Eastern **M**editerranean **U**niversity
Faculty of **E**ngineering
Department of **M**echanical **E**ngineering

MENG332 – Systems Control

Instructor: Assist. Prof. Dr. Mostafa Ranjbar
Office: To be announced
Office Hours: To be announced
E-mail: To be announced
Phone: To be announced
Lecture Hours: To be announced (Based on 4 classes per week)
Tutorials: To be announced (One-Hour per week)
Assistant: To be announced

Course Number:	**Credits:**	**Year/Semester:**	**Required Course:**	**Prerequisite(S):**
MENG332	4 Credits	2013-2014 Spring	Yes	MENG331

Course Description:

- Control engineering mathematics, complex variables and Laplace transforms.
- Initial and final value theorems.
- Introduction to practical controllers and control principles.
- Mathematical modeling of dynamic systems, transfer functions and block diagrams, transient response analysis, stability analysis.
- Analysis of system s, deviation of transfer function and frequency response for various systems, devices and elements.

Course Web Page: To be announced

Textbook:
R. C. Dorf and Robert H. Bishop, Modern Control Systems, Prentice Hall, 11th edition, 2007.

Topics:

Week 1	Introduction to Control Systems
Weeks 2-3	Mathematical Models of Systems
Weeks 3-4	Feedback Control System Characteristics
Weeks 4-5	Performance of Feedback Control Systems
Weeks 5-6	Stability of Linear Feedback Systems
Weeks 6-7	The Root Locus Method
Weeks 8-9	**Midterm Examination**
Week 10-11	Frequency Response Method
Weeks 11-12	Stability in the Frequency Domain
Weeks 12-14	The Design of Feedback Control Systems
Week 15	**Final Examination**

Laboratory Schedule: To be announced

Assesment:
Midterm Exam: 25%
Homework: 15% (No late homework will be accepted.)
Quizzes and/or Laboratory: 10%
Design Projects: 10%
Final Examination: 40%

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Laboratory Work: To be announced.

Contents in the lecture

1. Introduction to Control Systems (1 week)
   * Introduction
   * Examples
   * Control system design
2. Mathematical Models of Systems (1.5 weeks)
   * Differential equations of physical systems
   * Laplace Transform
   * Transfer function and block diagram
3. Feedback Control System Characteristics (1.5 weeks)
   * Open- and closed-loop control systems
   * Sensitivity of control systems to parameter variations
   * Transient response and steady-state error of control systems
4. Performance of Feedback Control Systems (1.5 weeks)
   * Test input signal
   * Performance of a second-order system
   * Estimation of damping ratio
   * Performance Indices

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5. Stability of Linear Feedback Systems (1.5 weeks)
   * The concept of stability
   * The Routh-Hurwitz stability criterion
   * The relative stability of feedback systems
6. The Root Locus Method (1.5 weeks)
   * The Root Locus concept
   * The Root Locus procedure
   * Design example
7. Frequency Response Method (1.5 weeks)
   * Frequency response plots
   * Performance specification in the frequency domain
   * Log magnitude and phase diagrams
8. Stability in the Frequency Domain (1.5 weeks)
   * The Nyquist Criterion and its applications
   * Relative stability and the Nyquist criterion
9. The Design of Feedback Control Systems (1.5 weeks)
   * Phase-Lead and Phase-Lag compensation
   * Compensation using Root Locus and Bode Diagram

How To Succeed In This Course

- Before Class
  - Review material (notes and textbook) from previous class
  - Preview material (textbook and notes if available) to be covered
  - Arrive on time

- During Class
  - Attend all classes and tutorials – not everything is on the website!
  - Pay attention, take notes and ask questions if needed

- After Class

  Review material (notes and textbook)

  Identify and understand key issues

  Do all the problem sets assigned in time

Motivation

- Control is a key enabling technology in all branches of engineering. It is often invisible to the user.
- Control methods are used whenever some quantity, such as temperature, altitude or speed, must be made to behave in some desirable way over time.

Applications of Control

- Control is used extensively in industry to run plants at maximum efficiency and minimal environmental impact while making products with stringent quality specifications
- Most modern industrial plants could not operated without control systems

Applications of Control

- Control is used in a variety of devices to obtain performance that simply would not be attainable otherwise
    - Black invention of feedback amplifier
    - Aeroplane autopilots
    - Disk drives and CD players
    - Cellular telephones
    - ABS in cars
    - Prosthetics
    - Etc…

Use of Control Theory

- Systems and control theory can be used to understand
  - Biological systems
    - Cell regulation mechanisms
    - Population dynamics
    - Epidemiology
  - Economic systems
    - Inflationary mechanisms
    - Fiscal policies

Implementation of Control

- Control operations are often implemented in an embedded microprocessor that observes signals from sensors and provides command signals to electromechanical actuators.
- Designers use Computer-Aided Design software (Matlab for example)
- Design usually tested on simulations before implementation
- Control engineering requires a thorough understanding of the application area

Foundations and Methods

- The study of dynamic systems is central to control engineering
- Feedback is a key concept
- Firm mathematical foundations
  - Differential or difference equations
  - Laplace and z-transforms
  - Fourier transform
  - Stability theory

Challenges in Control

- Autonomous systems able to function in presence of significant uncertainty and failures
- Autonomous land, underwater, air and space vehicles
- Highly automated manufacturing
- Intelligent robots
- Highly efficient and fault tolerant voice and data networks
- Reliable electric power generation and distribution
- Seismically tolerant structures
- Highly efficient fuel control for a cleaner environment

Course Content

- Mathematical models (ODE, transfer function, state-space)
- Feedback control (characteristics, performance and stability)
- Frequency domain analysis and design
- State feedback

Goals of the Course

- Understand the role of control in engineering systems
- Know key ideas and concepts of Dynamics and Feedback
- Understand relevant mathematical theory
- Be able to solve simple control design problems
- Know relevant computational tools
- Recognize difficult control problems

Introduction to Control Systems

- The discipline of control
- Brief history
- The principle of feedback
- Sensors and Actuators
- Control system design

The Discipline of Control

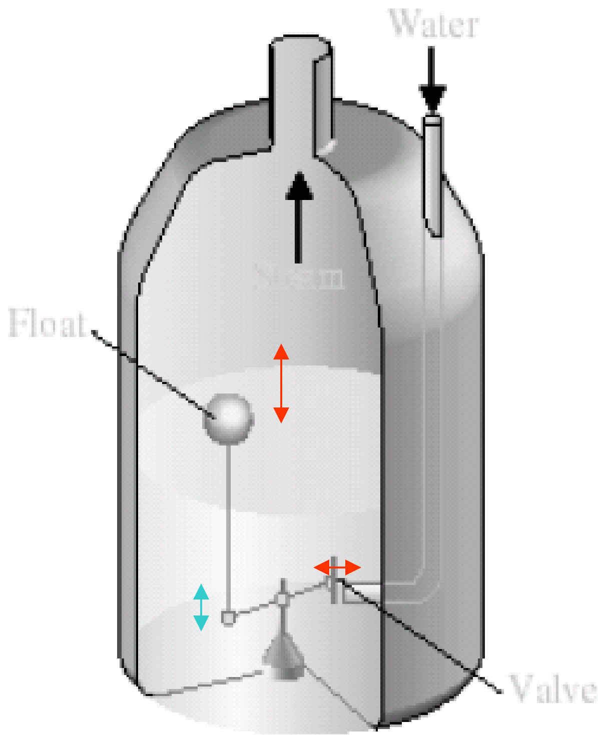
- The central goal of control engineering is the design of a technically feasible way to act on a given process so that it behaves in a prescribed manner.

- The desired behaviour should be achieved as closely as possible in the presence of
  - uncertainty in the process (modelling error)
  - uncontrollable external disturbances acting on the process (process and measurement noise).

Control Engineering

- At the core of control engineering are
  - Feedback theory
  - Linear system analysis
- The idea of feedback was known in ancient Egypt and ancient Greece, in particular the float regulator used in waterclocks

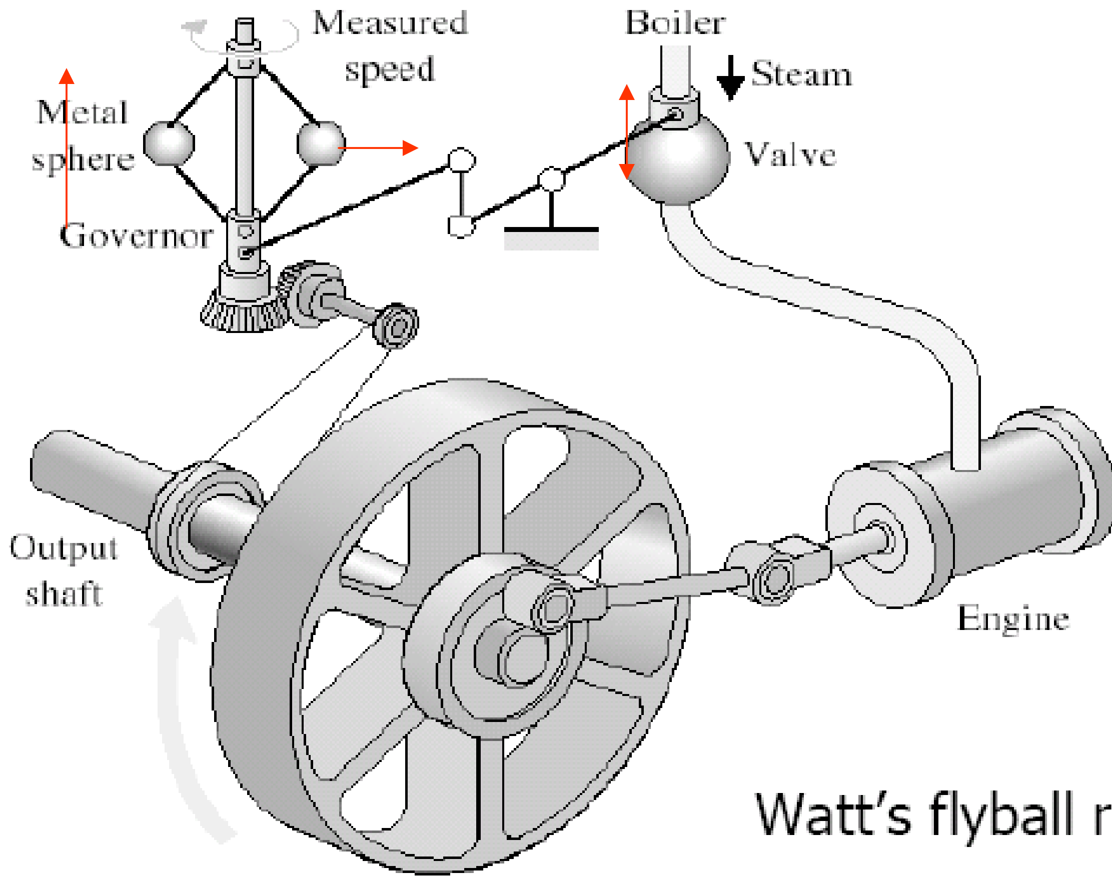
The Concept of Feedback



Water-level

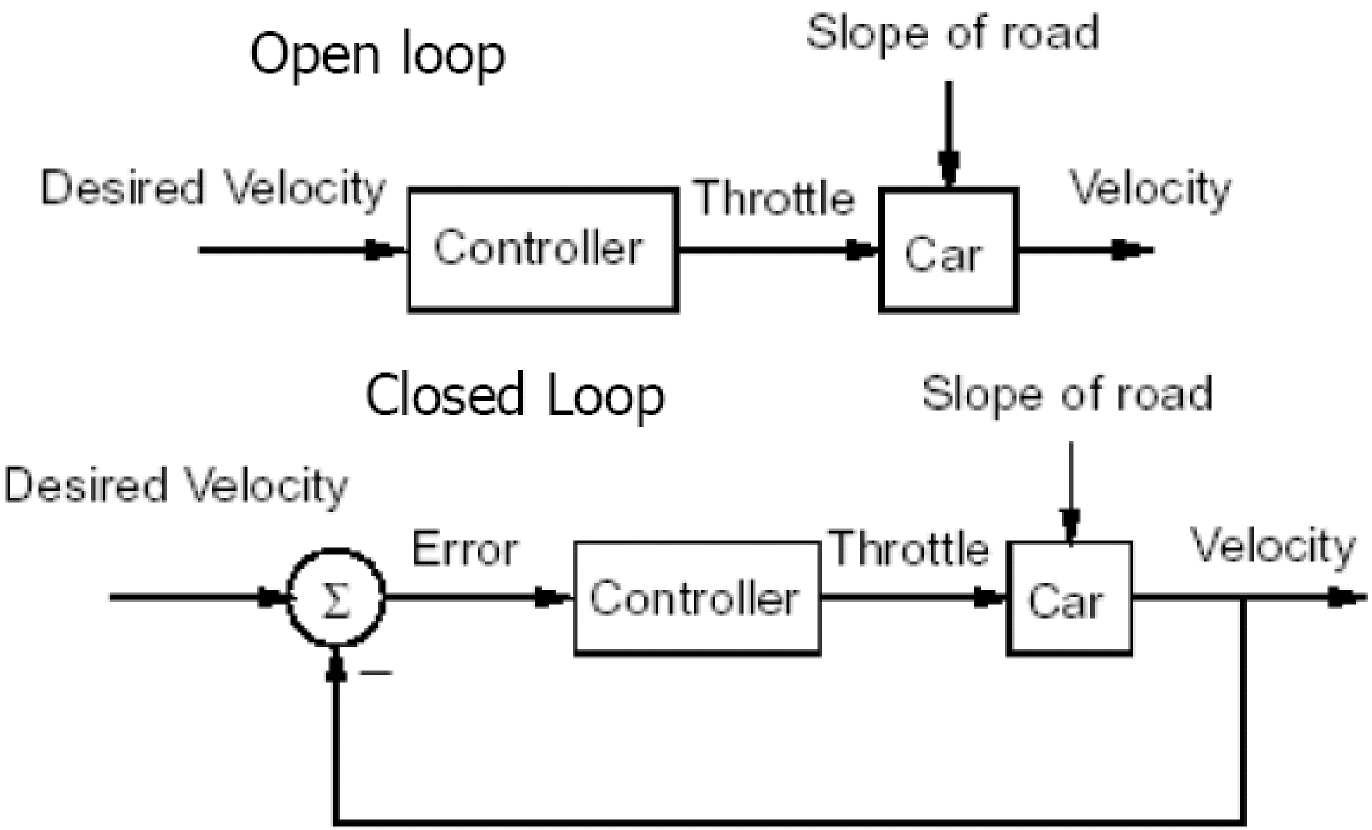
float regulator

The Concept of Feedback

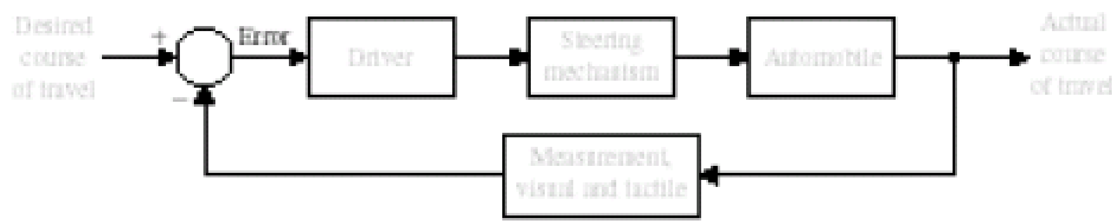


Watt's flyball regulator

Automobile Cruise Control

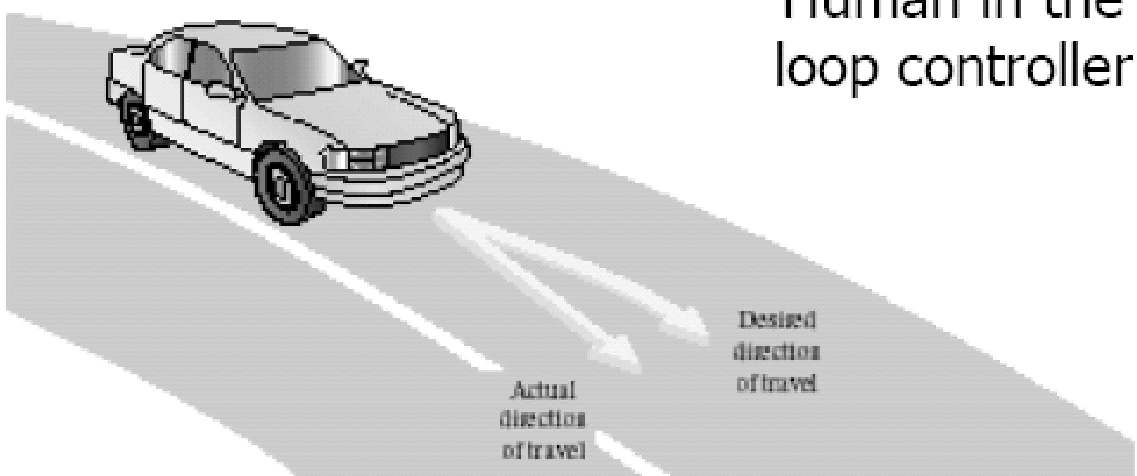


Car Steering



(a)

Human in the loop controller



"Modern" History of Control

TABLE 1.1 Selected Historical Developments of Control Systems

1769	James Watt's steam engine and governor developed. The Watt steam engine is often used to mark the beginning of the Industrial Revolution in Great Britain. During the Industrial Revolution, great strides were made in the development of mechanization, a technology preceding automation.
1800	Eli Whitney's concept of interchangeable parts manufacturing demonstrated in the production of muskets. Whitney's development is often considered as the beginning of mass production.
1868	J. C. Maxwell formulates a mathematical model for a governor control of a steam engine.
1913	Henry Ford's mechanized assembly machine introduced for automobile production.
1927	H. W. Bode analyzes feedback amplifiers.
1932	H. Nyquist develops a method for analyzing the stability of systems.
1952	Numerical control (NC) developed at Massachusetts Institute of Technology for control of machine-tool axes.
1954	George Devol develops "programmed article transfer," considered to be the first industrial robot design.
1960	First Unimate robot introduced, based on Devol's designs. Unimate installed in 1961 for tending die-casting machines.
1970	State-variable models and optimal control developed.
1980	Robust control system design widely studied.
1990	Export-oriented manufacturing companies emphasize automation.
1994	Feedback control widely used in automobiles. Reliable, robust systems demanded in manufacturing.

The Idea of Feedback

- Compare actual behaviour with desired behaviour
- Take corrective action based on the difference
- Deceivingly simple idea, but very powerful concept
- Feedback is a key idea in control

Open-Loop Control

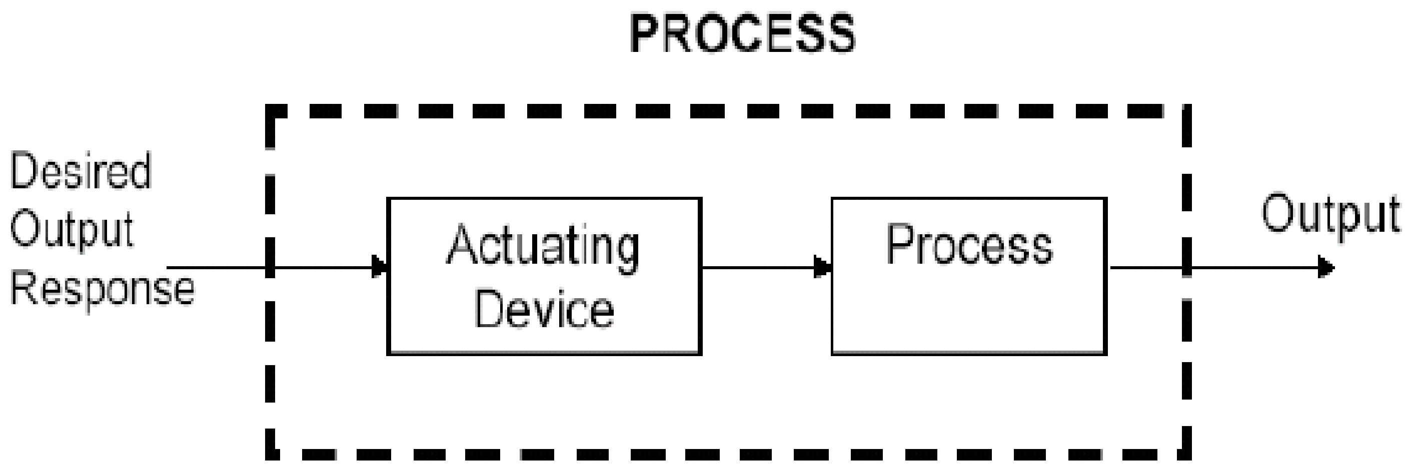


Figure 1.2 Open-loop Control System (without feedback)

Examples?

Closed-Loop Control

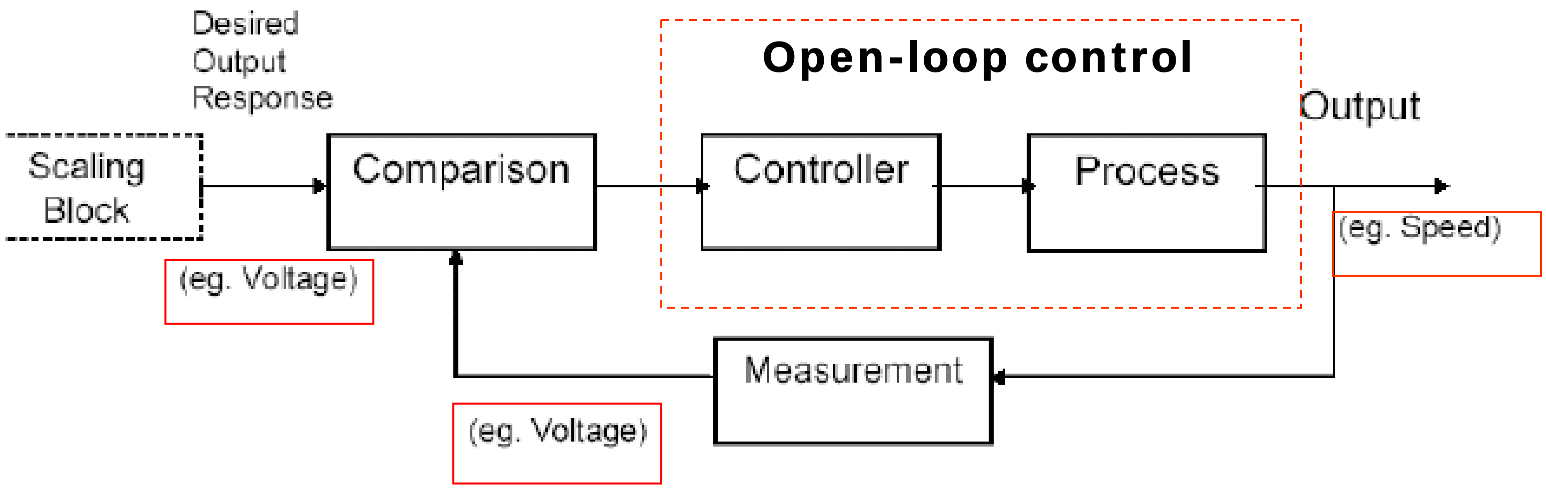
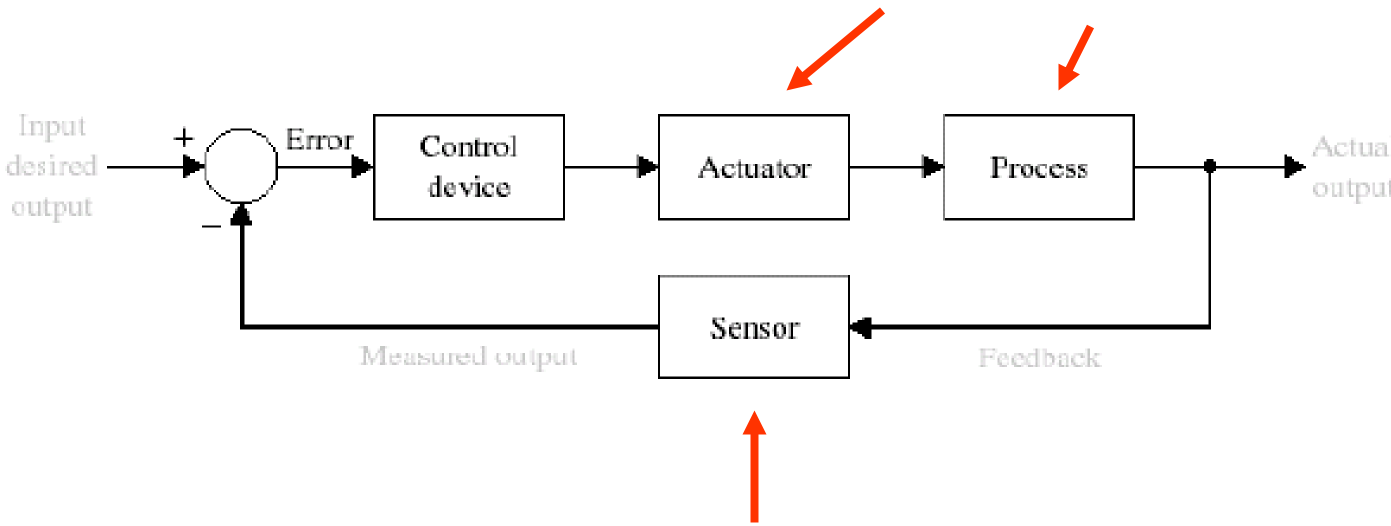


Figure 1.3 Closed-loop Control System (with feedback)

Typical Feedback Loop

- The sensor and the actuator are key components of the feedback loop



Process

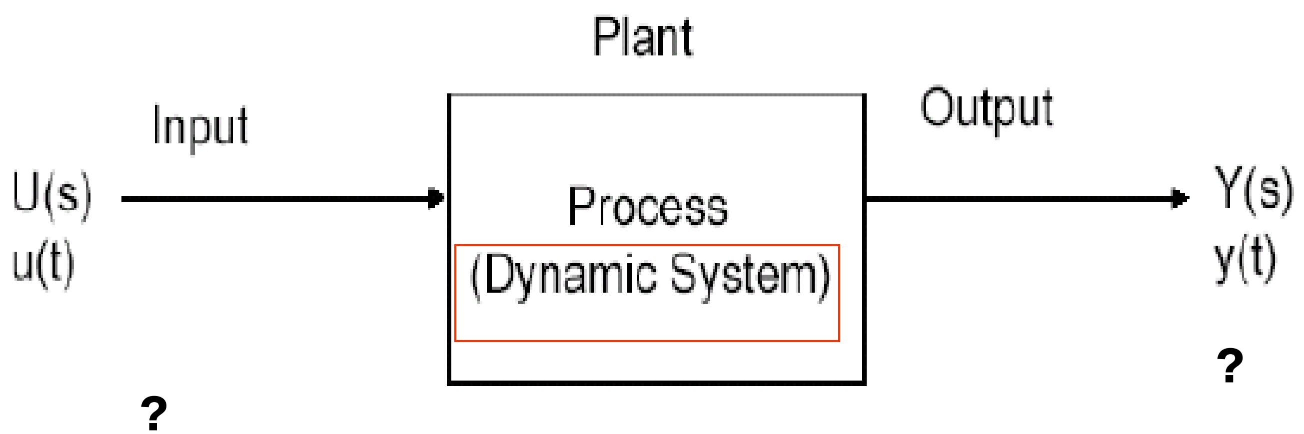


Figure 1.1 Process to be controlled

Desirable Sensor Attributes

- Reliability
- Accuracy
- Responsiveness
- Noise immunity
- Linearity
- Non-intrusiveness

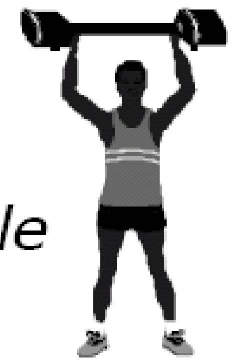
"If it can be measured, it can be controlled"

Actuators

- Actuators provide the ability to affect or actuate the process in order to move from its current state to the desired state
- Actuators should be sized appropriately and be as linear as possible (minimum backlash, stiction, hysteresis)

Better Sensors

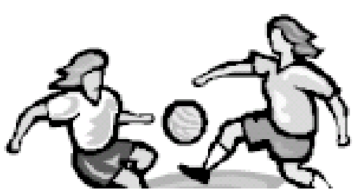
Provide better *Vision*

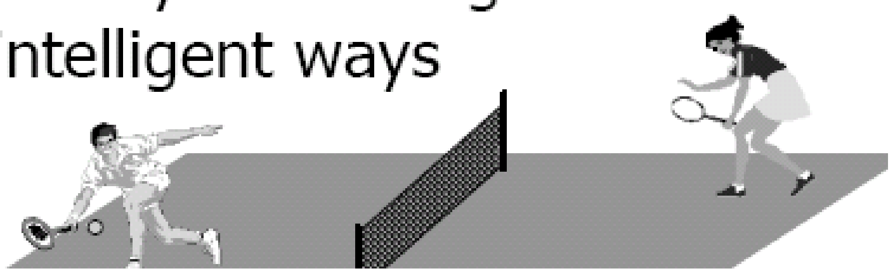


- **Better Actuators**
  Provide more *Muscle*

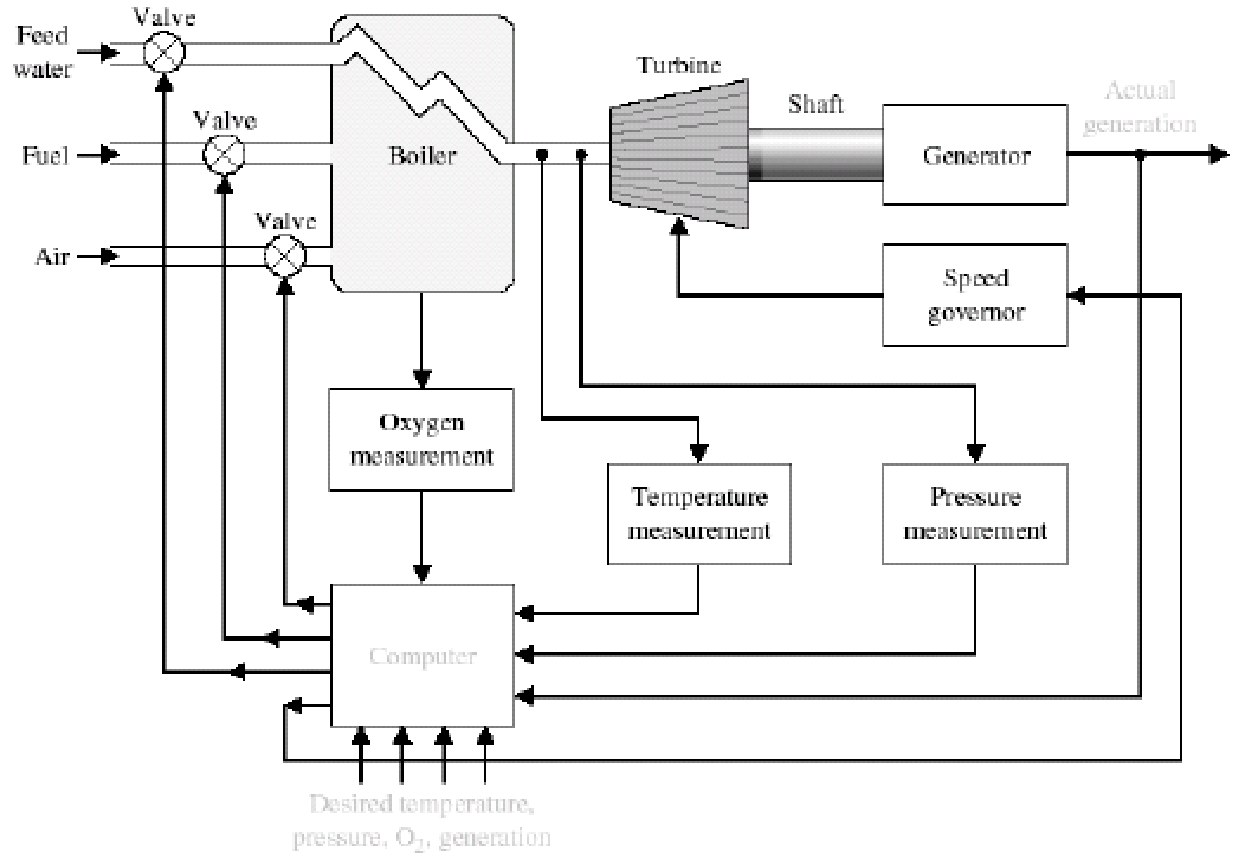
Better Control

Provides more finesse by combining *sensors* and *actuators* in more intelligent ways





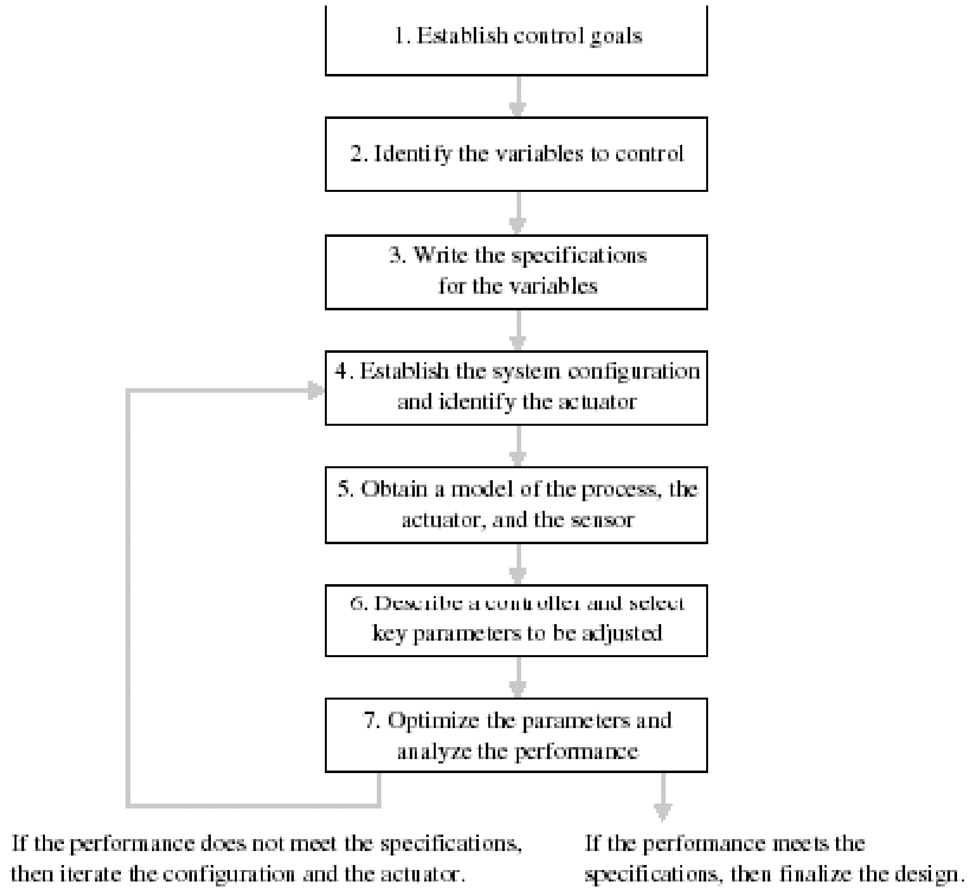
Multivariable Control



Control Objectives

- Two broad classes of control problems
  - The regulator problem:Controlled output is held as close as possible to a constant setpoint, despite disturbances
    - **Temperature control, water lever control, ect.**
  - The servomechanism or tracking problem: Controlled output follows as closely as possible a time-varying command, despite disturbances
    - Tanker autopilot, radar tracking device

Control System Design Process



Fundamental Trade-off in Control Design

- Increasing the responsiveness of a control system increases sensitivity to
  - Measurement noise
  - Actuator imperfections
  - Model uncertainty
- Control design consists of designing the controller that achieves the optimal trade-off between performance and robustness

Examples

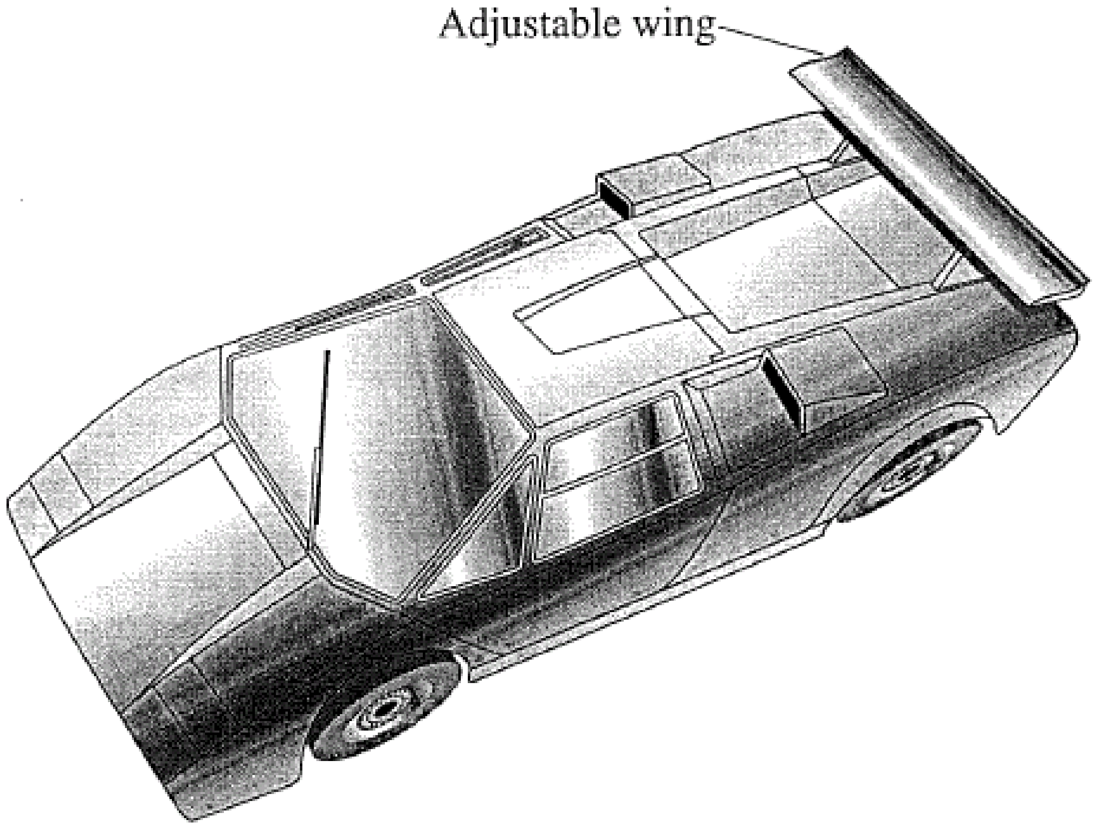
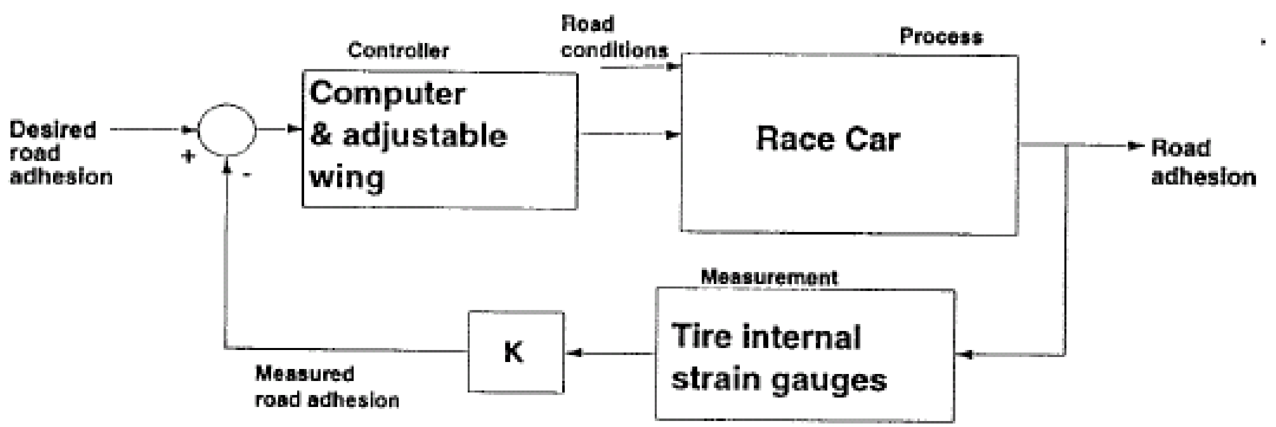


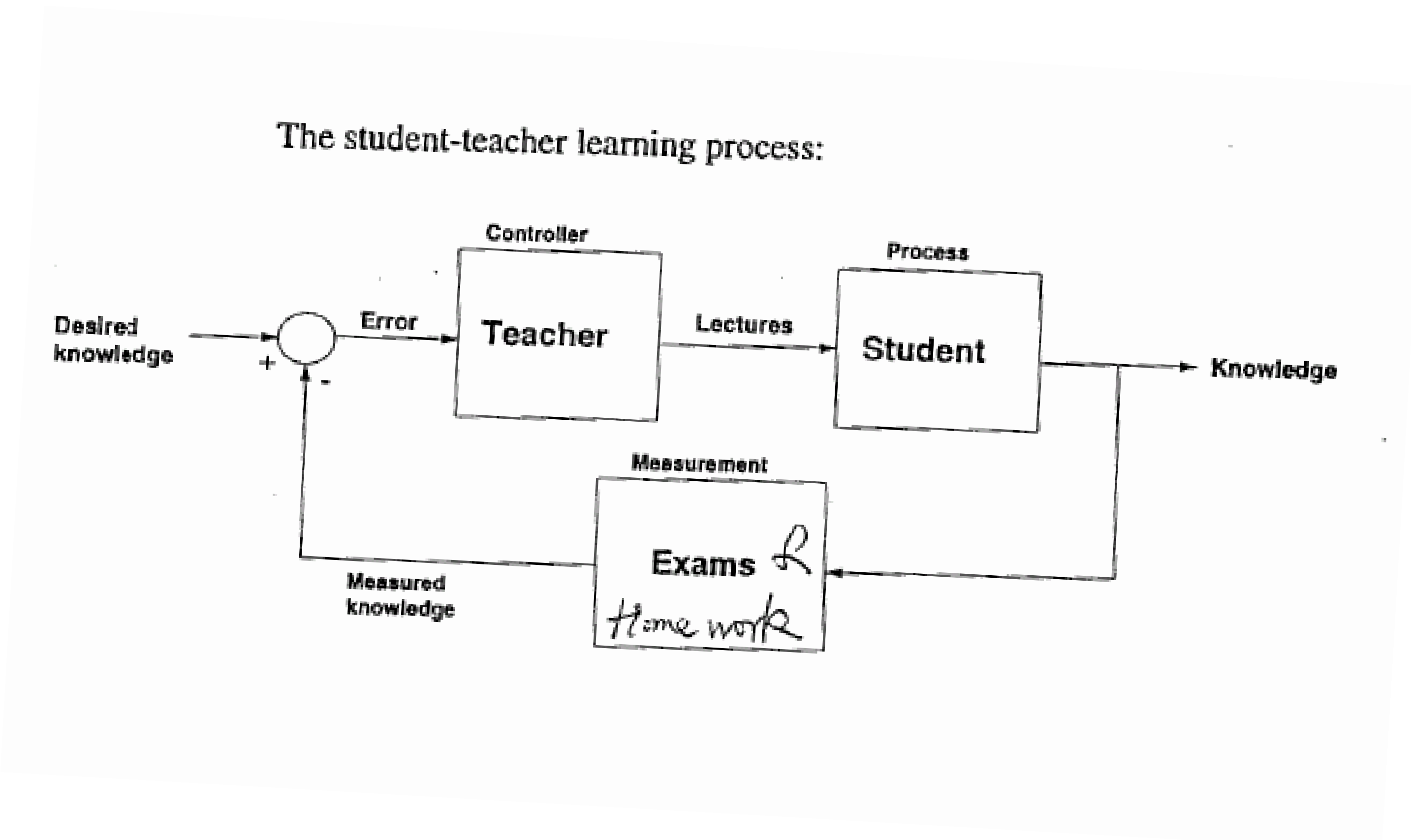
Figure P1.20 A high-performance race car with an adjustable wing

Examples

A control system for a high-performance car with an adjustable wing:



Examples



The student-teacher learning process:
Controller
Process
Desired knowledge
+
-
Error
Teacher
Lectures
Student
Knowledge
Measurement
Exams
Measured knowledge
Home work