

MCE441: Intr. Linear Control Systems

Lecture 1: Introduction and Motivations for Automatic Control

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Control-Oriented Notion of System

- System: A device or process having identifiable inputs and outputs. Drawing the boundaries of a system involves a degree of abstraction.
- Example: Input: Accelerator pedal position; Output: Speed. Alternative: Input: Fuel flowrate; Output: Torque.
- Inputs can be either manipulated at will or be undesirable external influences. We can set the pedal accurately, but we can't predict or set the wind force. Undesirable, generally unpredictable and often unmeasurable inputs (one of the control engineer's enemies) are called **disturbances**.

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What is Control?

- *To control a system* means to make outputs of interest follow a desired behavior (trajectory, profile) despite disturbances and other errors.
- In *Automatic Control*, the corrective actions required to achieve the required output behavior are performed by machine.
- The design, construction and deployment of the control machinery involves diverse skills, usually not found in a single person. Control technologists deal mostly with the construction and deployment of control hardware. Control theorists deal with the mathematical principles behind dynamic systems (usually described by differential equations). The ME's role in control is focused in the early stages of design: mathematical modeling, simulation and determination of control algorithms.

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Advantages of Automatic Controls

Our textbook cites 4 reasons to build control systems:

- **Power amplification:** command high-power outputs from low-power control interfaces.
- **Remote control:** keep operator away from controller object: radioactive material, minesweeping .
- **Convenience of input form:** Manipulate thermal, mechanical, electrical, chemical and other variables from simple commands (knob turn, keystroke, etc.)
- **Compensation for disturbances:** keep car speed at 65 mph despite grade. Keep CNC machine spindle rotating at nominal speed (\pm small margin) despite forces from metal cutting.

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Advantages of Automatic Controls

Here are three important applications where (feedback) control is a necessity:

- Stabilization of naturally unstable systems: fighter aircraft, magnetic levitation...
- Performance improvement: hard disk drives, automotive ABS, EFI...
- Multi input/output systems: process control

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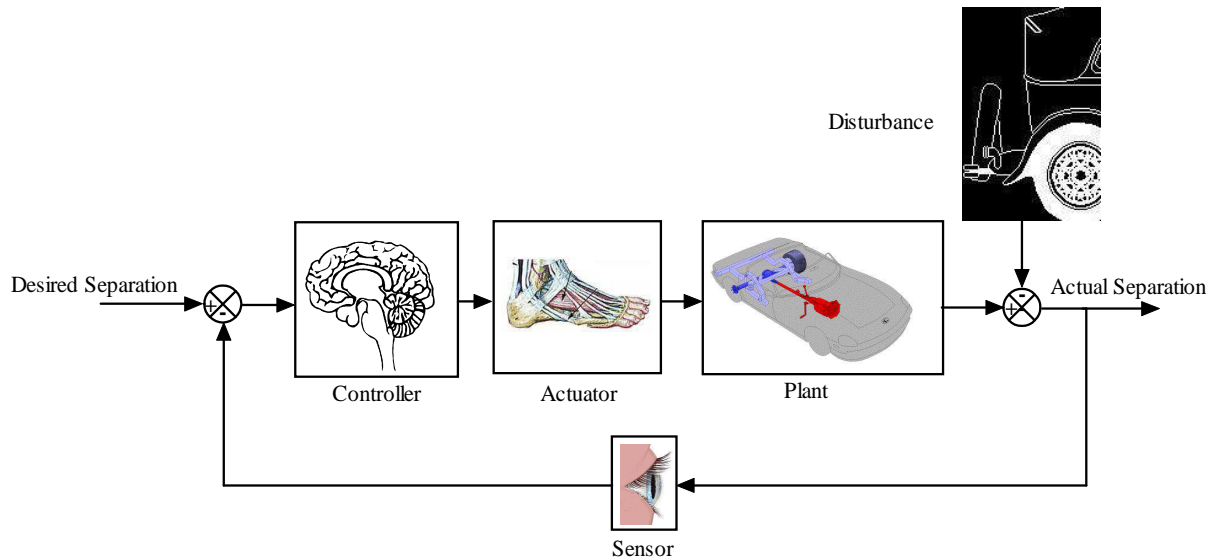
Open-Loop Control

In an open loop control system, the input applied to the process under control does not depend on the actual output. **In open-loop control there is no error correction.** Examples: 1) Toaster; 2) Clothes washer; 3) Holding the accel. pedal down with a block; 4) Not returning grades to students until final grade assigned; 5) Fan speed settings; 6) Oven temperature settings.

The severity of the disturbances determines which of the above examples can operate under open-loop control. Regardless of disturbances, the ability to *calibrate* the system can determine whether or not open-loop control is applicable. Calibration is difficult for multi-input, multi-output systems.

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Feedback: a familiar idea



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Closed-Loop (Feedback) Control

In a closed-loop control system, the input applied to the process under control depends on the actual output. **Automatic error correction is running at all times in closed-loop control.** In error feedback structures (studied in MCE441), the error between desired and actual outputs is used to calculate the input applied to the process. Coming up with this calculation is called *control design*. The calculation itself is called *control law* or *control algorithm*. The device implementing this calculation is called *controller* or *compensator*.

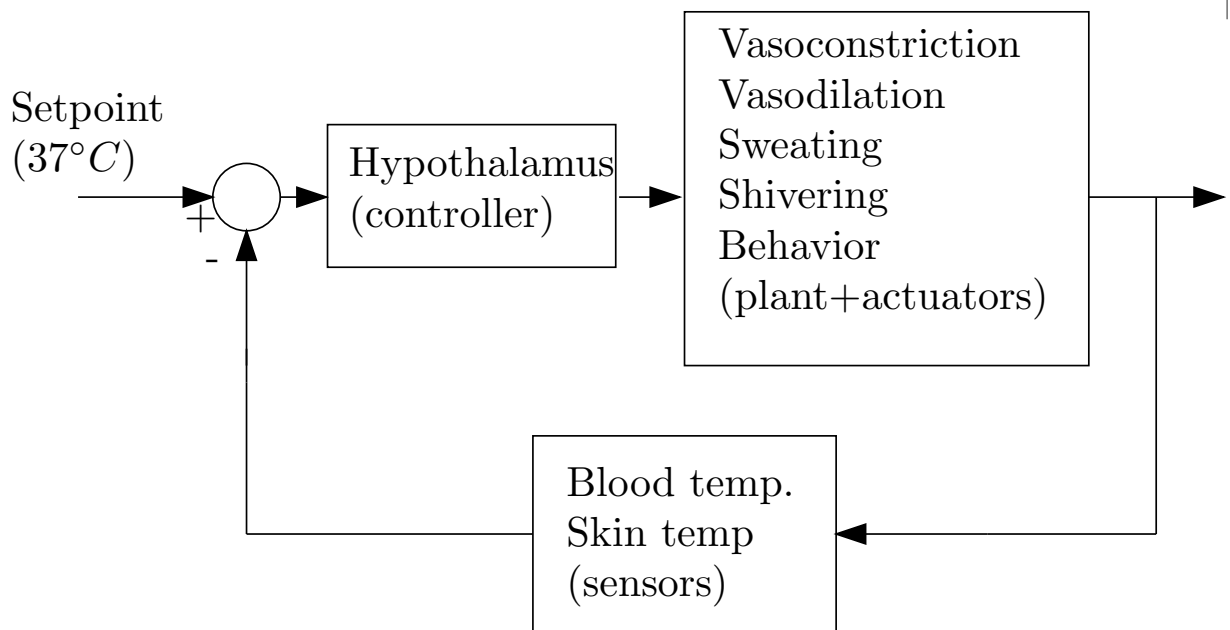
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Closed-Loop (Feedback) Control

It is important to realize that the control input is calculated *on the fly*, as the control system is running. Examples: 1) Aircraft autopilot; 2) Automotive cruise control; 3) Fancy car climate control; 4) Interest rate adjustment by the Fed to reduce inflation; 4) Increasing number of study hours after first quiz. All these involve a **running error correction**.

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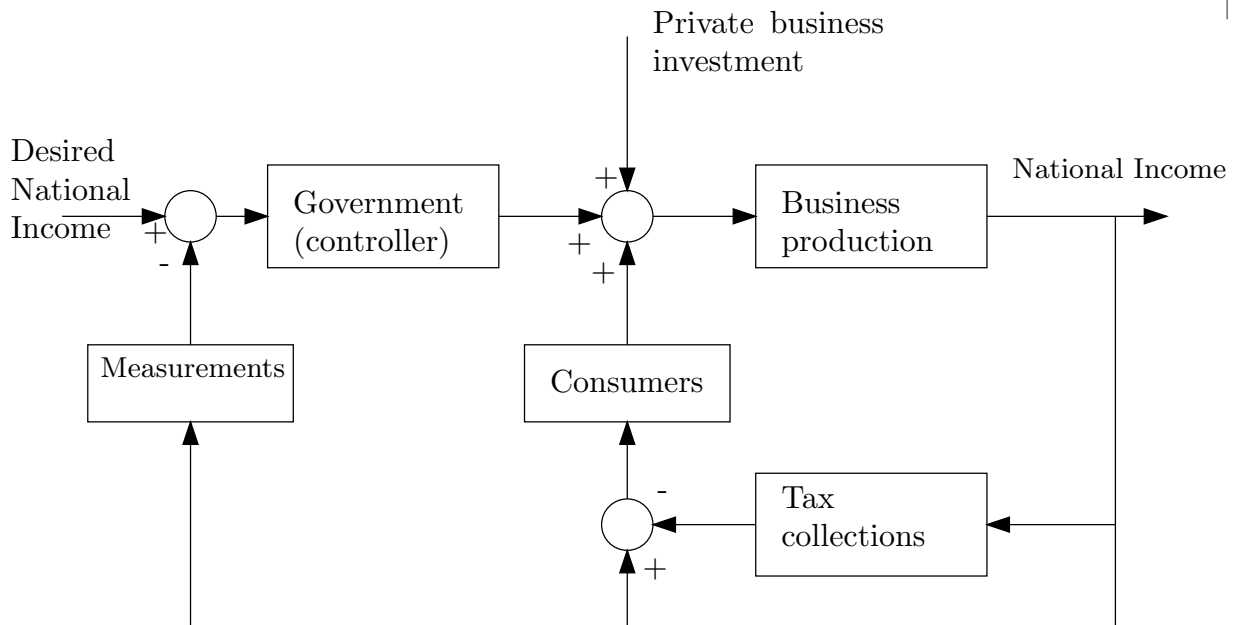
Thermal Homeostasis



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Balancing the Stick

Feedback in Economics



A little history+reading assignment

- 300 BC, Greece: Water clocks using float regulators.
- 1st century AD: Heron of Alexandria conceives water level regulators in *Pneumatica*
- 16th century, Holland: Cornelis Drebbel invents temperature regulator
- 17th century, France: Dennis Papin invents pressure regulator
- 18th century, England: James Watt's flyball governor
- 19th century, England: James C. Maxwell starts mathematical approach using ODEs

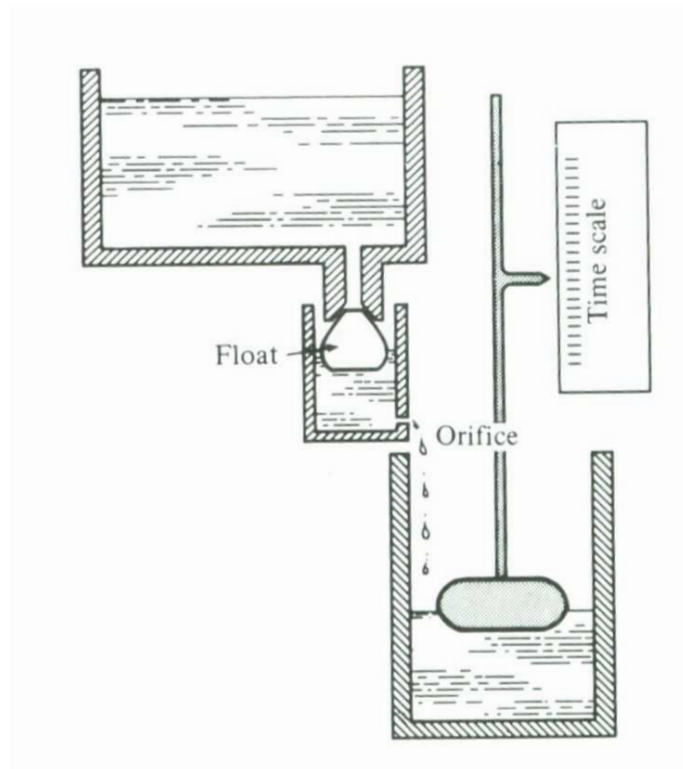
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a little history...

- 19th century, Russia: I.A. Vyshnegradskii formulates mathematical theory of regulators
- In the 20th century, Bell Labs researchers (Nyquist, Bode, Black) develop frequency domain techniques
- In Russia, mathematicians take the lead and formalize control theory in the time domain
- Control theory came from technology. Now it is an important and active branch of applied mathematics.
- Very active research field: CSS, IFAC, IEEE, ASME, AIAA, EUCA, SICE and more
- Reading assignment: Dorf, Ch. 1, articles in ME magazine

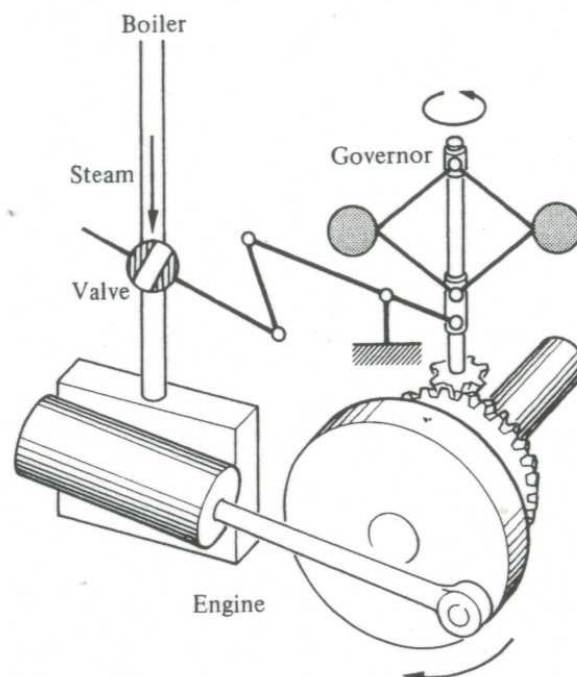
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Clepsydra (Water Clock)



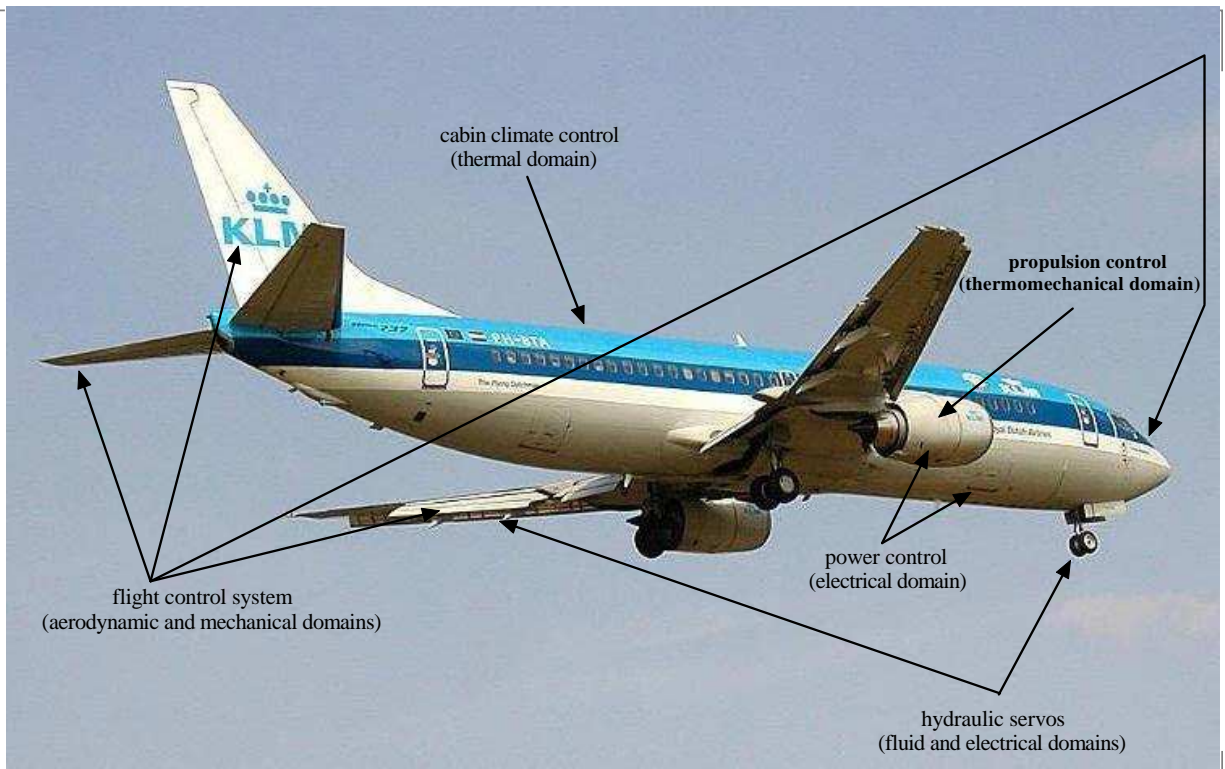
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Watt's Flyball Governor



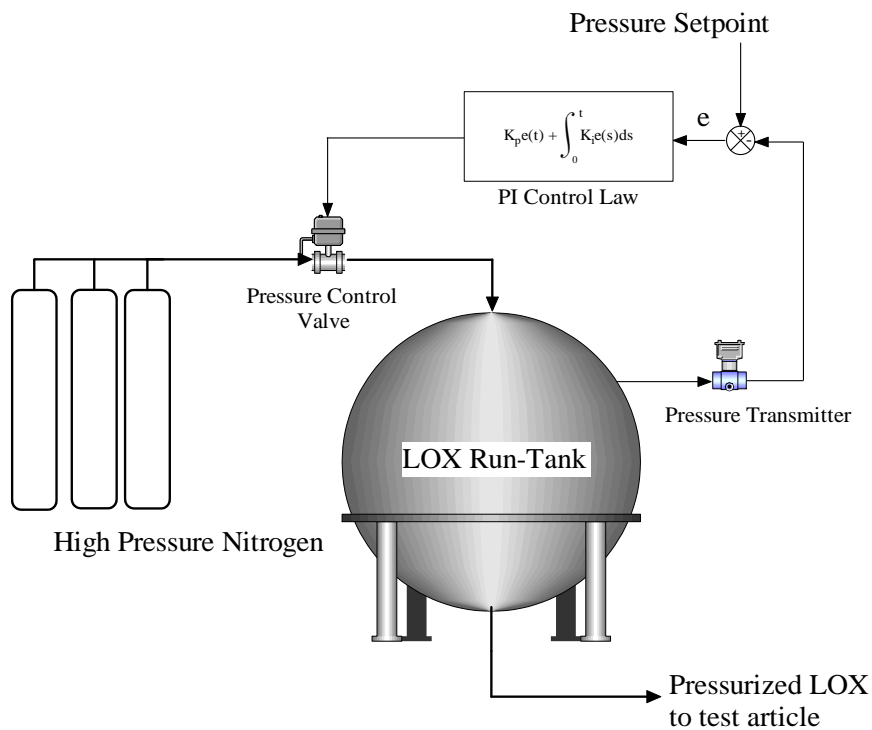
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Complex Engineering Systems



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Complex Engineering Systems



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Tech. Advances Enabled by Ctrl.

- CNC machining
- Robotics
- Implantable biomedical devices and artificial organs
- Air and space travel
- Industrial automation in general

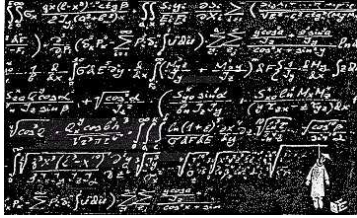
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Control in Non-Traditional Fields

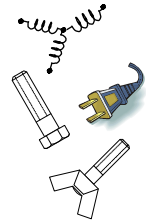
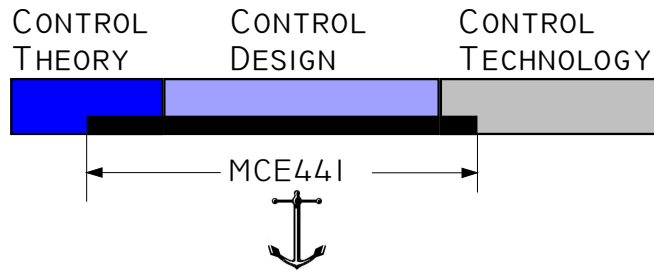
- Biology and medicine
- Congestion of Networks
- Economics
- Social systems (example: dynamics of rumor spreading)

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Our Scope



THE JOY OF MATH



BOLTS, NUTS AND WIRES

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Links

- **Honda Humanoid Robots:**
<http://asimo.honda.com/>
- **NASA Dynamics and Controls Branch:**
<http://www.grc.nasa.gov/WWW/cdtb/index.html>
- **Segway Dynamic Stabilization:**
<http://www.segway.com/individual/learn-how-wo>

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