A Brief Introduction to Feedback Control

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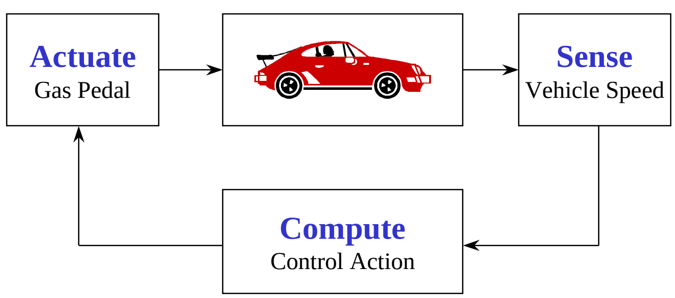
Sensing + Computation + Actuation = *Control*

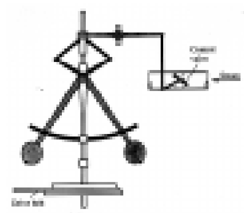


Goals: Stability, Performance, Robustness

Early Uses of Feedback

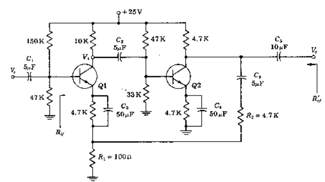
Watt Governor (1788)

- One of the first uses of feedback
- Regulate speed of steam engine
- Reduce effects of variations in load (disturbance rejection)



Feedback Amplifiers (1920s)

- Laid mathematical foundations for classical control
- Use feedback to reduce uncertainty (robustness)



Traditional Application Areas

Flight Control Systems

- Modern commercial and military aircraft are "fly by wire"
- Autoland systems, unmanned aerial vehicles (UAVs) are already in place

Robotics

- High accuracy positioning for flexible manufacturing
- Manipulation tasks are more difficult and still emerging

Chemical Process Control

- Regulation of flow rates, temperature, concentrations, etc.
- Long time scales, but only crude models of process

Heating Ventilation and Air Conditioning (HVAC)

- Basic thermostatic controls to building level systems
- Very distributed system with many local control loops

Automotive

- Engine control, transmission control , cruise control, climate control, etc
- Luxury sedans: 12 control instruments in 1976, 42 in 1988, 67 in 1991

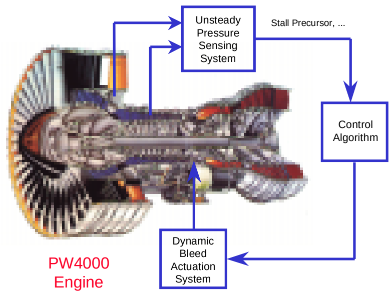
Emerging Application Areas

Materials Processing
- Rapid thermal processing for increased throughput
- Control of vapor deposition process for special purpose materials (e.g. thin films)

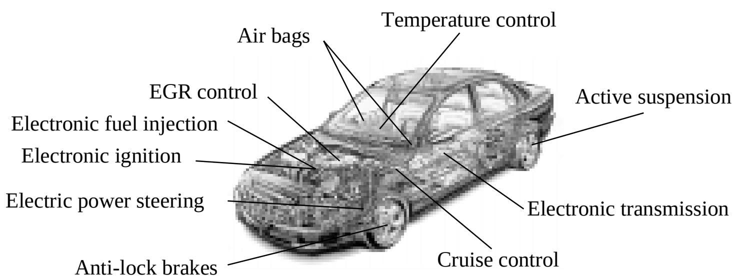
Noise and Vibration Control
- Active mounts and speaker systems for noise and vibration reduction
- Variety of applications: cars, planes, HVAC

Intelligent Vehicle Highway Systems
- Platooning of cars for high speed, high density travel on freeways
- PATH project in California is already in test near San Diego

Smart (Jet) Engines
- Compression systems: stall, surge, flutter control for increased operability
- Combustion systems: operation at leaner air/fuel ratios for low emissions



Feedback Control in Automobiles



1995 engine control summary
- 10 sensors, 20 actuators, 32 control functions
- 96K program memory

Source: Barron & Powers, *IEEE/ASME T. Mechatronics*, Mar 96

Reasons for increase in control functions
- Emissions/fuel economy requirements
- Safety
- Comfort/performance

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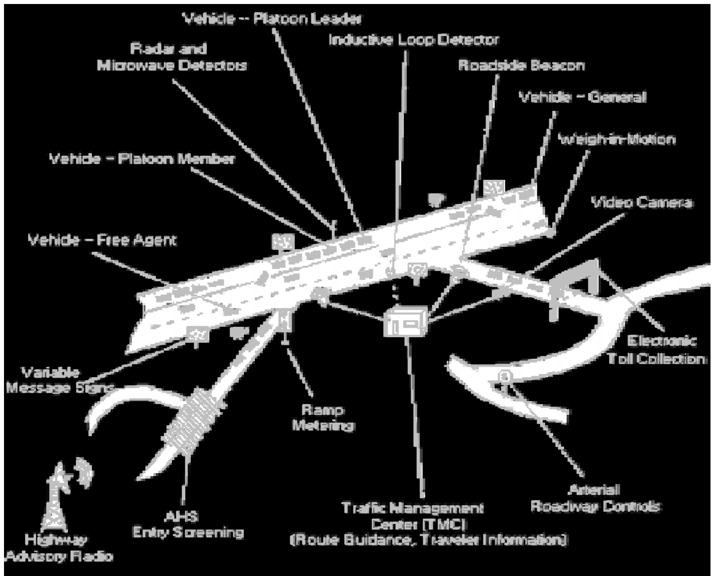
Intelligent Vehicle Highway Systems (IVHS)



Sensing + Computation + Action = Control

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A Brief History of Control Theory

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Classical control 1940

- Frequency domain based tools; stability via gain and phase margins
- Mainly useful for single-input, single output (SISO) systems
- Still one of the main tools for the practicing engineer

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Modern control 1960

- “State space” approach to linear control theory
- Works for SISO and multi-input, multi-output (MIMO) systems
- Performance and robustness measures are often not made explicit

CDS 112

Post-modern control 1980

- Generalizes ideas in classical control to MIMO context
- Uses operator theory at its core, but can be easily interpreted in frequency domain

Nonlinear control 1990

- Specialized techniques for control of nonlinear plants

8

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Representations of Systems

Ordinary Differential Equations

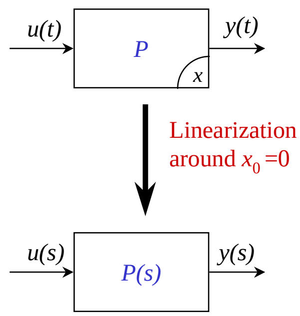
$$\dot{x} = f(x,u)$$
$$y = h(x,u)$$

Linearization around x_0=0

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$

Laplace transform

Block diagrams



$$P(s) = \frac{a_{n-1}s^{n-1} + \cdots + a_0}{s^n + b_{n-1}s^{n-1} + \cdots + b_0}$$

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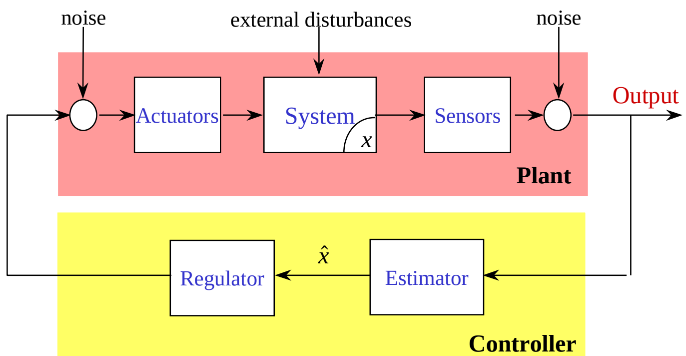
Control System Components



Plant	Physical system, actuation, sensing
Controller	State estimator plus regulator
Feedback	Interconnection between plant output, controller input

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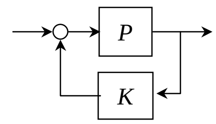
Stability, Robustness, Performance

Stability: bounded inputs produce bounded outputs

- Necessary and sufficient condition: check for nonzero solutions around feedback loop
- Basic problem: positive feedback (internal or external)

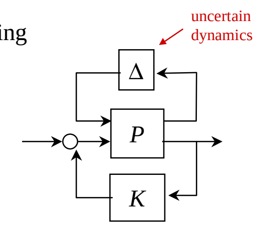


Performance: achieve desired response

- Specify performance in terms of frequency response
- Main problems: disturbance rejection, command following

Robustness: stability/performance in the presence of unknown dynamics

- Check for stability in presence of uncertainty
- Need to check stability for *set* of systems
- "Small gain theorem" gives tight conditions based on bounds of uncertainty operator



$$\boxed{\text{No uncertainty} \implies \text{No need for feedback}}$$

11