Introduction to Control Systems

MEM 355 Performance Enhancement of Dynamical Systems

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Outline

- Course practical information
- Control: open loop and closed loop
- Short history of control
- Contemporary applications
- Technology drivers
- Summary

What is the course content? What is control?
Why should an ME care? Why all the math?

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Practical Information

- Lectures: Tues & Thurs 3:30-4:50 pm
- URL: http://www.pages.drexel.edu/~hgk22/
- Text Book: Kwatny & Chang, Introduction to Control Systems Engineering, Cognella.
- Software: The MathWorks, Inc. The Student Edition of MATLAB, Version +Control Toolbox. (UG lab, CAD lab). Tutorial @ http://www.engin.umich.edu/group/ctm/basic/basic.html

Grading:

- Homework (7): 70%
- Final Project (take home): 30%

Specific Goals

- Define the control system design problem and develop a preliminary appreciation of the tradeoffs involved and requirements for robust stability and performance.
- Develop concepts and tools for ultimate state error analysis.
- Develop the relationship between time domain and frequency domain performance specifications, e.g, rise time, overshoot, settling time, sensitivity function and bandwidth.
- Develop frequency domain design methods, including: the root locus method, Nyquist & Bode methods, and stability margins.
- Provide an introduction to state space design: controllability and observability, pole placement, design via the separation principle.
- Emphasize computational methods using MATLAB.

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What is Control?

- Control refers to the manipulation of the inputs to a physical system in order to cause desirable behavior.
  - Cause output variables to track desired values
  - Impose desirable dynamical behavior, e.g., stabilize an unstable system
- Open loop (feedforward) control
  - Exploit knowledge of system behavior to compute necessary inputs
  - Requires accurate model of system
- Closed loop (feedback, active) control
  - Process information from sensors to derive appropriate inputs
  - Allows compensation for model uncertainty, disturbances, noise
  - Alters system dynamics

Familiar Examples

- Household Temperature Control
- Cruise Control +
- Traction Control
- Electronic Stabilization
- Airplane Autopilot

What do Control Engineers Do?

- System Design/System Integration
  - Participate in defining system/subsystem requirements and specifications
  - Develop subsystem/component specifications – including cyberstructure
  - Participate in component selection/design
  - Develop math models and simulations of components/subsystems/system
  - *Design/implement control systems*
  - Participate in testing/validation/verification

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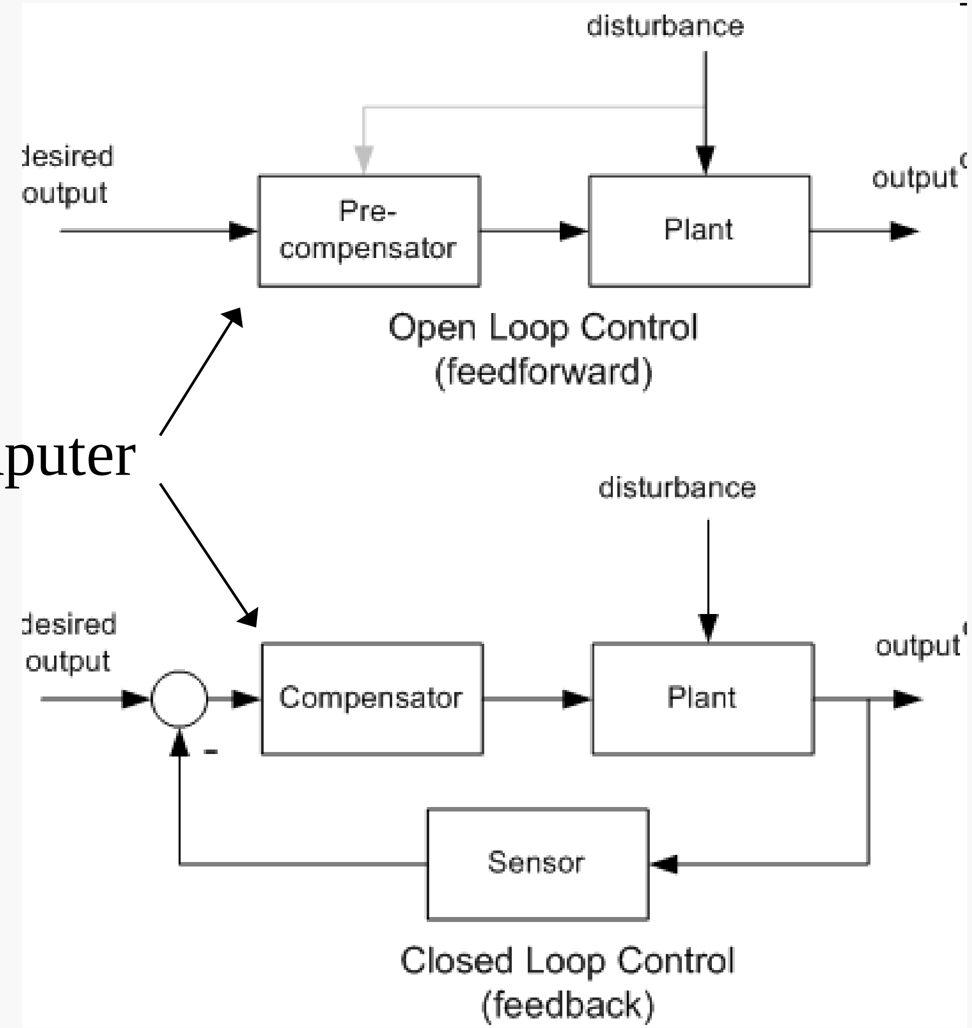
Open & Closed Loop Control

Control computer



Feedforward <u>does not</u> alter plant dynamics. Feedback <u>does</u>.

The Magic of Feedback

- ***The adjustment of system inputs based on the observation of its outputs***
- ***Feedback is a universal strategy to cope with uncertainty***

In engineering we use feedback to:

- Cause a system to behave as desired
- Keep variables constant
- Stabilize unstable system
- Reduce effects of disturbances
- Minimize the effect of component variations
- Another alternative for designers

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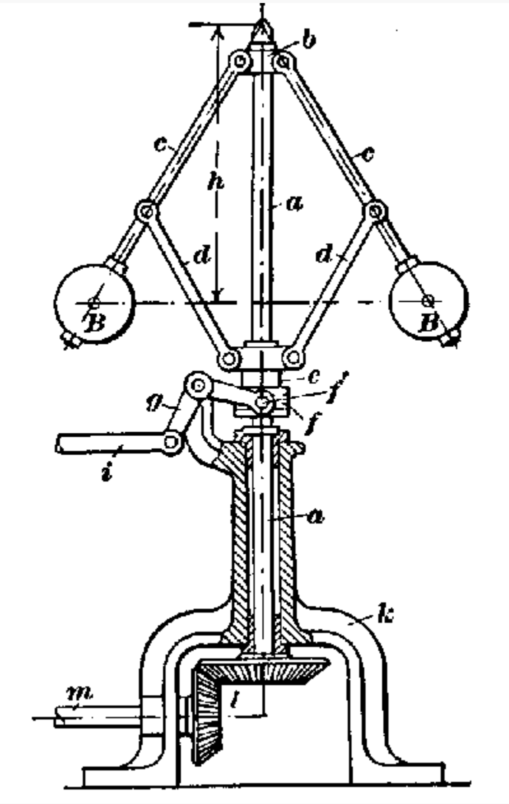
Origins of Control Engineering

Clocks (escapement)	1200-1400
Windmills	1787
Steam Engines (Watt)	1788
Maxwell ~ Governors	1868
Water Turbines	1893
Wright brothers ~ Airplane	1903
Sperry ~ Autopilot (Gyro)	1914
Minorsky ~ Ship steering	1922
Black ~ Feedback amplifier	1928
Ivanoff ~ Temperature regulation	1934



First real control system analysis.
First journal article.
Invention of new control paradigm-PI

Wilber Wright 1901

“We know how to construct airplanes. Men also know how to build engines. The inability to balance and steer still confronts students of the flying problem. When this one feature has been worked out, the age of flying will have arrived, for all other difficulties are of minor importance.”

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Contemporary Applications

Widespread use of automatic control in many fields

- Power generation
- Power transmission
- Process control
- Discrete manufacturing
- Robotics
- Communications
- Automotive
- Buildings
- Aerospace
- Medicine
- Marine Engineering
- Computers
- Instrumentation
- Mechatronics
- Materials
- Physics
- Biology
- Economics

There is a unified framework of theory, design methods and computer tools that cut across fields of application.

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Examples

- Aerospace
  - Commercial & military “fly-by-wire”
  - Autopilot, auto-landing
  - UAV
  - Satellite attitude control
  - Reentry control
- Robotics
  - Precision positioning in manufacturing
  - Remote space/sea environments
  - Minimally-invasive surgery
  - RPV’s for surveillance, search and rescue

Mercedes Benz SLR

- Automotive
  - Engine
  - Transmission
  - Cruise, climate control
  - ABS, Traction control, ESP
  - Active suspension
  - Self driving
- Power plants
  - Various temps/pressures
  - Power output
  - Emissions control
- Heating, ventilation, air conditioning (HVAC)

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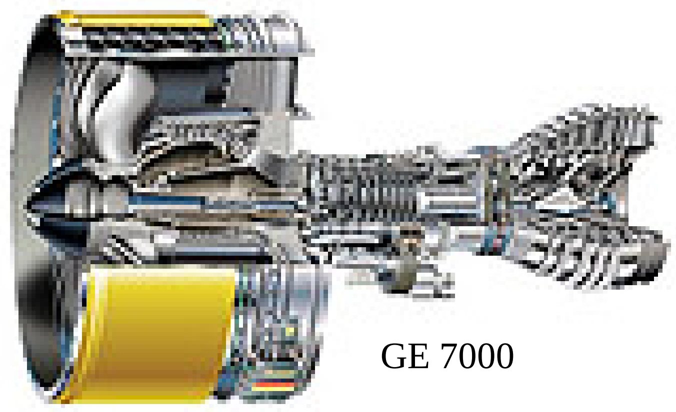
Examples

- Materials processing
  - Rapid thermal processing
  - Vapor deposition
- Noise and vibration control
  - Active mounts
  - Speaker systems
- Intelligent vehicle highway systems
  - ‘platooning’ for high speed, high density travel
  - Automatic merge
  - Obstacle avoidance
  - Lane Following
  - Long haul fuel optimization
- Smart engines
  - Compression systems stall, surge, flutter control
  - Combustion systems lean air/fuel ratio for low emissions, improved efficiency



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Evolution of the Control Discipline

- **Classical control** — 1940
  - Frequency-domain based tools for linear systems
  - Mainly useful for single-input single-output (SISO) systems
  - WWII years saw 1st application of ‘optimal’ control
  - Still the main tools used in practice
- **Modern control** — 1960
  - ‘State space’ approach for linear systems
  - Useful for SISO and multi-input multi-output (MIMO) systems
  - Relies on linear algebra computations rather than Laplace transform
  - Performance and robustness measures not always explicit
  - Just in time for space exploration
- **Optimal control** — 1970
  - Find the input that optimizes some objective function (e.g., min fuel, min time)
  - Used for both open loop and closed loop design
- **Robust control** — 1980
  - Generalizes classical control to MIMO case
  - Enabled by modern control development
  - Expanded concepts of stability
  - New concepts and tools for enhanced robustness
- **Nonlinear, adaptive** — 1990
  - Geometric theory of affine systems, variable structure
  - Self-tuning and adaptive control
- **Discrete Event & Hybrid Systems** — 2000+
  - Mixed Logic-Dynamical Systems

Key Technology Trends

- Computation: Design Tools (computers & software)
- Computation: implementation mechanisms (microprocessors)
  - Cheap and powerful microprocessors opened the door to widespread control applications from 1970's onward
- Sensors and actuators
  - Sensors continue to get smaller, cheaper, faster
  - Macro/micro – scale actuation evolving (power electronics, piezo-electric, EM-rheological fluids)
- Communications and networking
  - Networks replacing point-to-point communication in large systems (e.g., electric power systems) and small (e.g. automotive)

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Active Control in Automobiles

A typical automobile has 200-300 feedback controllers. Here are a few examples in a contemporary Mercedes.

- Cruise Control
- ABC-active body control
- ABS-anti-lock braking system
- ASR acceleration skid control
- ESP electronic stabilization program
- SBC sensotronic brake control
- BAS brake assist system
- Proximity controlled cruising

http://www.mercedes-benz.com/e/innovation/rd/sicherheitspecial/default.htm

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Biology/Biomechanics

- Feedback governs how we grow, respond to stress and challenge.
- Feedback regulates factors such as body temperature, blood pressure, and cholesterol level.
- Feedback makes it possible for us to stand upright.
- Feedback enables locomotion.
- Feedback operates at every level, from the interaction of proteins in cells to the interaction of organisms in complex ecologies.
- Feedback control is used to design drug treatment strategies for diseases like HIV/Aids, Cancer

“Biologically inspired control”

Research Applications in MEM

- Automotive
- Aircraft/Flight Safety
- Power Plants
- Robotics
- Autonomous Vehicles
- Mechatronics
- Biology/Biomechanics
- Electric Power Systems (terrestrial, automotive, ship)

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Summary

- Course content.
- What is a control system?
  - Open loop/closed loop (feedforward/feedback)
- Why is control relevant to ME?
  - Applications! Applications! Applications!
- Why so much math?
  - Abstraction to accommodate many applications in a common framework
  - Better understanding of physical system behaviors & modeling
  - Explicit design approaches to meet (optimize) specific performance goals.