CONTROL SYSTEMS

Introduction to Control Systems

A control system consisting of interconnected components is designed to achieve a desired purpose. To understand the purpose of a control system, it is useful to examine examples of control systems through the course of history. These early systems incorporated many of the same ideas of feedback that are in use today.

Modern control engineering practice includes the use of control design strategies for improving manufacturing processes, the efficiency of energy use, advanced automobile control, including rapid transit, among others.

The design gap exists between the complex physical system under investigation and the model used in the control system synthesis.

The iterative nature of design allows us to handle the design gap effectively while accomplishing necessary tradeoffs in complexity, performance, and cost in order to meet the design specifications.

Introduction

System – An interconnection of elements and devices for a desired purpose.

Control System – An interconnection of components forming a system configuration that will provide a desired response.

Process – The device, plant, or system under control. The input and output relationship represents the cause-and-effect relationship of the process.

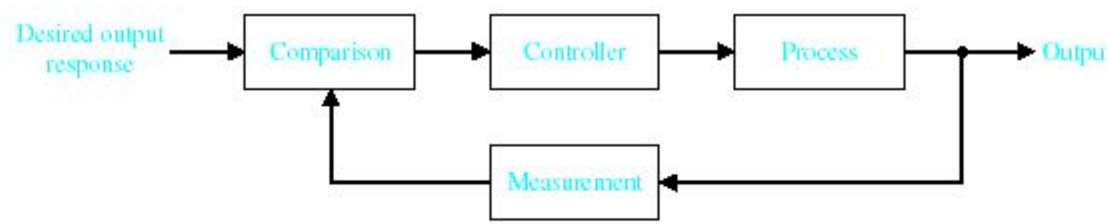
Process to be controlled.

Introduction

Open-Loop Control Systems utilize a controller or control actuator to obtain the desired response.

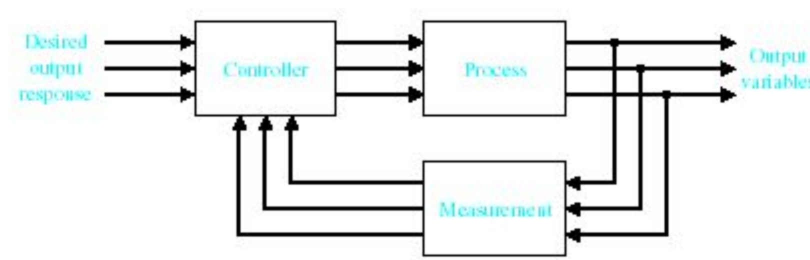
Open-loop control system (without feedback).

Closed-Loop Control Systems utilizes feedback to compare the actual output to the desired output response.



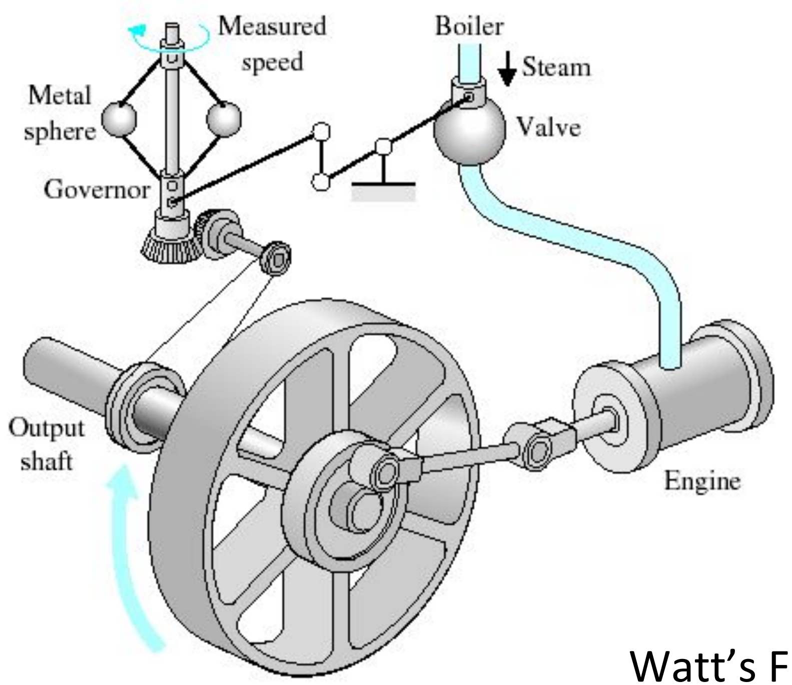
Closed-loop feedback control system (with feedback).

Multivariable Control System



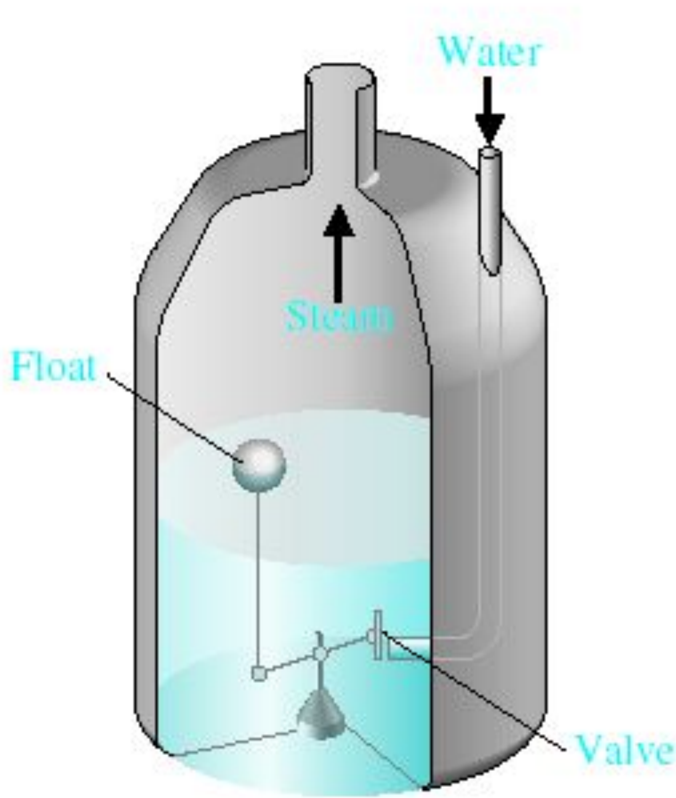
History

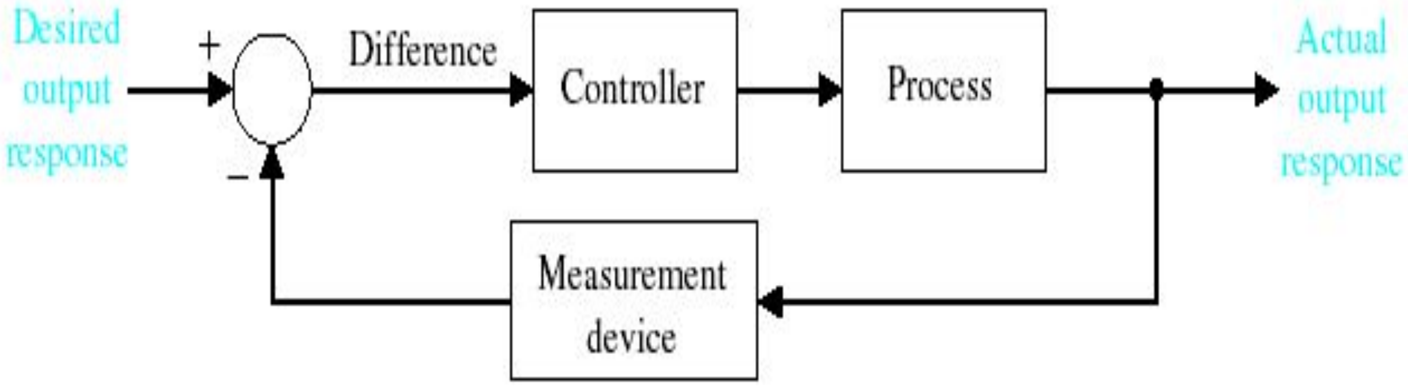
Greece (BC) – Float regulator mechanism
Holland (16th Century)– Temperature regulator



Watt's Flyball Governor
(18th century)

Water-level float regulator





Closed-loop feedback system.

History

18th Century James Watt’s centrifugal governor for the speed control of a steam engine.

1920s Minorsky worked on automatic controllers for steering ships.

1930s Nyquist developed a method for analyzing the stability of controlled systems

1940s Frequency response methods made it possible to design linear closed-loop control systems

1950s Root-locus method due to Evans was fully developed

1960s State space methods, optimal control, adaptive control and

1980s Learning controls are begun to investigated and developed.

Present and on-going research fields. Recent application of modern control theory includes such non-engineering systems such as biological, biomedical, economic and socio-economic systems

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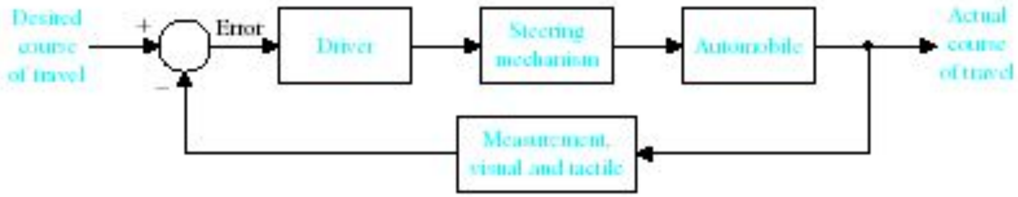
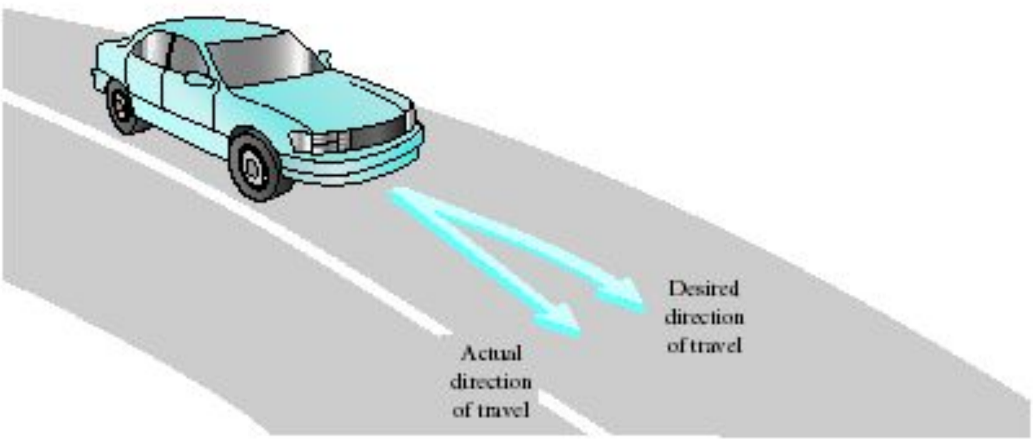
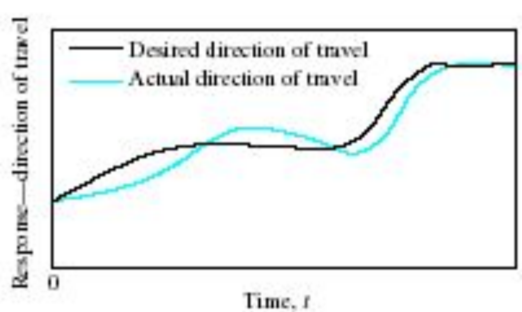
Examples of Modern Control Systems



(a)



(b)



(c)

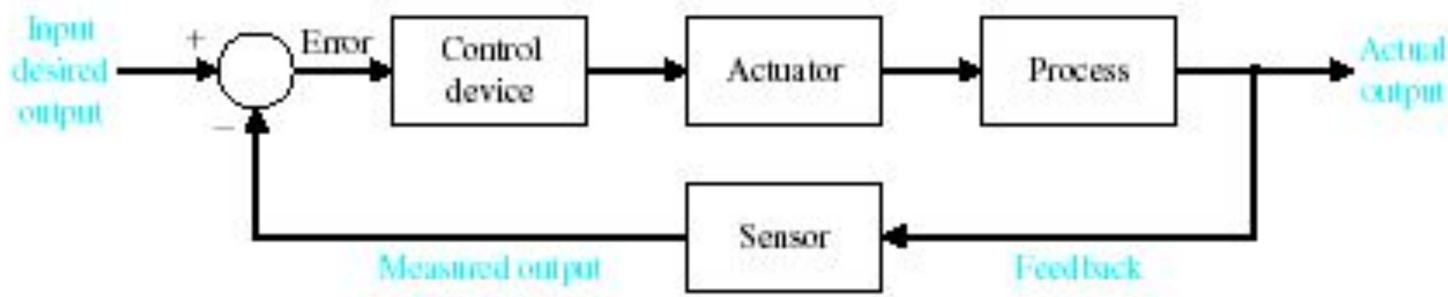
(a) Automobile steering control system.

(b) The driver uses the difference between the actual and the desired direction of travel

to generate a controlled adjustment of the steering wheel.

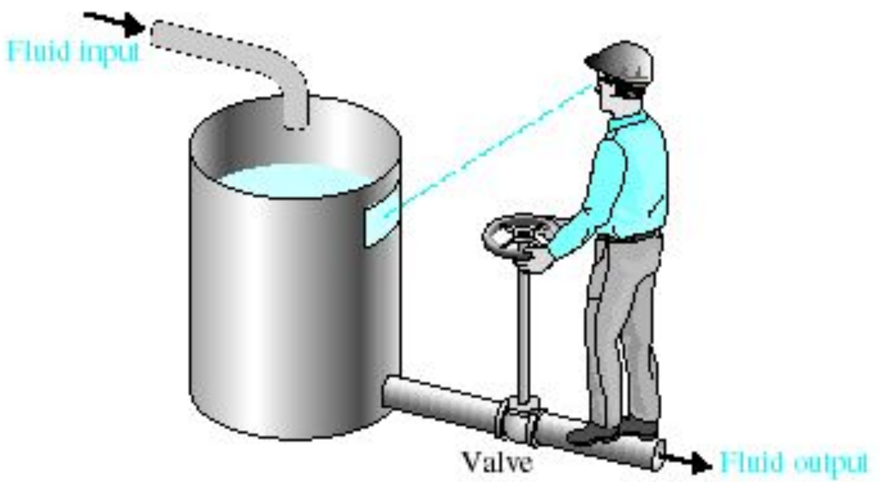
(c) Typical direction-of-travel response.

Examples of Modern Control Systems



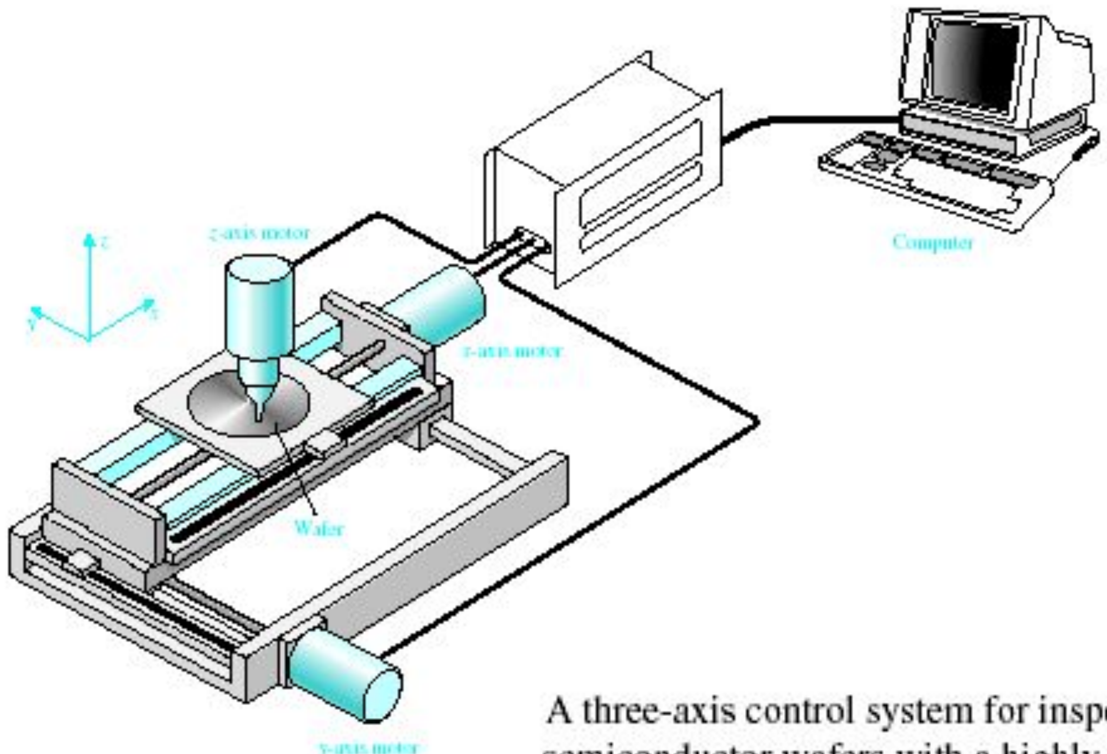
A negative feedback system block diagram depicting a basic closed-loop control system.
The control device is often called a "controller."

Examples of Modern Control Systems



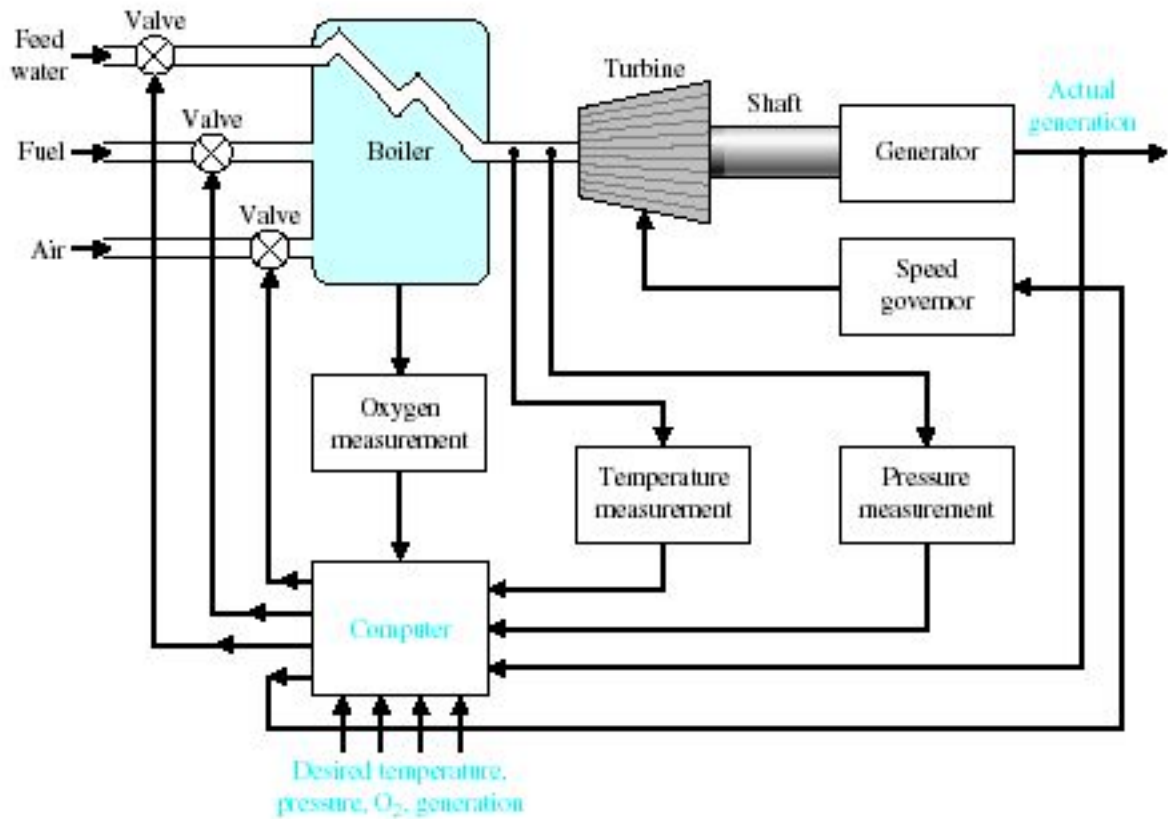
A manual control system for regulating the level of fluid in a tank by adjusting the output valve. The operator views the level of fluid through a port in the side of the tank.

Examples of Modern Control Systems



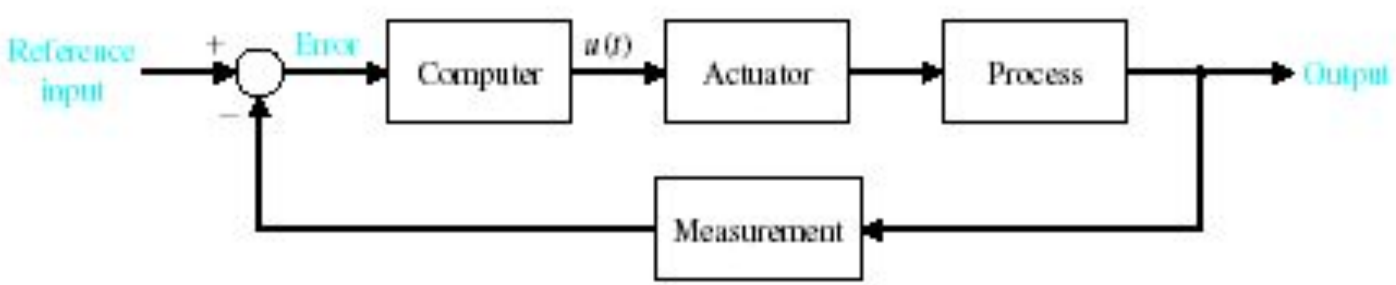
A three-axis control system for inspecting individual semiconductor wafers with a highly sensitive camera.

Examples of Modern Control Systems



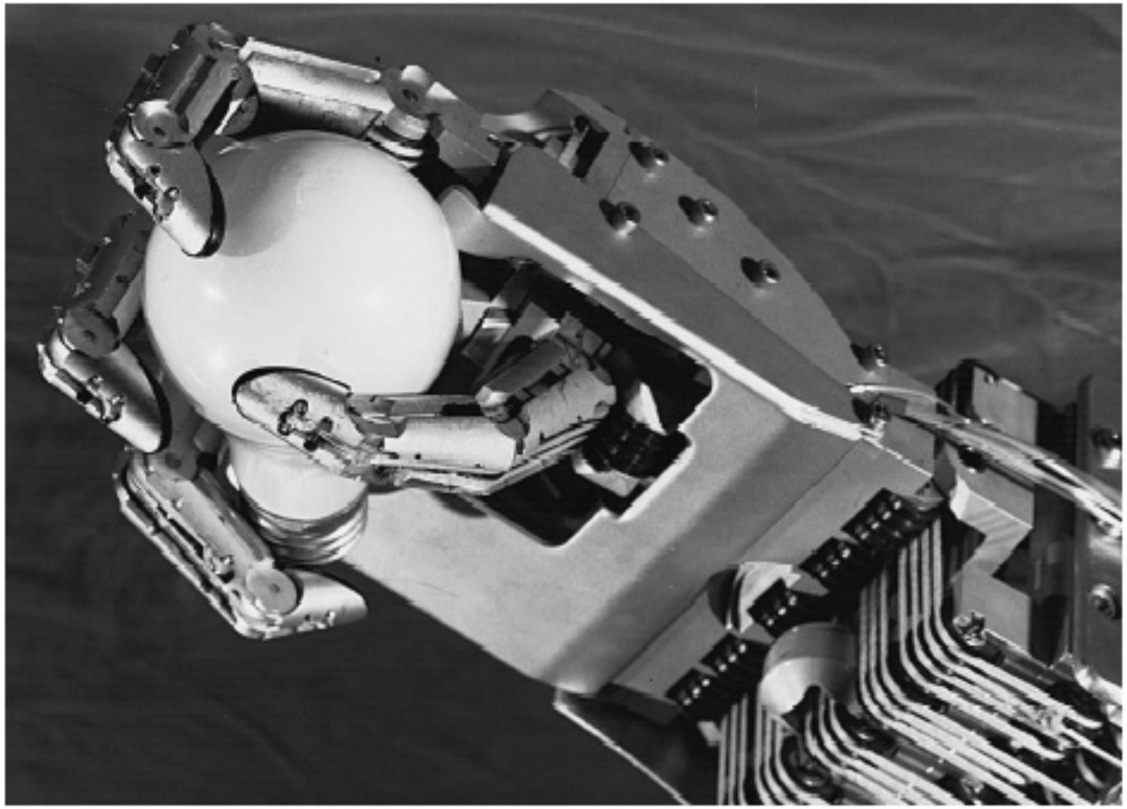
Coordinated control system for a boiler-generator.

Examples of Modern Control Systems



A computer control system.

Examples of Modern Control Systems



The Utah/MIT Dextrous Robotic Hand: A dextrous robotic hand having 18 degrees of freedom, developed as a research tool by the Center for Engineering Design at the University of Utah and the Artificial Intelligence Laboratory at MIT. It is controlled by five Motorola 68000 microprocessors and actuated by 36 high-performance electropneumatic actuators via high-strength polymeric tendons. The hand has three fingers and a thumb. It uses touch sensors and tendons for control. (Photograph by Michael Milochik. Courtesy of University of Utah.)

ADAPTIVE CONTROL SYSTEM

- Adaptive control is a self-correcting form of optimal control that includes feedback control.
- Measures the relevant process variables during operation (feedback control)
- Uses a control algorithm that attempts to optimize some index of performance (optimal control).
- ADAPTIVE CONTROL SYSTEMS is a logical extension of the numerical control and computer control Improvement of the cutting process by automatic online determination of the feed and/or cutting speed.
- Basically a feedback system in which the cutting speed and feed automatically adapt themselves to the actual conditions of the process
- The cutting speed and feed have to be varied in such a way as to improve the performance level Can be classified into two types: Adaptive Control with Optimization (ACO).
- Adaptive Control with Constraints (ACC) The use of AC systems is mostly justified when extremely hard materials have to be machined Basic block diagram of adaptive control system.

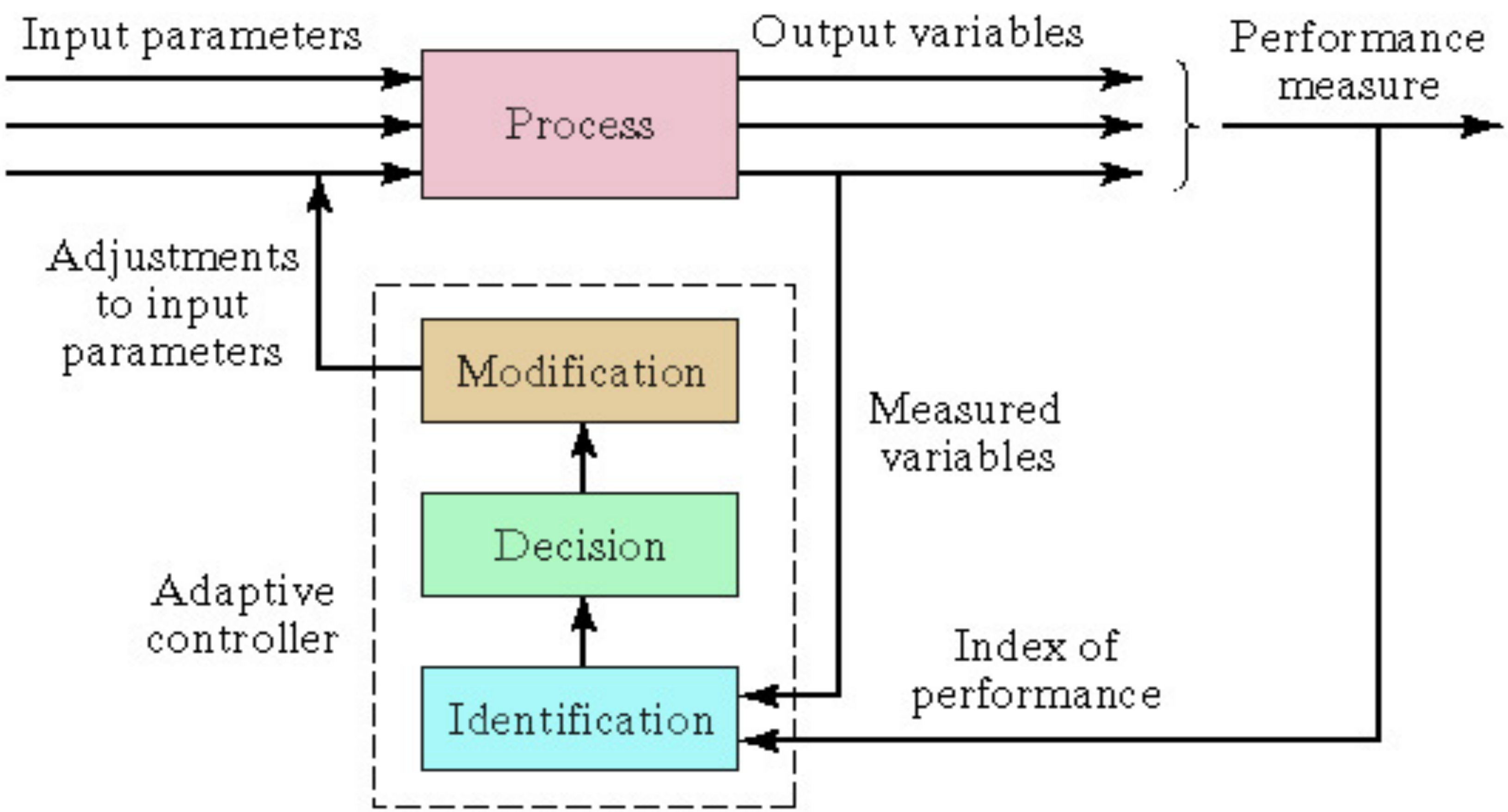
Adaptive Control Operates in a Time-Varying Environment

- The environment changes over time and the changes have a potential effect on system performance
- Example: Supersonic aircraft operates differently in subsonic flight than in supersonic flight
- If the control algorithm is fixed, the system may perform quite differently in one environment than in another
- An adaptive control system is designed to compensate for its changing environment by altering some aspect of its control algorithm to achieve optimal performance

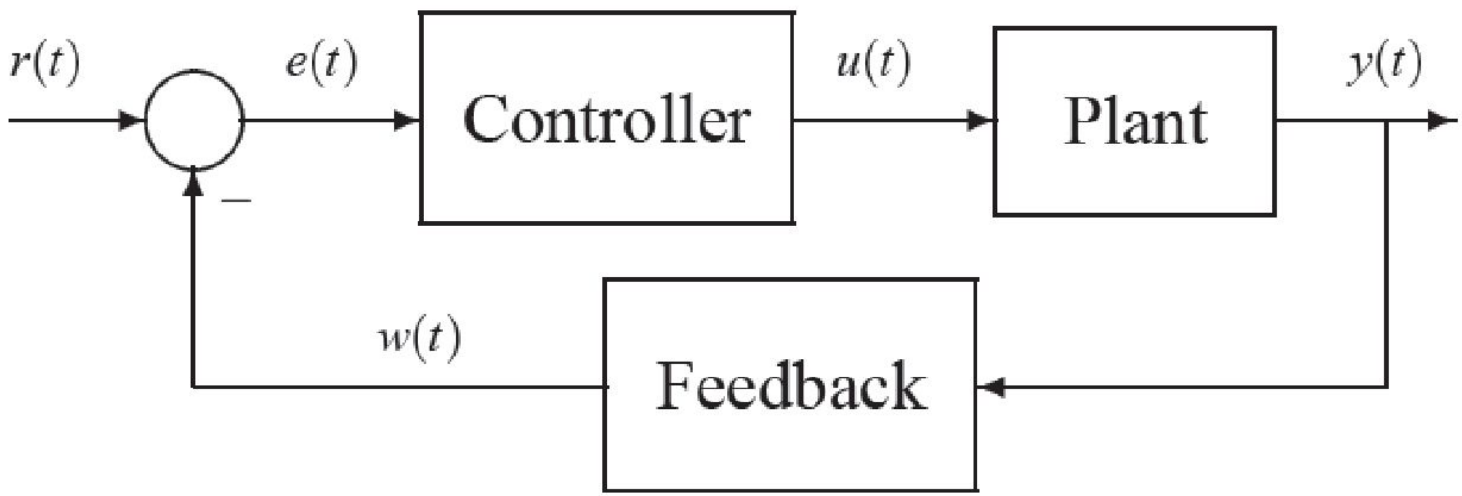
Three Functions in Adaptive Control

- Identification function – current value of IP is determined based on measurements of process variables
- Decision function – decide what changes should be made to improve system performance
  - Change one or more input parameters
  - Alter some internal function of the controller
- Modification function – implement the decision function
  - Concerned with physical changes (hardware rather than software)

BLOCK DIAGRAM OF ADPTIVE CONTROL SYSTEM



Feedback Control System



Adaptive Control Methodology

- Adapting to parametric uncertainties
- Robust to structural and environmental uncertainties
- Aimed at both stability (signal boundedness) and tracking
- Self-tuning of controller parameters
- Systematic design and analysis
- Real-time implementable
- Effective for failures and nonsmooth nonlinearities
- High potential for applications
- Attractive open and challenging issues

Classification:

1. Direct Adaptive Control System
2. Indirect Adaptive Control System

Summary

- System uncertainties
  - Common in control systems
  - Challenges for system performance
- Adaptive control
  - handles system uncertainties effectively
  - ensures desired asymptotic performance
- Adaptive control theory
  - mature with systematic design procedures
  - developing with new challenges
- Adaptive control techniques
  - proved to be useful for many practical control problems
  - promising for new aerospace applications

Types of Controllers

- Feedback control
  - Sense error, determine control response.
- Feedforward control
  - Sense disturbance, predict resulting error, respond to predicted error before it happens.
- Model-predictive control
  - Plan trajectory to reach goal.
  - Take first step.
  - Repeat.

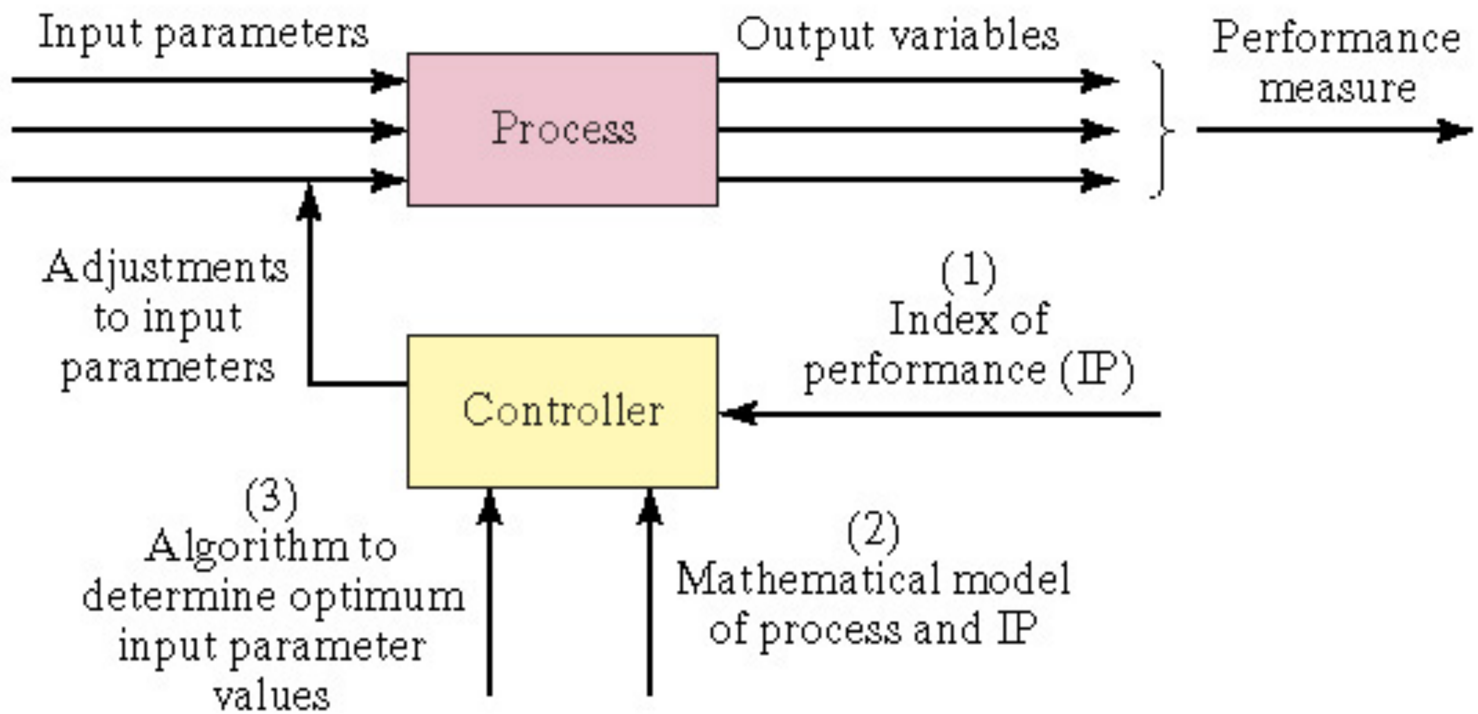
What is Optimal Control Theory?

- Dynamic Systems: Evolving over time.
- Time: Discrete or continuous.

  Optimal way to control a dynamic system.

- <u>Prerequisites</u>: Calculus, Vectors and Matrices, ODE&PDE
- <u>Applications</u>: Production, Finance/Economics, Marketing and others.

Steady State (Open-Loop) Optimal Control



Optimal Control Theory

- Dynamic programming, Bellman equations, optimal value functions, value and policy iteration, shortest paths, Markov decision processes.
- Hamilton-Jacobi-Bellman equations, approximation methods, horizon formulations, basics of stochastic calculus.
- Pontryagin.s maximum principle, ODE and gradient descent methods, relationship to classical mechanics.
- Linear-quadratic-Gaussian control, Riccati equations, iterative linear approximations to nonlinear problems.
- Optimal recursive estimation, Kalman .lter, Zakai equation.
- Duality of optimal control and optimal estimation (including new results).
- Optimality models in motor control, promising research directions.