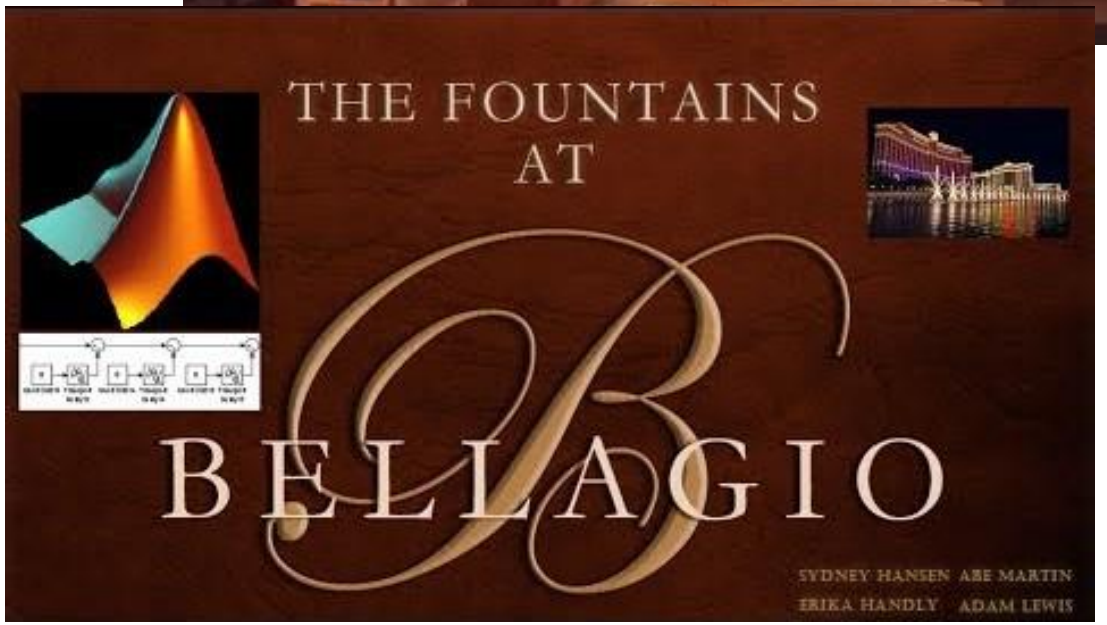
MODULE 3

- Tentative schedule

	Date	Time	Label	Topic	Review Quiz	Due Deliverable(s)
Module 3: Dynamic System Analysis	26-Feb	1:30 PM	Lecture 16	Laplace transforms	Quiz 10	TCLab Project Report
	26-Feb	2:30 PM	Lecture 17	Transfer functions		
	28-Feb	1:30 PM	Lecture 18	Stability analysis	Quiz 11	--
	28-Feb	2:30 PM	Tutorial 6	Tutorial on transfer functions & stability		--
	4-Mar	1:30 PM	Lecture 19	SOPDT models	Quiz 12	Assignment 6
	4-Mar	2:30 PM	Lecture 20	SOPDT parameter estimation		
	6-Mar	1:30 PM	Lecture 21	State space models	Quiz 13	--
	6-Mar	2:30 PM	Tutorial 7	Simulating higher order systems		--
	11-Mar	1:30 PM	Lecture 22	Cascade control	Quiz 14	Assignment 7
	11-Mar	2:30 PM	Lecture 23	Feedforward control		
	13-Mar	1:30 PM	Tutorial 8	Case studies	--	--
	13-Mar	2:30 PM	Tutorial 9	Test review	--	--
	18-Mar	1:30 PM	Test 3	Test on Module 3	--	Assignment 8

COURSE PROJECT (20%)

- Automate a physical or simulated system
- Most have a sensor, actuator, and controller
- Open-ended, creative projects encouraged
- Work in teams of ~3
- Two progress reports (report drafts)
- 2-page final report
- 5-minute oral presentation



ADVANCED TOPICS

- Tentative schedule

	Date	Time	Label	Topic	Review Quiz	Due Deliverable(s)
Course Project and Advanced Control Topics	21-Mar	3:30 PM	Lecture 24	Control project introduction	--	--
	21-Mar	4:30 PM	Tutorial 10	Introduction to Julia	Quiz 15	--
	25-Mar	1:30 PM	Lecture 25	Introduction to optimization	Quiz 16	Project Progress Report 1
	25-Mar	2:30 PM	Lecture 26	Constrained optimization		
	27-Mar	1:30 PM	Lecture 27	Model predictive control	Quiz 17	--
	27-Mar	2:30 PM	Tutorial 11	Control project help session	--	--
	1-Apr	1:30 PM	Lecture 28	Introduction to machine learning	Quiz 18	Project Progress Report 2
	1-Apr	2:30 PM	Tutorial 12	Final review	--	Extra Credit: Assignment 9
	3-Apr	12:30 PM	--	Project presentations	--	--
	8-Apr	11:59 PM	--	--	--	Course Project Report

- Extra credit assignment on optimization and model predictive control

FINAL EXAM (25%)

- Summative assessment
  - Modules 1-3 are fair game
  - Any quiz questions from the advanced topics are fair game
- 2.5 hour limit
- Closed-book, 1-page of single-sided notes are allowed

COURSE POLICIES

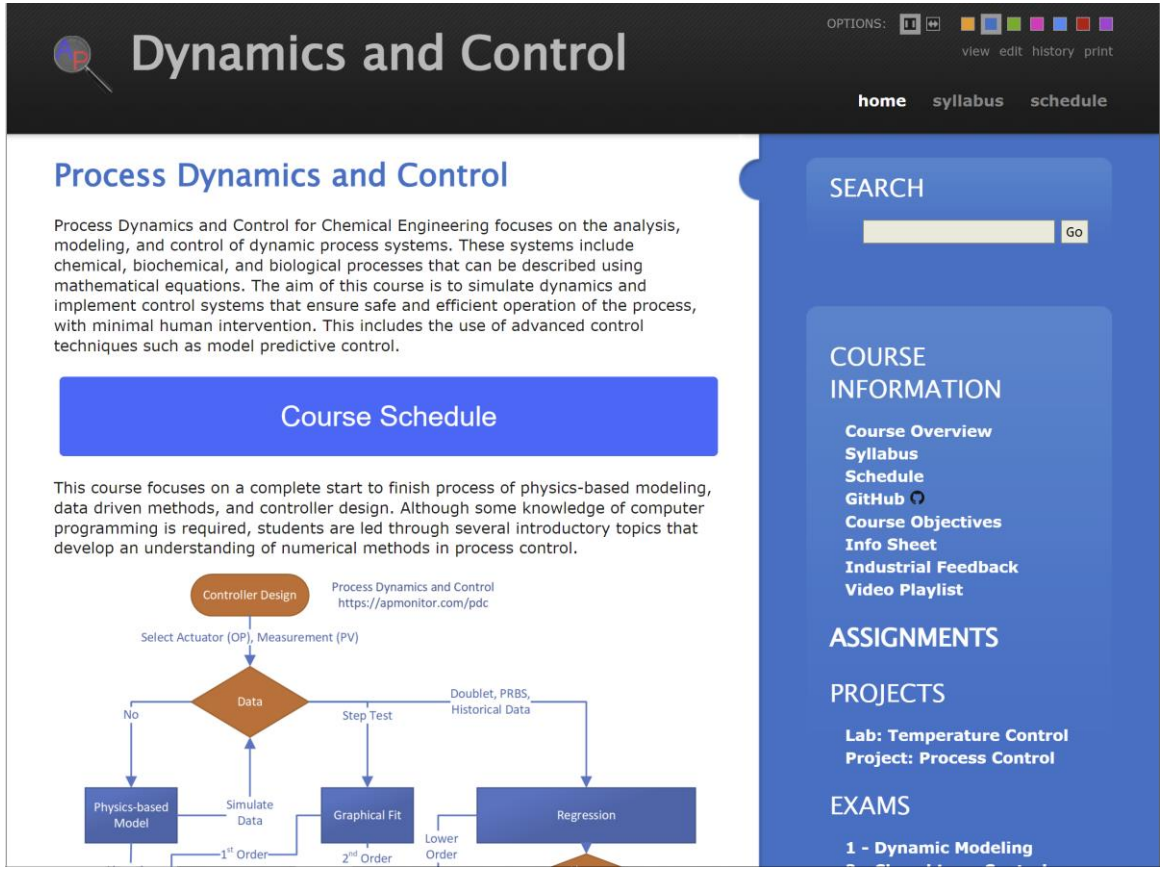
- Late policy
  - No late assignments accepted
  - For university established extenuating circumstances, weight will be moved to next deliverable
- Generative AI
  - Allowed for use on projects with explicit acknowledgement
  - Useful to provide **rough initial content** for coding and writing
- Academic dishonesty
  - Not tolerated, all offenses will be reported to the Dean's office, no exceptions

REQUIRED MATERIALS

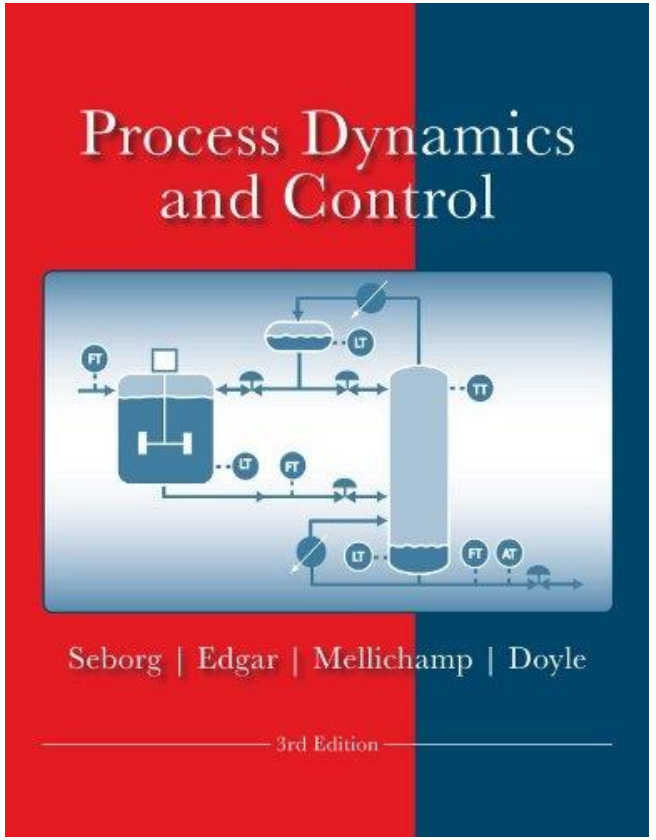
- No textbook required
- TCLab
  - Available from Amazon ($39 USD): https://www.amazon.com/TCLab-Temperature-Control-Lab/dp/B07GMFWMRY
  - Needed for lab and assignments
  - Can be shared by multiple students
  - Limited number available for check out
- Laptop or similar
  - Participate in tutorial python activities

RESOURCES

- APMonitor Control Course (our “textbook”)
  - https://apmonitor.com/pdc/index.php



- Process Dynamics and Control by Seborg



EXPECTATIONS*

- Instructor expectations
  - Provide resources/feedback to guide deliberate practice
  - Promote an inclusive learning environment
  - Be available during regular hours to assist students
- Student expectations
  - Actively listen (no talking when instructor is speaking)
  - Participate in tutorials/examples and help other students
  - Be respectful of others, all should feel included and safe
  - Reach out when you need help

*Not an exhaustive list

STRATEGIES FOR SUCCESS

- **80-100:** Read or watch material in advance. Be attentive and ask questions in lectures, understand and do all homework on time, study hard for exams well before the exam starts, work hard and perform well on exams.
- **70-80:** Skim material in advance, attend lectures and try to stay awake, depend on TA for homework help, casually study for the exam by working the practice exam instead of learning concepts.
- **60-70:** Never read material, work on other homework during class, skip some homework assignments, start cramming for the exam the night before the exam.
- **<60:** Skip class, don't turn in homework, start learning during the exam.