a place of mind

MECH468 : Modern Control Engineering
MECH509 : Controls

L1 : Introduction

Dr. Ryozo Nagamune
Department of Mechanical Engineering
University of British Columbia

Zoom lecture to be recorded and posted on Canvas

Remarks before starting …

- No need to take notes extensively in this course!
  - All the lecture slides will be posted on Canvas.
  - All lectures are recorded and posted on Canvas.
  - You may want to write down some additional information that I present in the lecture and that you feel important.
- Just listen to me carefully!
- Ask me any question at any time!
  - Write your questions in Zoom chat message.
  - Use “raise-hand” functionality in Zoom.
  - Interrupt me by turning on your mic and speaking.

Instructor and TA

- Instructor : *Dr. Ryozo Nagamune (Call me "Ryozo".)*
  - Associate Professor at MECH Department
  - Email: nagamune@mech.ubc.ca
  - Office hours
    - TuTh 5-6pm, at Zoom location given on Canvas, or
    - by appointment, at Zoom location given by email
  - Research interest: Control theory and applications

    e.g. wind turbine/farm, solar thermal system, automotive engine system
- TA for HW marking
  - *Yue Niu:* niuyueubc@gmail.com

Course information

- Canvas canvas.ubc.ca.
  - All information on this course (including lecture slides and homework) will be posted.
- Email will be sent to you if necessary.
- Recommended co-requisite: Classical control (UBC courses: MECH466, MECH467, ELEC341)
- Required textbook: None
- Optional textbooks: given in Syllabus
- Matlab installed on your computer is required.

  https://blogs.ubc.ca/labsos/software-listing/matlab-w-simulink/

Main components of the course and grading scheme

- Live lectures (30 times), MWF at 1-1:50pm
- 5 homework assignments (20%)
  - Schedule is given on Canvas.
  - Scan and upload your answers on Canvas.
  - **Late hand-in will NOT be accepted.**
  - **No plagiarism! (Do NOT copy and paste other's work.)**
- Midterm (on Feb 24, Wed, 1-1:50pm) (30%)
- Final (in April) (50% for MECH468, 30% for MECH509)
- Project for MECH509 (20%)

Project (for MECH509 students)

- To show the usefulness and/or the limitation of linear control theory, each student is required to:
  - formulate a realistic control problem (preferably related to his/her own research, or otherwise we can help),
  - do analysis and design for the problem using the course material,
  - analyze the designed controller in simulations (and in experiments if possible),
  - give a seminar, and
  - submit a report.
- Start the project after the midterm.

Policies

- Exams
  - Open-book, no calculators
  - Alternative exams can be arranged:
    - for medical reasons with doctor's notes.
    - for those who live in non-PST time zone.
    - Discuss your case with the instructor before the exam dates.
  - Your exams are invigilated on Zoom or Proctorio. Please make sure that you have a computer with a webcam.
- Students pass this course based on their final course mark greater than or equal to 50%.

Expectations

- Roughly 9 hours of study per week
  - 3-hour lecture
  - 6-hour out-of-class activities (review, reading, homework, exam preparation etc.)
  - Extra 3-hour for MECH509 students (for project)
- Come to the lecture as many times as you can, or otherwise listen to the recorded lecture after each class.
- Questions (both by emails and in-person on Zoom) are welcome at any time (even outside office hours).
  - Ryozo: General questions and technical questions
  - Yue: Questions about HW marking
- Late hand-in will not be accepted.

Modern control engineering

- In this course, we learn a basic “modern” theory of automatic feedback control systems.
  - What is control?
  - What is automatic control? And why?
  - What is feedback control? And why?

What is "Control"?

- Make some object, called *system or plant*, behave **AS WE DESIRE**.

  "move an object" is not control! "as we desire" is important!

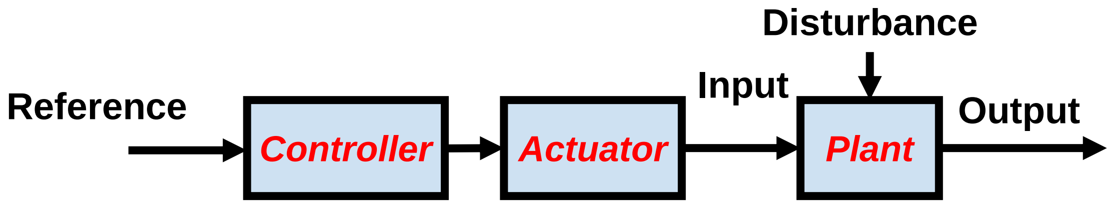
- Imagine "control" around you!
  - Room temperature control
  - Car/bicycle driving
  - Balance of bank account
  - "Control" (move) the position of the pointer
  - Laundry machine
  - Automobile direction and speed control
  - Airplane, rocket, satellite control

What is “Automatic Control”?

- Not manual!
- Why do we need automatic control?
  - Convenient (room temperature control, laundry machine, autonomous car, drone delivery)
  - Dangerous (hot/cold places, space, bomb removal)
  - Impossible for human (nanometer scale precision positioning, work inside the small space that human cannot enter)
  - It exists in nature. (human body temperature control)
  - Low cost, high efficiency, etc. (internal combustion engine, wind turbine, solar thermal collector)
- Many examples of automatic control around us

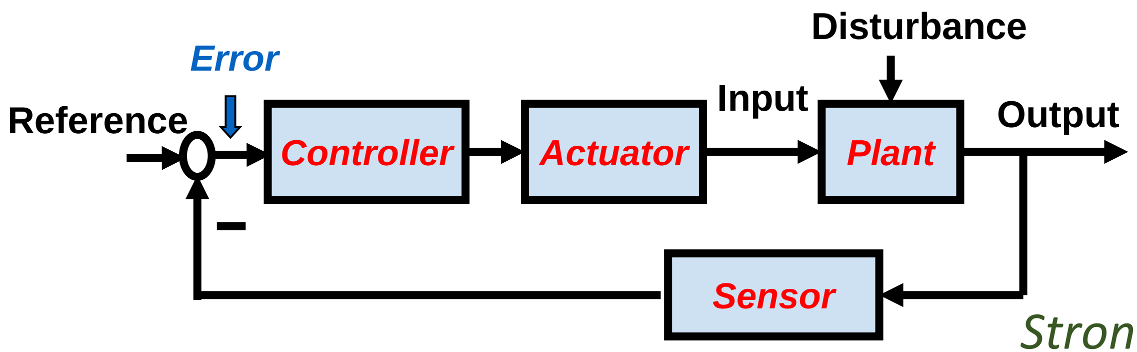
Open-loop & closed-loop (feedback) control

- Open-loop



Less expensive
Weak against uncertainty

- Closed-loop (feedback)



More expensive
Strong against uncertainty

Examples

- Open-loop control
  - Imagine to drive a car as fast as possible.

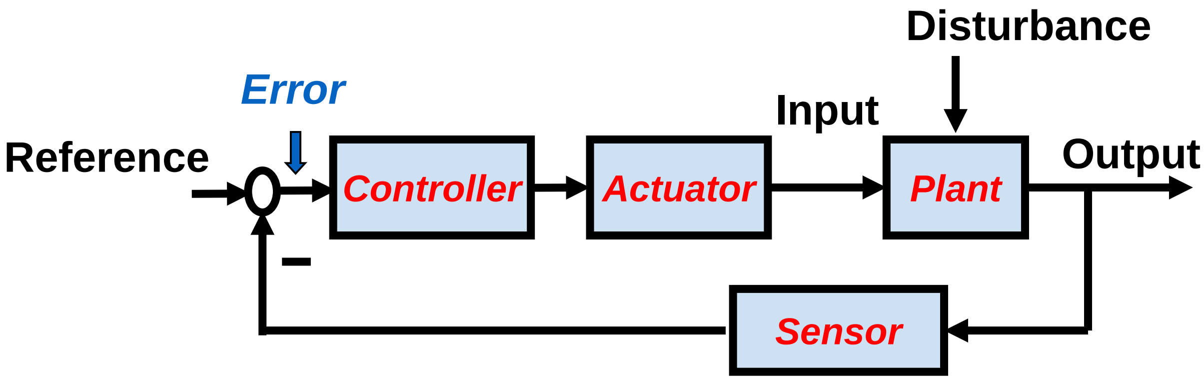
    What will you do?
- Closed-loop control (Feedback control)
  - Imagine to drive a car at a constant speed.

    What will you do?

In this course, we are interested in theory for automatic open/closed-loop control systems.

Control system design objective

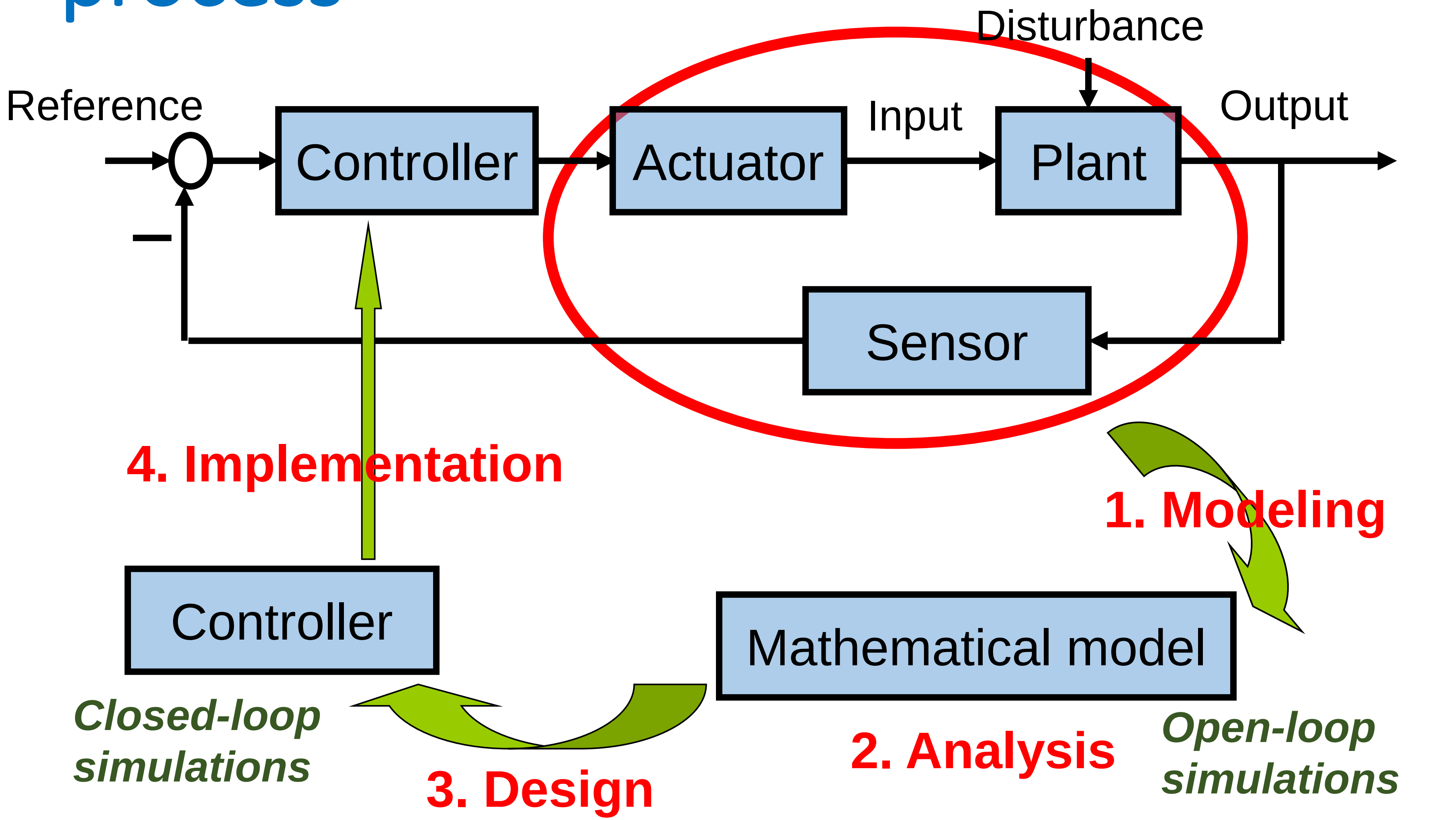
- Design a controller such that
  - the output follows the reference, namely, the error is reduced, in a “satisfactory” manner
  - even in the face of uncertain disturbance, reference and plant.



Two approaches to controller design

- Model-free controller design
  - Does not rely on a plant's mathematical model
  - For easy control problem (e.g. room temperature control)
  - Non-critical (not safety-critical, not costly) applications
- Model-based controller design (our interest)
  - Rely on a plant's mathematical model
  - For non-trivial control problem (e.g. nanometer precision motion control, stabilization of drone, Segway)
  - Critical applications (e.g. airplane, rocket, etc.)

Model-based controller design process



Goals of classical control course

To learn basics of feedback control systems

- Modeling as a transfer function and a block diagram
  - Laplace transform (Mathematics!)
  - Mechanical, electrical, electromechanical systems
- Analysis
  - Time response, frequency response
  - Stability: Routh-Hurwitz criterion, Nyquist criterion
- Design
  - Root locus technique, frequency response technique, PID control, lead/lag compensator

Remarks on classical control

- Weak points
  - Classical control theory deals with only
    - Single-input single-output (SISO) systems
    - Linear time-invariant (LTI) systems
  - No optimality concept in controller design
  - No robustness consideration, except gain margin and phase margin
- *Advanced control theories are necessary!*
  - Multivariable control
  - Nonlinear and time-varying control
  - Optimal and robust control

Brief history of control engineering

- Classical control (-1950)
  - Transfer function
  - Frequency domain
- Modern control (1960-) (contents in this course)
  - State-space model
  - Time domain
  - Optimality
- Post-modern control (1980-)
  - Robust control
  - Hybrid control, etc.

Linear state-space models

Continuous-time (CT)

$$\begin{cases} \dfrac{dx(t)}{dt} &= A(t)x(t) + B(t)u(t) \\ y(t) &= C(t)x(t) + D(t)u(t) \end{cases}$$

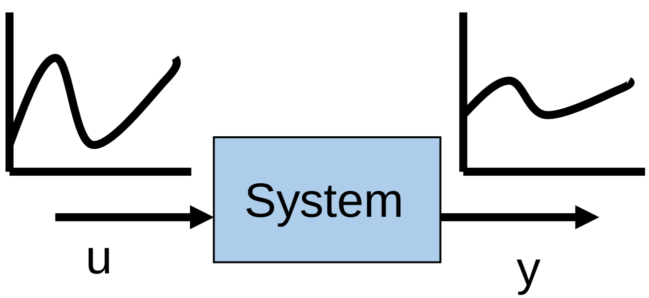
$t \in \mathbb{R}$(Real numbers)

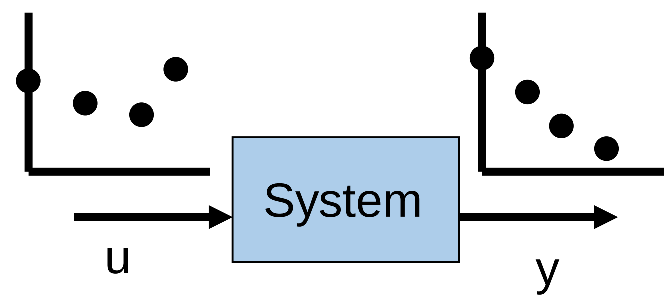
Discrete-time (DT)

$$\begin{cases} x[k+1] &= A[k]x[k] + B[k]u[k] \\ y[k] &= C[k]x[k] + D[k]u[k] \end{cases}$$

$k \in \mathbb{Z}$(Integers)

x : state vector
u : input vector
y : output vector





Advantages of state-space models

- State-space models can represent fairly general systems, such as
  - Multivariable systems
  - Time-varying systems
  - Nonlinear systems
- Under certain conditions, "variables inside the system" (called ***states***) can be
  - controlled without actuators,
  - observed without sensors.
- Analysis and design can be done in a numerically reliable manner.

Goal of this course (This will be shown again at the last class.)

To learn control theory with linear state-space models

- Modeling as a state-space model
  - Differential or difference equation (instead of TF)
  - Linear algebra (instead of Laplace transform)
- Analysis
  - Stability, controllability, observability
  - Realization, minimality
- Design
  - State feedback, observer
  - Linear Quadratic Regulator (LQR), Kalman Filter
- Matlab simulation

Course plan

Topics	CT	DT
Modeling		
Stability		
Controllability/observability		
Realization		
State feedback/observer		
LQR/Kalman filter		

Summary

- Introduction of the course
- This course gives foundations for advanced control theory. (e.g., nonlinear control, robust and optimal control, adaptive control, digital control, sampled-data control, hybrid control, system identification)
- The course material is applicable to various systems. (e.g., mechanical, electrical, electromechanical, aerospace, fluid, thermal, biological, economic)
- Next, model classification
- Read the course syllabus and schedule (in Canvas).