# EE3331C/EE3331E Feedback Control Systems
# L1: Overview

Arthur TAY

ECE, NUS

# Outline I

# Outline II

## Contact Information

- Lecturers: Profs. Abdullah Al Mamun, Arthur Tay
- Day/Time: EE3331C: Tuesday (9-11am @ LT3), Thursday 10-12pm @ LT3)
  EE3331E: Monday (6-9.30pm @ [redacted])
  E1-06-03
- Office: ECE Dept office or E4-08-12
- Tel: 6516-3135/6326
- Email: arthurtay@nus.edu.sg
- Office hours: please email or call me before you come

# Course Mechanics

- all class info, lectures notes, lab manuals on IVLE course website.
- course requirements:
  - midterm quiz (20%)
  - laboratory sessions (20%) – 2 sessions (tentatively, weeks 5 and 8), Matlab and DC motor.
  - final exam (60%)
    (These weights are approximate; we reserve the right to change them later).
  - PLUS homework and reading assignments.
- textbook and references (copies are available at the Central library, RBR)
  - *Feedback Control of Dynamic Systems* by Franklin, Powell and Emami-Naeini, 6th edition. (FPE)
  - *Modern Control Systems* by Dorf and Bishop, 11th edition (DB)

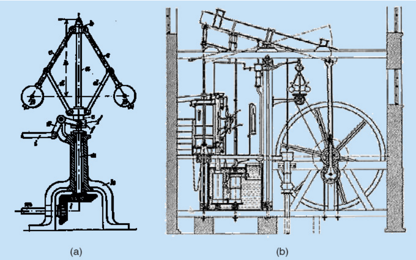
What is Control?

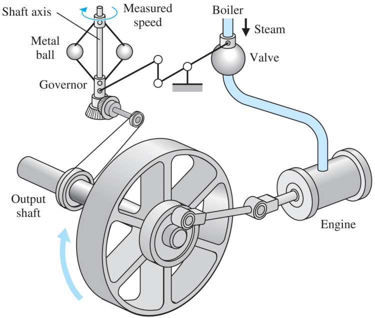
- Control refers to the use of algorithms and feedback in engineered systems.
- At its simplest, a control system is a device in which a sensed quantity is used to modify the behavior of a system through computation and actuation.
- The modern view of control sees feedback as a tool for uncertainty management. By measuring the operation of a system, comparing it to a reference, and adjusting available control variables, we can cause the system to respond properly even if its dynamic behavior is not exactly known or if external disturbances tend to cause it to respond incorrectly.

Reference: 'Future Directions in Control in an Information-Rich World', IEEE Control Systems Magazine, April 2003.

# Early Feedback Control Systems

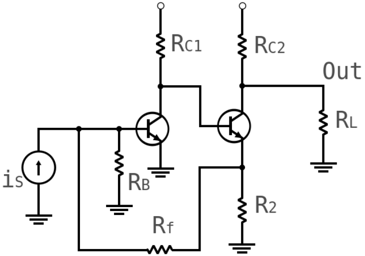
- In 1788 James Watt invented the flyball governor which is a feedback mechanism for controlling the speed of a steam engine.



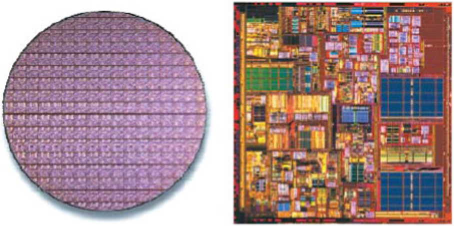



# Early Feedback Control Systems

- Feedback Amplifers (1920s)
  - Invented by H.S. Black from Bells Lab
  - Laid the mathematical foundations for classical control
  - Use of negative feedback to improve performance (gain stability, linearity, frequency response) and reduce sensitivity to parameter variations



# Success & Impact

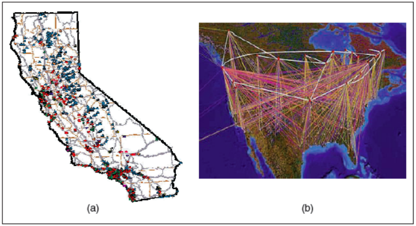


Intel Pentium IV wafer & chip

Boeing 777

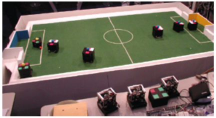
Harddisk Drive

# Opportunities & Challenges



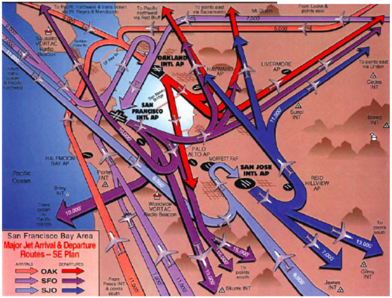
(a) (b)

Robotics & Intelligent Machines

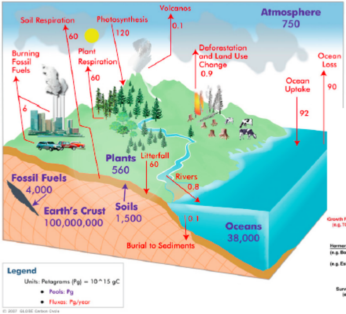


Information & Networks

Aerospace & Transportation

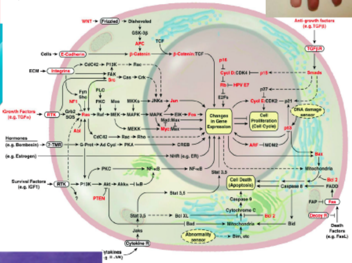


# Opportunities & Challenges




Environmental Systems

Biology & Medicine



Materials & Processing

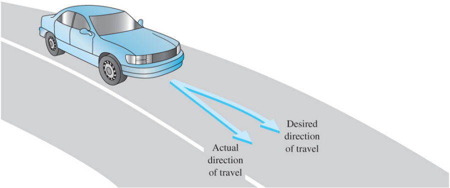
# Historical Development

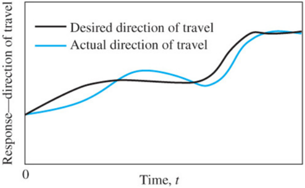
- The roots (before 1940)
  - Early applications of feedback includes windmills, steam engines, engines, ships, airplanes, process control, telecommunication
- The field emerges (1940 – 1945)
  - The Second World War
  - Spread like wildfire: education, industry, organization
- The second wave (1960 –)
  - Demanding applications: space, process industry
  - New components: digital computers
- New applications, opportunities and challenges
  - information and communications
  - biology and medicine
  - materials and processing
  - environmental systems
  - economics and finance; molecular and quantum systems, etc.

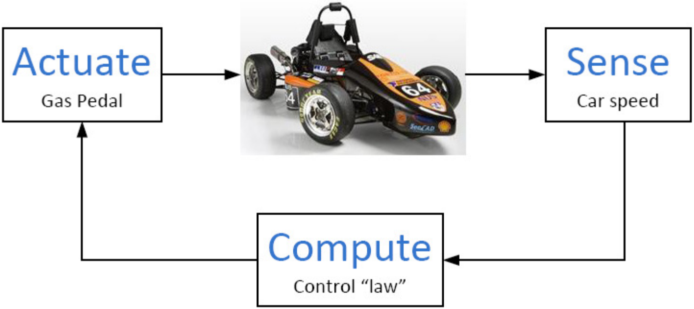
| | Classical Control – 1960 | Modern Control 1960–1980 | Post Modern 1980– |
|---|---|---|---|
| Analysis | Bode plots<br>Nyquist plots<br>Root loci<br>Gain/Phase margins | State-space models<br>Random processes<br>Controllability / Observability | $\mathcal{H}_\infty$ robustness<br>Singular values<br>Lyapunov stability<br>LMI's |
| Synthesis | PID<br>Lead-Lag Comp. | LQR feedback<br>Kalman Filters<br>LQG<br>Optimization | $\mathcal{H}_\infty$ synthesis<br>$\mu$ synthesis<br>Robust $\mathcal{H}_2$ synthesis<br>Error modeling |
| Paradigm | Frequency Domain | Time Domain | Frequency domain but state-space tools |

## Automobile steering control

- The driver uses the difference between the acutal and the desired direction of travel to generate a controlled adjustment of the steering wheel based on measurements/feedback from:
  - visual
  - feel of the steering wheel
- Typical direction of travel response.






Control = Sensing + Computation + Actuation

## Control of household furnace

- Consider a household furnace controlled by a thermostat:
  - Objective: to make the room temperature adhere to a desired temperature by controlling the furnace.
  - Figure 1.1 shows the schematic diagram of a control system for controlling the room temperature.

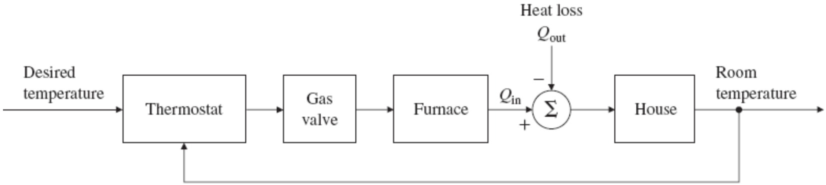



Figure 1.1 : Block diagram of a room temperature control system.

- Figure 1.2 shows the controlled room temperature using a simple on-off control strategy.

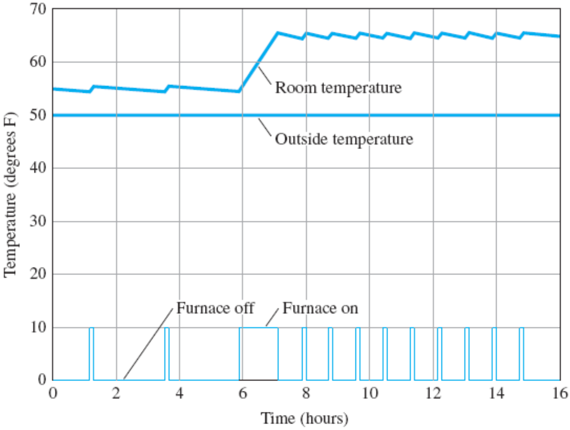



Figure 1.2 : Plot of room temperature and furnace action.

# A Simple Feedback Control System

- Figure 1.3 shows the generic components of a simple feedback control system.
- Key components: Process, Actuator, Sensor and Controller

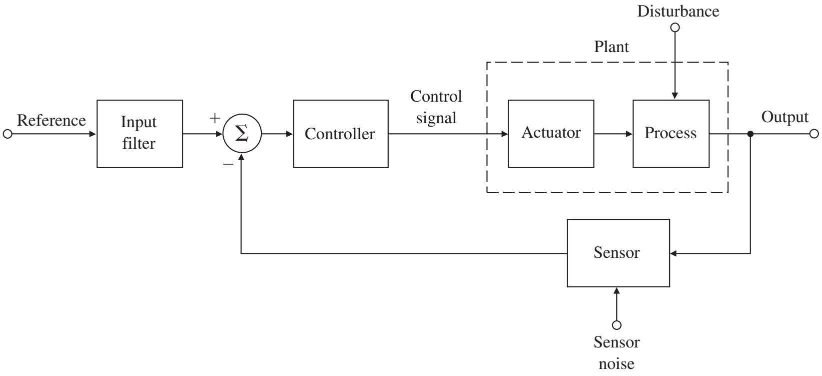
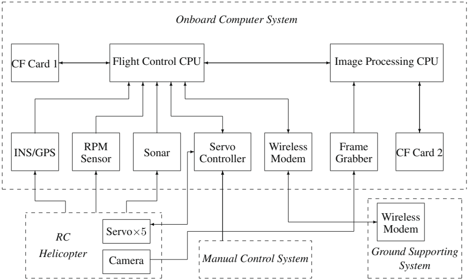



Figure 1.3 : Block diagram of a feedback control system.

- At its simplest, a control system is a device in which a sensed quantity is used to modify the behavior of a system through computation and actuation.
- A simple feedback system consists of the **process** whose output is to be controlled, the **actuator** whose output causes the process output to change, **reference** and **output sensors** that measure these signals, and the **controller**, which implements the logic by which the control signal that commands the actuator is calculated.
- In addition, advances in **communication devices** led to a new class of networked systems that uses wireless technology, enabling spatially-distributed control.
- Two important concepts: **Signals** and **Systems**.
- Mathematical techniques can be used to help describe and analyze systems which process signals:
  - Signals are variables that carry information.
  - Systems process input signals to produce output signals.
  - Identify the signals and systems in Figure 1.3.

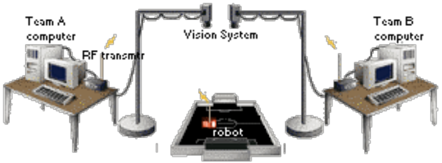
- Examples:
  - **Plants**: CD player, disk drive mechanics; aircraft or missile; car suspension, engine; rolling mill; high-rise building, XY stage on stepper machine for lithography; computer network; industrial process; elevator.
  - **Sensors**: radar altimeter; GPS; shaft encoder; LVDT; strain gauge; accelerometer; tachometer; microphone; pressure and temperature transducers; chemical sensors; microswitch.
  - **Actuators**: hydraulic, pneumatic, electric motors; pumps; heaters; aircraft control surfaces; voice coil; solenoid; piezo-electric transducer.
  - **Disturbances**: wind gusts; earthquakes; external shaking and vibration; road surface variations; variation in feed material
  - **Controller**: human operator; mechanical; electro-mechanical; analog electrical; general purpose digital processor; special purpose digital processor.

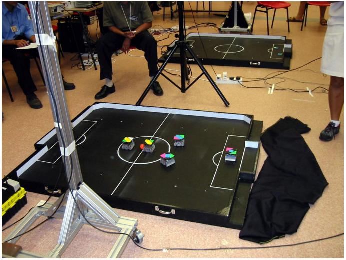
- Unmanned Aerial Vehicles
  More information: uav.ece.nus.edu.sg




| | |
|---|---|
| Sensing | GPS, ultrasonic sonar, RPM sensor, camera |
| Actuation | various rotor torques |
| Computation | on-board computer system, image processing |
| Effect | autonomous UAVs, ground target tracking |

- Robot Soccer
  More information: www.prahlad.in; www.robocup.org



| | |
|---|---|
| Sensing | overhead camera system, wheel angle encoders |
| Actuation | motor torques, kick mechanism |
| Computation | centralized computer, vehicle microcomputers |
| Effect | autonomous robot soccer platform, agile motion |

- Congestion control and Internet

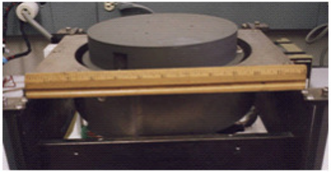
NSFNET Internet backbone

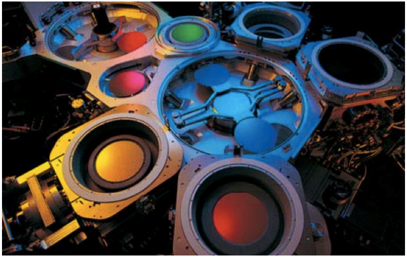
More information:
1) 'Future Directions in Control in an Information-Rich World', IEEE Control Systems Magazine, April 2003.
2) 'Host-to-host congestion control for TCP', IEEE Communication Surveys and Tutorials 12 (3), 2010.

| | |
|---|---|
| Sensing | data, ACK packets via TCP |
| Actuation | transmit rate, router paths |
| Computation | source, destination, router processors |
| Effect | high speed data transmission, tolerant to link failures |

- Thermal processing systems in semiconductor manufacturing
  - Objective: to heat a heater plate to a desired temperature, $T_d$ with a electrical heater.
  - Plant:
  - Actuator:
  - Controller:
  - Input, $u$:
  - Output, $y$:

Can you draw the control system block diagram?





# Summary

- Control engineering is present in viturally all modern engineering systems, often the hidden technology.
- Key elements in a simple feedback control system: process, actuators, sensors, and controller.
- Control is a multidisciplinary subject that includes:
  - sensors
  - actuators
  - communications
  - computing
  - architectures and interface
  - algorithms

Reading: introductory chapters in any control engineering books. For more background on the history of control, see the survey papers appearing in the *IEEE Control System Magazine* of Nov 1984, Jun 1996 and Apr 2002. You can download the papers from NUS digital library.

# Practice Problems

1. Describe the block diagram of a person playing a video game. Suppose the input device is a joystick and the game is being played on a desktop computer. Use Figure 1.3 as a model of the block diagram.
2. Consider the following chemical process control system, the objective is to control the chemical composition of the product. To do so, a measurement of the composition can be obtained using an infrared stream analyzer. The valve on the additive stream may be controlled. Sketch the control system block diagram.

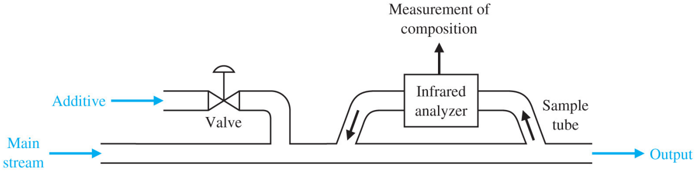



Figure: 01-27-04UNP1.3

# Learning Outcomes

Students should be able to :

- Explain a linear time invariant system and its properties
- Derive a linear time invariant system model using mathematical tools such as differential equations and transfer functions
- Describe and analyze the behavior of a system in time and frequency domain
- Apply feedback to achieve stable automatic control
- Evaluate stability and performance of a negative feedback system
- Design a simple feedback controller
- Use MATLAB/Labview to simulate/design/control a practical system

## Topics to be covered (first half)

- Review of signals, systems and Laplace Transform
- Modeling of dynamic systems, Transfer Functions
- Time domain analysis of dynamic system's response
- Open loop versus Closed-loop control: Transient performance, steady-state error analysis
- Stability, Root Locus Analysis
- Proportional, Integral and Derivative (PID) control

## Topics to be covered (second half)

- Frequency response, Bode plot and polar plot, Nyquist Stability Criterion
- Robust stability – gain and phase margins
- Lead and Lag compensator, design of lead compensator (both s-plane method and Bode plot method)
- Digital implementation of feedback control (via lab)