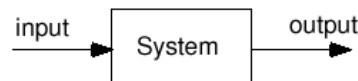


: EEM 322 Denetim Sistemleri
Lecture 1

1. Ogata, K., "Modern Control Engineering", Prentice-Hall, 4-th Ed., 2002
2. Dorf, R.C., Bishop, R.H., "Modern Control Systems", Prentice-Hall,
- 3-Norman S. Nise ,CONTROL SYSTEMS ENGINEERING Sixth Edition, Wiley & Sons,
- 4- Uraz,A., "Control Systems", H.Ü., 2003
- 5-Web: ders notları (Hamit erdem)

Definition of a system:

A system is any structure of interconnected components created to perform some desired function.



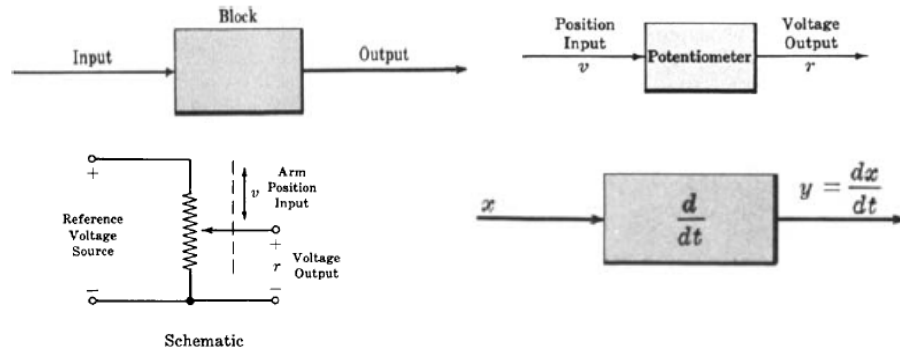
A system is an arrangement of physical components connected or related in such a manner as to form and/or act as an entire unit.

A control system is an arrangement of physical components connected or related in such a manner as to command, direct, or regulate itself or another system.

- A system has inputs and outputs
- A system produces an output signal in response to an input signal
- a system has a mathematical model which relates the inputs to outputs.

A block diagram : A block diagram is a shorthand, pictorial representation of the cause-and-effect relationship between the input and output of a physical system. It provides a convenient and useful method for characterizing the 'functional relationships among the various components of a control system. System **components are alternatively called elements of the system.** The simplest form of the block diagram is the single block, with one input and one output,

Block diagrams are graphical representation developed to make control systems easier to understand

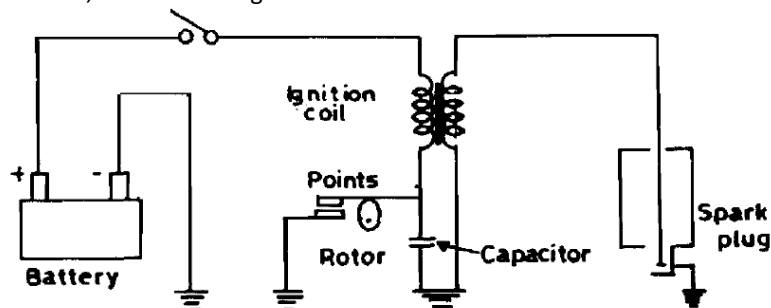


Classify systems into the following independent categories:

- (1) Linear or non-linear system
- (2) Dynamic or static system
- (3) Time invariant or time-varying system
- (4) Continuous time or discrete time system
- (5) Deterministic or stochastic system

Modelling example: Automobile Ignition System (schematic diagram)

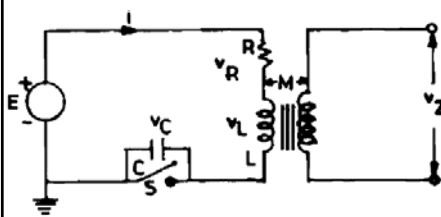
The main components of the system are; spark plug, ignition coil, spring-loaded contact points, engine driven cam rotor, capacitor and the car battery. The closing and opening of the contact points by the cam causes sudden change in the primary current of the ignition coil, inducing very high voltage in the secondary winding. This high voltage appears across the spark plug producing the igniting spark. A capacitor is connected across the contact points to prevent sparking and consequent wear-out of the points. In the car engine there are four cylinders and four spark plugs. The high voltage of the secondary of the ignition coil passes through a 'distributor' which directs it to the appropriate cylinder. However, for our study it is sufficient to assume only one spark plug connected directly to the ignition coil, as shown in Fig.



Understanding of the performance of this system: (single-variable systems.)

1. How does the voltage across the spark plug change as a function of time? In other words, what is the waveform of the voltage across the spark plug?
2. What is the maximum value of this voltage and at what time does it occur?
3. How do the voltage waveform, its peak value and the time of peak voltage depend upon the rotor speed, battery voltage, number of primary and secondary turns and the value of capacitor?

Circuit Model of the Automobile Ignition System



system variables

- output variable(s) : secondary voltage v_2
- input variable(s) : battery voltage E
- internal variables. primary current i and capacitor voltage v_c
- system variables are functions of time

the behaviour of a system is dependent upon certain fixed quantities (R, L and C) are independent of the system variables. R, L, C are : parameters of the system

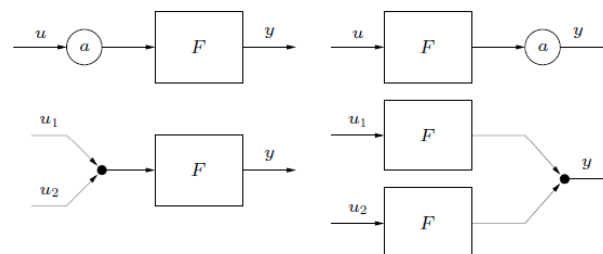
Linearity: Linear and Non-linear Systems

a system F is linear if the following two properties hold:

1. **Homogeneity:** if u is any signal and a is any scalar, $F(au) = aF(u)$
2. **Superposition:** if u and $\tilde{u}$ are any two signals,

$$F(u + \tilde{u}) = F(u) + F(\tilde{u})$$

- scaling before or after the system is the same
- summing before or after the system is the same



examples of linear systems: scaling system, differentiator, integrator, running average, time shift, convolution, summer, difference systems
examples of nonlinear systems: sign detector, multiplier, comparator

Time invariant and time variant systems:

Parameters of a system as the quantities which depend only on the properties of system elements and not on its variables.

Example:

$$L \frac{d^2 i}{dt^2} + R \frac{di}{dt} + \frac{i}{C} = 0$$

parameters R , L and C appear as coefficients. If these parameters become functions of the dependent variable $i(t)$ in this case, then the system becomes non-linear. When the parameters are fixed, i.e., do not change with time, the system to which they belong is called a time invariant system. When one or more parameters are functions of time, the system is called a time-varying system.

The terms stationary system and non-stationary system are also used in place of time invariant and time-varying systems.

Linear Systems Analysis Yazar: A N Tripathi

The input is the stimulus, excitation or command applied to a control system, typically from an external energy source, usually in order to produce a specified response from the control system.

The output is the actual response obtained from a control system. It may or may not be equal to the specified response implied by the input.

EXAMPLE (For input output)

An electric switch is a manufactured control system, controlling the flow of electricity. By definition, the apparatus or person flipping the switch is not a part of this control system. Flipping the switch on or off may be considered as the input. That is, the input can be in one of two states, on or off. The output is the flow or non-flow (two states) of electricity. The electric switch is one of the most rudimentary control systems.

EXAMPLE . A thermostatically controlled heater or furnace automatically regulating the temperature of a room or enclosure is a control system. The input to this system is a reference temperature, usually specified by appropriately setting a thermostat. The output is the actual temperature of the room or enclosure. When the thermostat detects that the output is less than the input, the furnace provides heat until the temperature of the enclosure becomes equal to the reference input. Then the furnace is automatically turned off. When the temperature falls somewhat below the reference temperature, the furnace is turned on again.

Dynamic and Static systems: A control system is *dynamic*: It responds to an input by undergoing a transient response before reaching a steady-state response

- Models of these systems are given by differential equations/ difference equations)

- Time is the independent variable

- The output is always a function of time, even when the input is a constant.

- There is a motion

- The output depends on not only upon the input but upon the initial conditions also (recall that the solution of an nth order diff. Equation requires knowledge of the initial value of the dependent variable, and its derivatives)

The system thus 'remembers' its past inputs or has 'memory'.

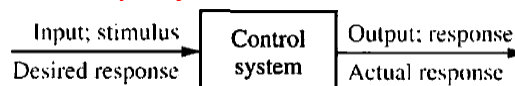
Example: A circuit with a single inductance or capacitance is a dynamic system (Energy storing elements)

presence of an energy storage element makes a system dynamic. Mass and spring provide energy storage elements in a mechanical system. System variables associated with storage of energy cannot change instantaneously through or across that element; e.g., voltage across a capacitor, current through an inductor, velocity across a mass, force through a spring. A sudden change of current through inductor would mean infinite rate of change of energy, i.e., infinite power—a physical impossibility. Therefore, even for a sudden change in the input, the system variables in a dynamic system will not change instantaneously. Thus, dynamic systems are not instantaneous

Linear Systems Analysis Yazar: A N Tripathi

Control System Definition

A control system consists of *subsystems and processes (or plants) assembled for the purpose of obtaining a desired output with desired performance, given a specified input. Figure shows a control system in its simplest form, where the input represents a desired output.*

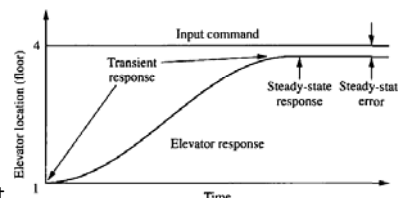


For example, consider an elevator. When the fourth-floor button is pressed on the first floor, the elevator rises to the fourth floor with a speed and floor-leveling accuracy designed for passenger comfort. The push of the fourth-floor button is an *input that represents our desired output, shown as a step function in Figure. The performance of the elevator can be seen from the elevator response curve in the figure.*

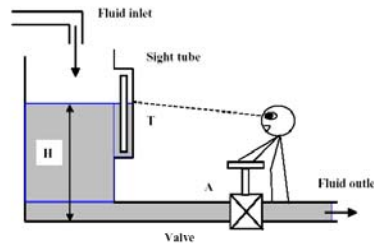
Two major measures of performance are apparent: (1) the transient response and (2) the steady-state error.

passenger comfort and passenger patience are dependent upon the transient response. If this response is too fast,

passenger comfort is sacrificed; if too slow, passenger patience is sacrificed. The steady-state error is another important performance specification since passenger safety and convenience would be sacrificed if the elevator did not properly level.



Manual Process Control



EXAMPLE . Most **automatic toasters** are **open-loop systems** because **they are controlled by a timer**. The time required to make “good toast” must be estimated by the user, who is not part of the system. Control over the quality of toast (the output) is removed once the time, which is both the input and the control action, has been set. The time is typically set by means of a calibrated dial or switch.

EXAMPLE

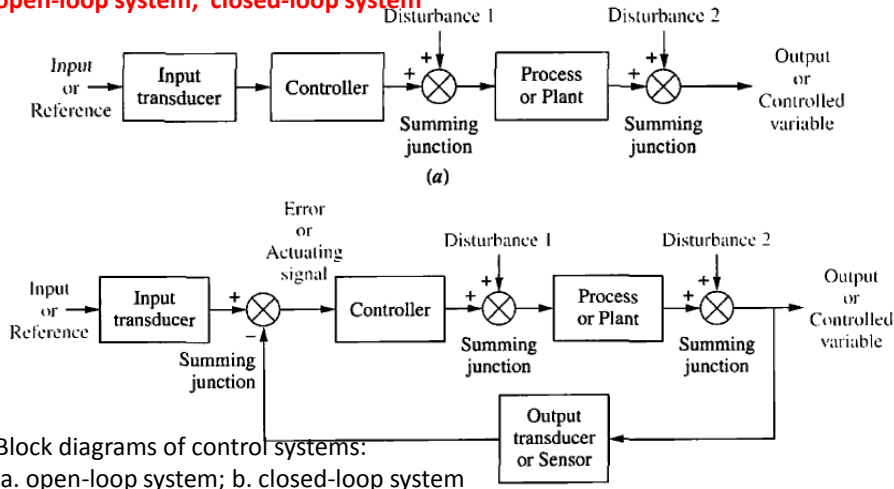
An **autopilot mechanism** and the airplane it controls is a **closed-loop (feedback) control system**. Its purpose is to maintain a specified airplane heading, despite atmospheric changes. It performs this task by continuously measuring the actual airplane heading, and automatically adjusting the airplane control surfaces (rudder, ailerons, etc.) so **as to bring the actual airplane heading into correspondence with the specified heading**. The human pilot or operator who presets the autopilot is not part of the control system.

EXAMPLE. A part of the human temperature control system is the **perspiration system**. When the **temperature** of the air exterior to the skin becomes too high the sweat glands secrete heavily, inducing cooling of the skin by evaporation. Secretions are reduced when the desired cooling effect is achieved, or when the air temperature falls sufficiently.

The input to this system may be “normal” or comfortable skin temperature, a “setpoint,” or the air temperature, a physical variable. The output is the actual skin

EXAMPLE . The control system consisting of **a person driving an automobile** has **components which are clearly** both manufactured and biological. The driver wants to keep the automobile in the appropriate lane of the roadway. He or she accomplishes this by constantly watching the direction of the automobile with respect to the direction of the road. In this case, the direction or heading of the road, represented by the painted guide line or lines **on either** side of the lane may be considered **as the input**. The **heading of the automobile** is the **output of the system**. The driver controls this output by constantly measuring it with his or her eyes and brain, and correcting it with his or her hands **on the steering wheel**. The **major components of this control system** are the **driver’s hands, eyes and brain**, and the vehicle.

open-loop system; closed-loop system



Block diagrams of control systems:

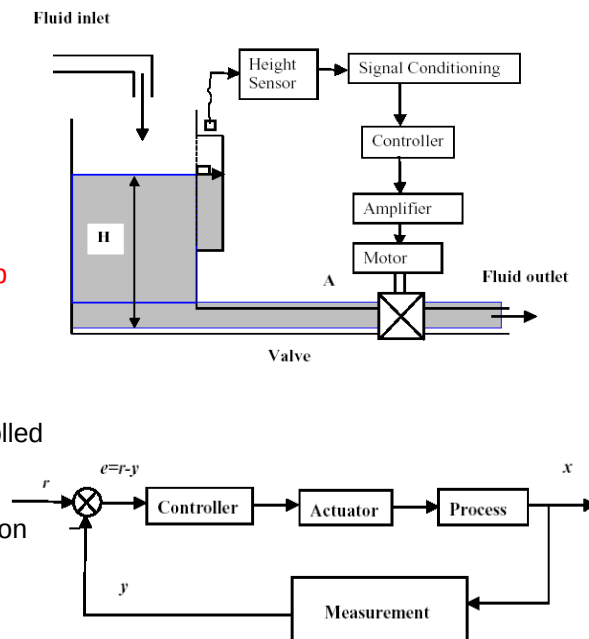
a. open-loop system; b. closed-loop system

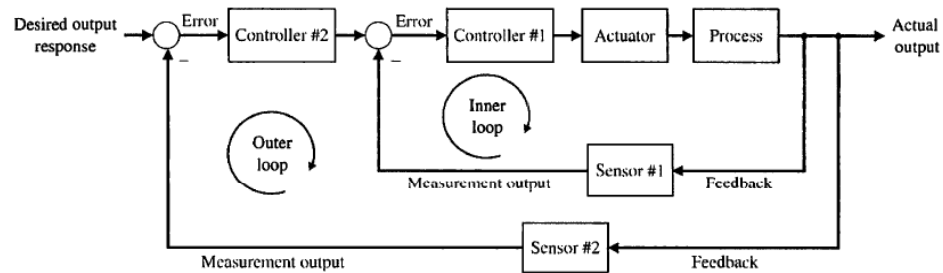
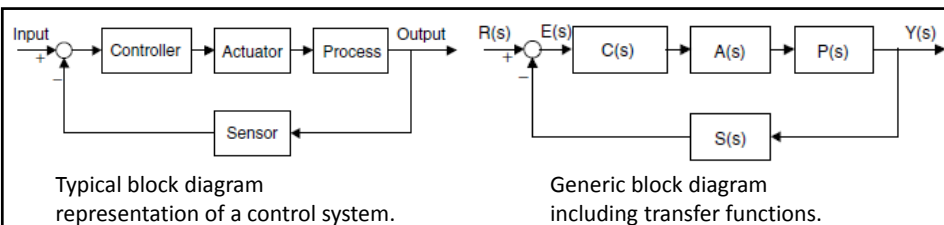
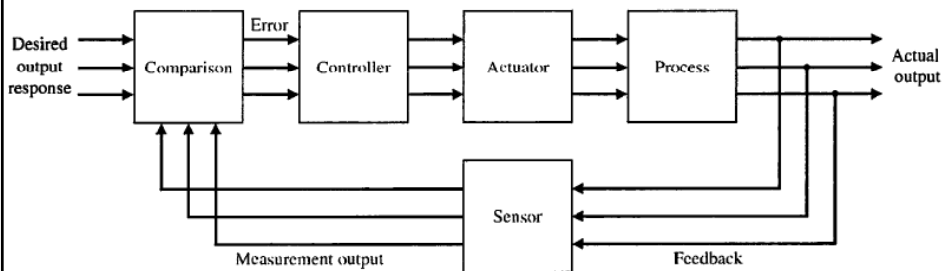
Control theory is used for analysis and design of feedback systems, such as those that regulate temperature, fluid flow, motion, force, voltage, pressure, tension, and current. Skillfully used, control theory can guide engineers in every phase of the product and process design cycle. It can help engineers predict performance, anticipate problems, and provide solutions

Feedback Process Control

The main parts of closed loop simple process control are:

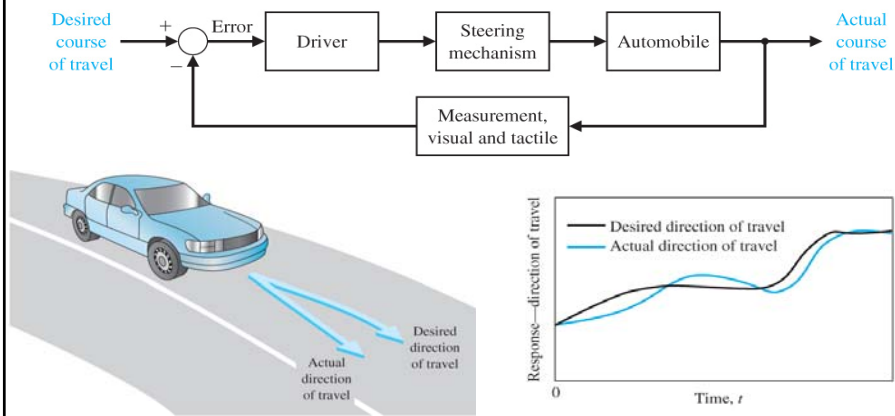
- Reference value
- Controller (analog /digital)
- Actuator
- Process or plant (the controlled environment)
- Measurement (sensor)
- Error detection and calculation circuit (analog /digital)



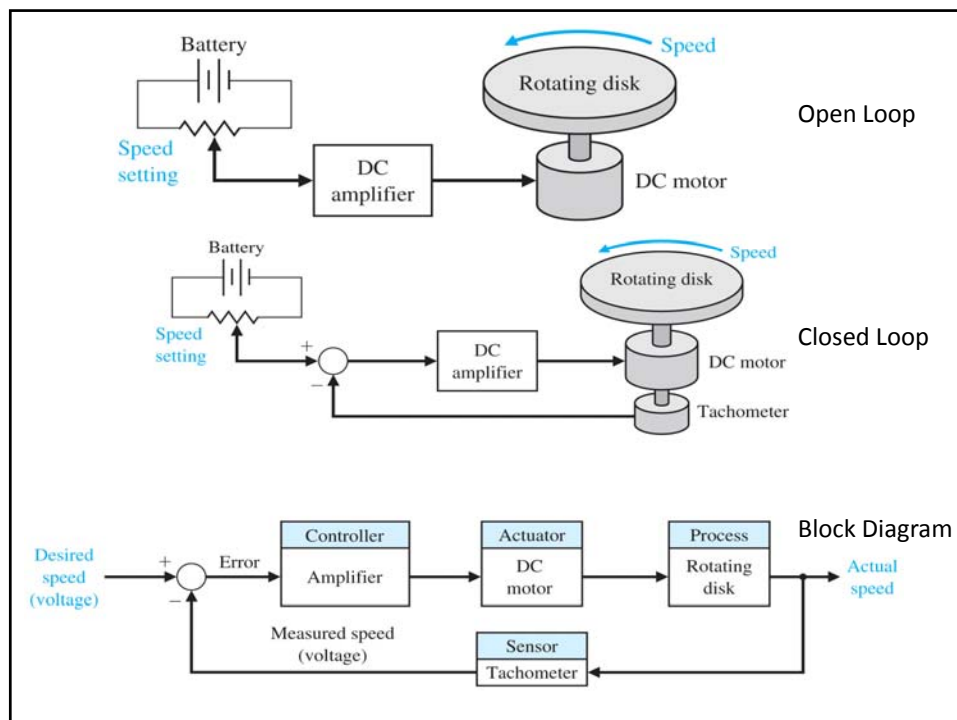
Multiloop feedback system with an inner loop and an outer loop.**Multivariable control system**

Closed-loop System	Open-loop System
Have the feedback path	Does not have the feedback path
Output response: greater accuracy	Output response: not accurate
Less sensitive to noise, disturbances and changes in the environment	Sensitive to noise, disturbances and changes in the environment
The system can compare the output response with the input and make a correction of there is any difference	The system cannot correct the disturbances.
More complex and expensive.	Simple and inexpensive.

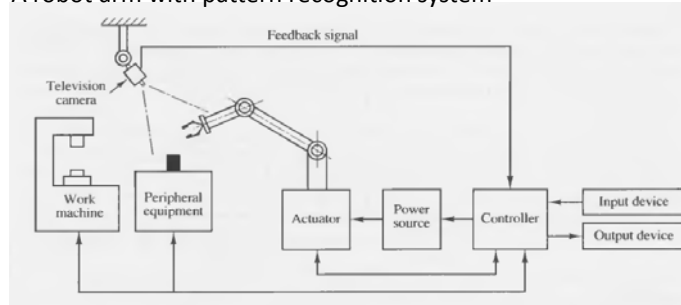
A simple block diagram of an automobile steering control system



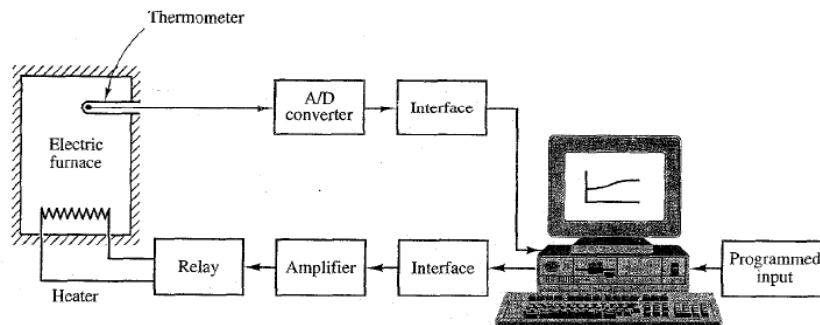
The goal of control engineering design is to obtain the configuration, specifications, and identification of the key parameters of a proposed system to meet an actual need.



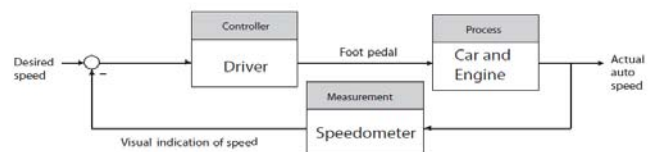
A robot arm with pattern recognition system



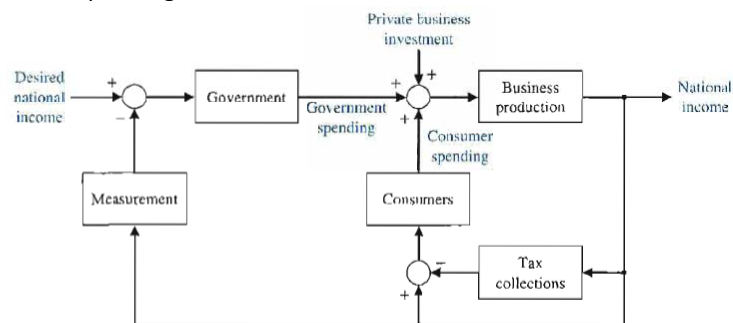
Temperature control system



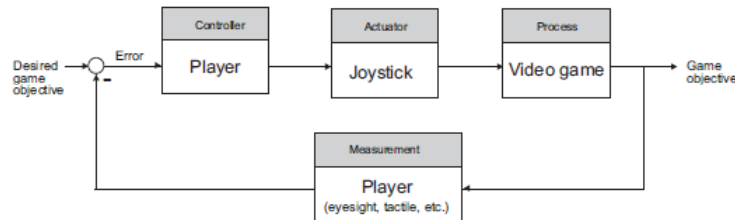
E1.2 | A driver controlled cruise control system:



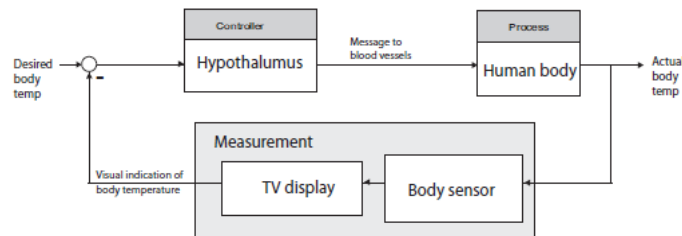
A simple lumped model of the national income feedback control system is shown in Figure . This type of model helps the analyst to understand the effects of government control—granted its existence—and the dynamic effects of government spending.



Block diagram example: The block diagram of a person playing a video game. The input device is a joystick and the game is being played on a desktop computer. the player can serve as both the controller and the sensor. The objective of the game might be to drive a car along a prescribed path.



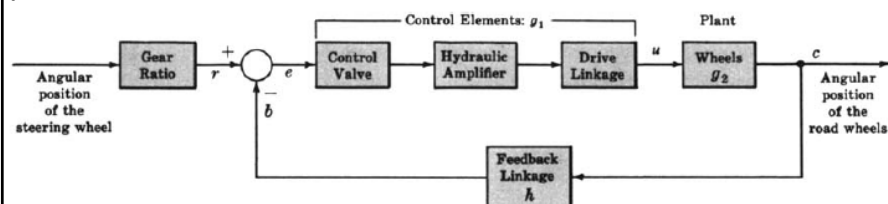
human biofeedback used to regulate factors such as pain or body temperature



Feedback controller: (Servomechanism or Regulating system)

A servomechanism is a power-amplifying feedback control system in which the controlled variable c is *mechanical position, or a time derivative of position such as velocity or acceleration*.

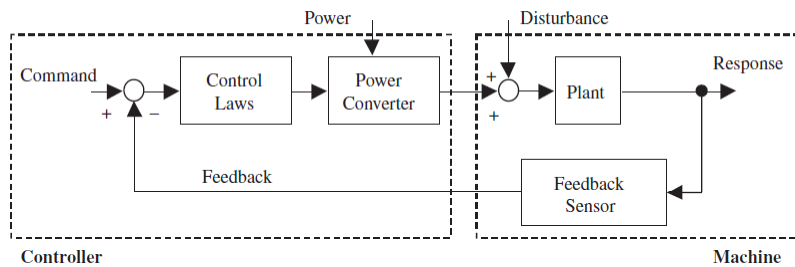
An automobile power-steering apparatus is a servomechanism. The command input is the angular position of the steering wheel. A small rotational torque applied to the steering wheel is amplified hydraulically, resulting in a force adequate to modify the output, the angular position of the front wheels.



A regulator or regulating system is a feedback control system in which the reference input or command is constant for long periods of time, often for the entire time interval during which the system is operational. Such an input is often called a **setpoint**.

A regulator differs from a servomechanism in that the primary function of a regulator is usually to maintain a constant controlled output, while that of a servomechanism is most often to cause the output of the system to follow a varying input.

Control laws and power conversion



The controller incorporates both control laws and power conversion. Control laws, such as proportional-integral-differential (PID) control

Virtually all controllers have power converters. The control laws produce information, but power must be applied to control the plant.

Setting or tuning gains to attain desired performance: For

- attaining a quick, stable command response.
- rejecting disturbances

Robust operation means control laws must be designed with enough margin to accommodate reasonable changes in the plant and power converter.

ANALOG AND DIGITAL CONTROL SYSTEMS

A signal dependent on a continuum of values of the independent variable t is called a continuous-time signal or, more generally, a continuous-data signal or (less frequently) an analog signal.

A signal defined at, or of interest at, only discrete (distinct) instants of the independent variable t (upon which it depends) is called a **discrete-time**, a **discretized data**, a **sampled-data**, or a **digital signal**.

Continuous-time control systems, also called continuous-data control systems, or analog control systems, contain or process only continuous-time (analog) signals and components.

Discrete-time control systems, also called discrete-data control systems, or sampled data control systems, have discrete-time signals or components at one or more points in the system. Some systems may be a combination of both (hybrid).

CONTROL SYSTEM MODELS OR REPRESENTATIONS

•Mathematical models, in the form of differential equations, difference equations, and/or other mathematical relations, for example, Laplace- and z-transforms; Block diagrams; Signal flow graphs

Analysis and Design Objectives: (In control systems)

Analysis is the process by which a system's performance is determined. For example, we evaluate its transient response and steady-state error to determine if they meet the desired specifications. Design is the process by which a system's performance is created or changed. For example, if a system's transient response and steady-state error are analyzed and found not to meet the specifications, then we change parameters or add additional components to meet the specifications.

Transient Response

Transient response is important. In the case of an elevator, a slow transient response makes passengers impatient, whereas an excessively rapid response makes them uncomfortable.

Steady-State Response

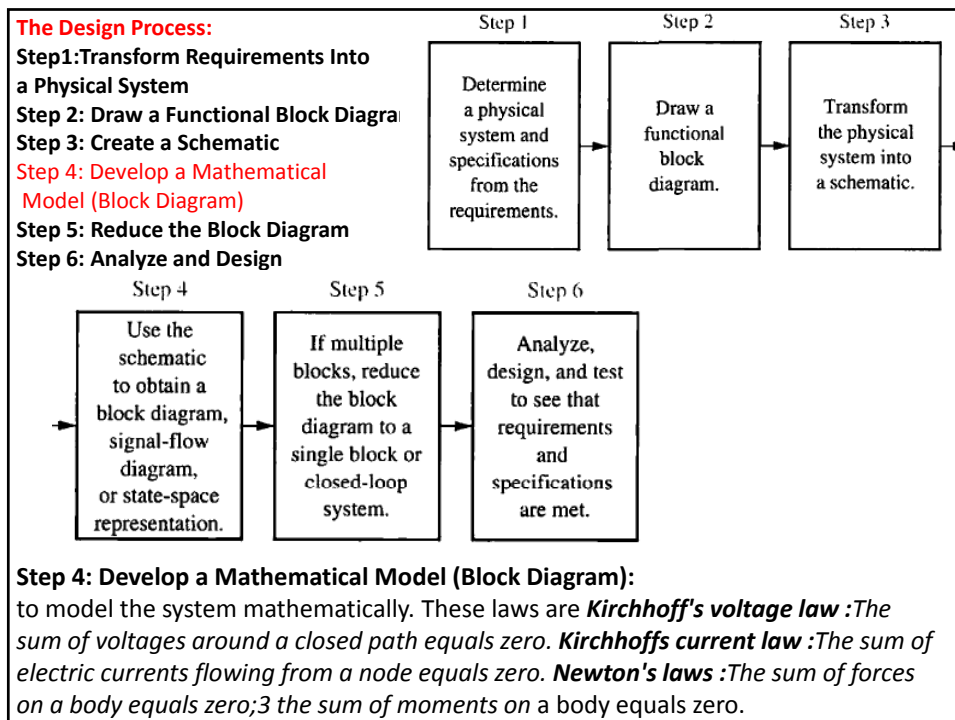
Another analysis and design goal focuses on the steady-state response. As we have seen, this response resembles the input and is usually what remains after the transients have decayed to zero. For example, this response may be an elevator stopped near the fourth floor or the head of a disk drive finally stopped at the correct track.

Stability

Discussion of transient response and steady-state error is moot if the system does not have *stability*. In order to explain stability, we start from the fact that the total response of a system is the sum of the *natural response* and the *forced response*. When you studied linear differential equations, you probably referred to these responses as the *homogeneous* and the *particular solutions*, respectively. Natural response describes the way the system dissipates or acquires energy. The form or nature of this response is dependent only on the system, not the input. On the other hand, the form or nature of the forced response is dependent on the input. Thus, for a *linear system*, we can write

Total response = Natural response + Forced response

For a control system to be useful, the natural response must (1) eventually approach zero, thus leaving only the forced response, or (2) oscillate. In some systems, however, the natural response grows without bound rather than diminish to zero or oscillate. Eventually, the natural response is so much greater than the forced response that the system is no longer controlled. This condition, called *instability*, could lead to self-destruction of the physical device if limit stops are not part of the design. For example, the elevator would crash through the floor or exit through the ceiling; an aircraft would go into an uncontrollable roll; or an antenna commanded to point to a target would rotate, line up with the target, but then begin to oscillate about the target with *growing oscillations and increasing velocity until the motor or amplifiers reached their output limits* or until the antenna was damaged structurally.



Step 6: Analyze and Design

The next phase of the process, following block diagram reduction, is analysis and design. If you are interested only in the performance of an individual subsystem, you can skip the block diagram reduction and move immediately into analysis and design. In this phase, the engineer analyzes the system to see if the response specifications and performance requirements can be met by simple adjustments of system parameters. If specifications cannot be met, the designer then designs additional hardware in order to effect a desired performance.

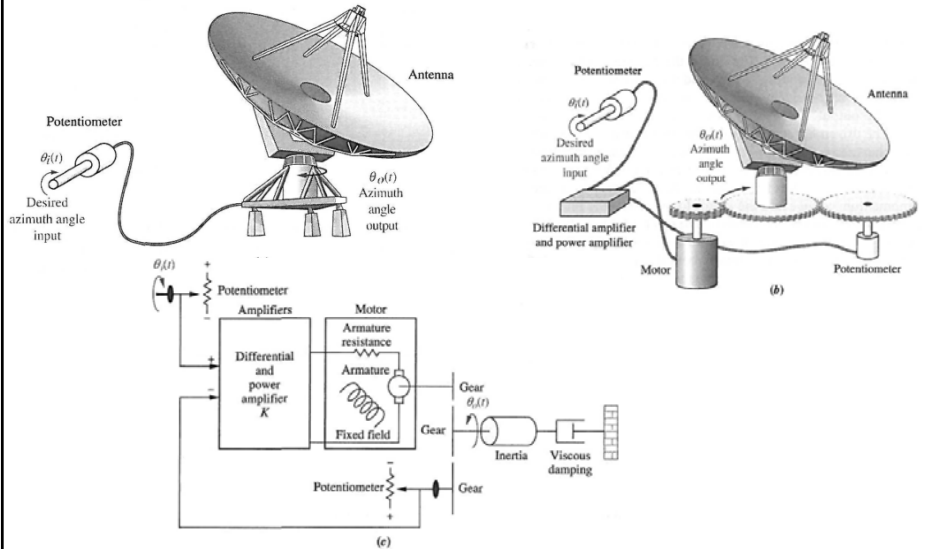
Test input signals are used, both analytically and during testing, to verify the design. It is neither necessarily practical nor illuminating to choose complicated input signals to analyze a system's performance. Thus, the engineer usually selects standard test inputs. These inputs are impulses, steps, ramps, parabolas, and sinusoids,

An impulse is infinite at $t = 0$ and zero elsewhere. The area under the unit impulse is 1. An approximation of this type of waveform is used to place initial energy into a system so that the response due to that initial energy is only the transient response of a system. From this response the designer can derive a mathematical model of the system.

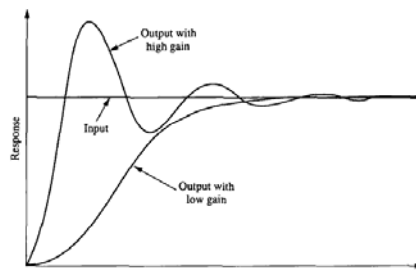
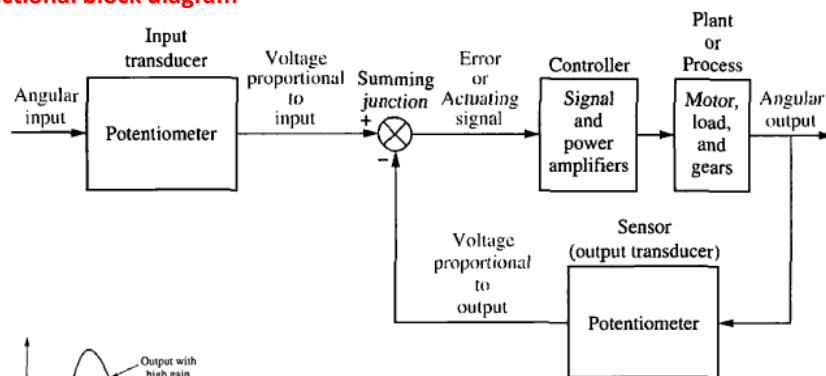
A step input represents a constant command, such as position, velocity, or acceleration. Typically, the step input command is of the same form as the output.

Antenna Azimuth: Example of position Control Systems

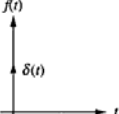
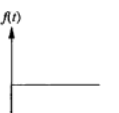
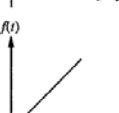
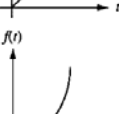
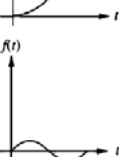
A position control system converts a position input command to a position output response. Position control systems find widespread applications in antennas, robot arms, and computer disk drives. The radio telescope antenna in Figure 1.8 is one example of a system that uses position control systems



functional block diagram



Response of a position control system, showing effect of high and low controller gain on the output response

Input	Function	Description	Sketch	Use
Impulse	$\delta(t)$	$\delta(t) = \infty$ for $0^- < t < 0^+$ $= 0$ elsewhere $\int_{0^-}^{0^+} \delta(t) dt = 1$		Transient response Modeling
Step	$u(t)$	$u(t) = 1$ for $t > 0$ $= 0$ for $t < 0$		Transient response Steady-state error
Ramp	$tu(t)$	$tu(t) = t$ for $t \geq 0$ $= 0$ elsewhere		Steady-state error
Parabola	$\frac{1}{2}t^2 u(t)$	$\frac{1}{2}t^2 u(t) = \frac{1}{2}t^2$ for $t \geq 0$ $= 0$ elsewhere		Steady-state error
Sinusoid	$\sin \omega t$			Transient response Modeling Steady-state error

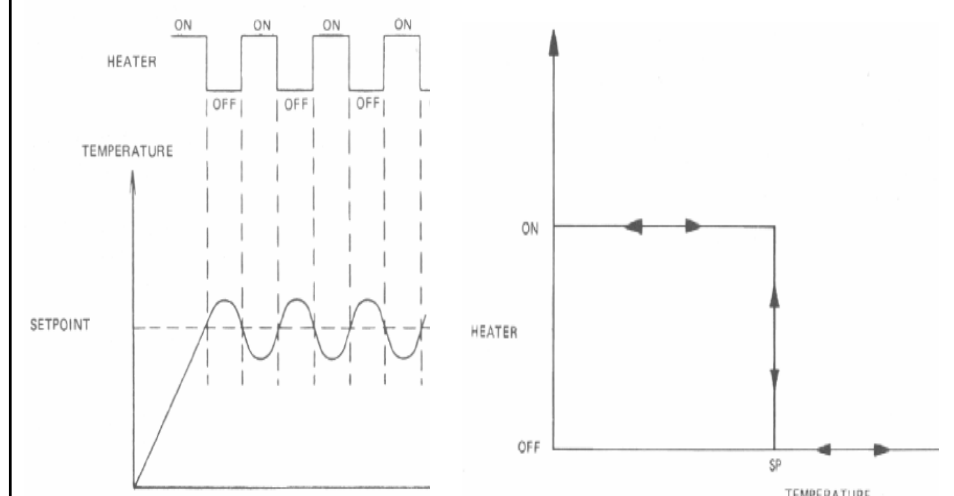
Test waveforms used in control systems:

Controller modes:

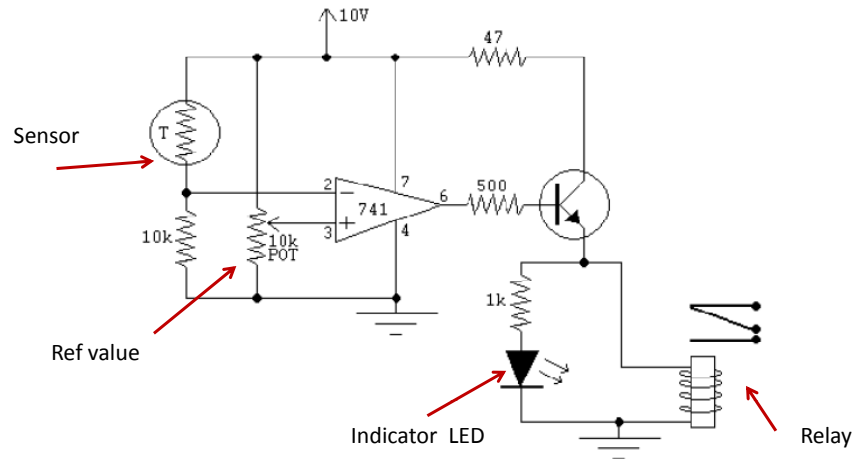
Discontinuous control (ON-OFF control): The simplest control

Continuous controller (P,PI,PD,PID): Needs design and analysis

Application examples: Simple ON/OFF controller (Example: Temperature controller)

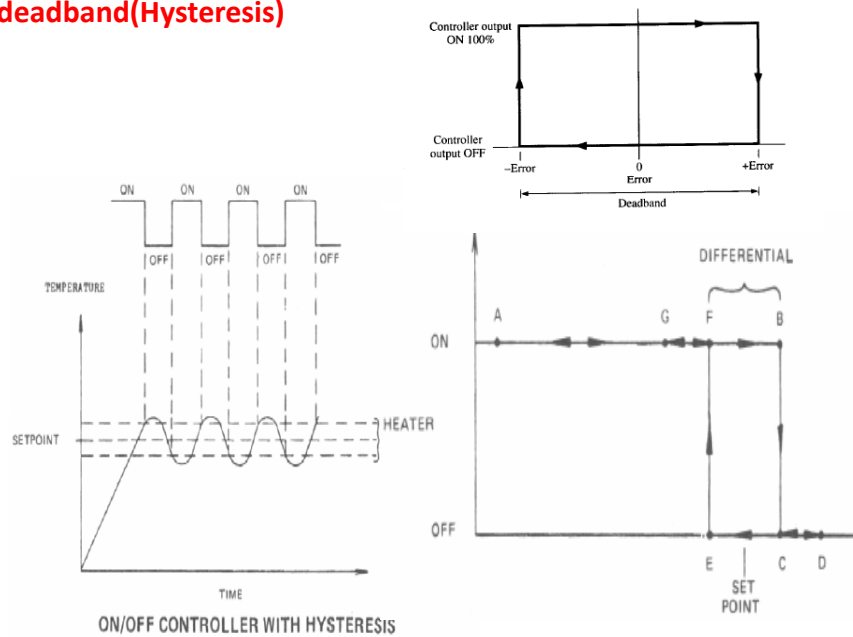


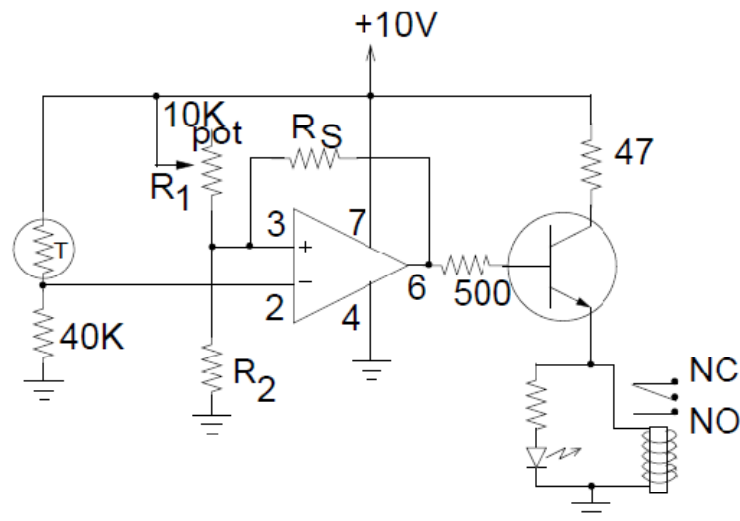
Realization by an OP-AMP (A comparator without feedback)



NTC Thermistor (temp sensor) + Potan. (Ref value) Op-Amp (simple on-off controller without feedback)

ON/OFF controller with deadband(Hysteresis)



Practical circuit: **deadband (Hysteresis) controller**

NTC Thermistor (temp sensor) + Potan (Ref value) Op-Amp (simple on-off controller without feedback)

Definitions:

The **plant (or process, or controlled system)** *g* is the system, subsystem, process, or object controlled by the feedback control system.

The **controlled output** *c* is the output variable of the plant, under the control of the Feedback control system.

The **forward path** is the transmission path from the summing point to the controlled output *c*.

A transducer is a device that converts one energy form into another

Modeling. Obtain mathematical description of the systems.

Controlled Variable and Manipulated Variable. The **controlled variable** is

the quantity or condition that is measured and controlled. The *manipulated variable* is the quantity or condition that is varied by the controller so as to affect the value of the controlled variable.

Analysis. Analyze the properties of the system.

Design. Given a plant, design a controller based on performance specifications.

The **plant** is the element or elements that produce the system response, and they usually dissipate power.

Plants. A plant may be a piece of equipment, perhaps just a set of machine parts

functioning together, the purpose of which is to perform a particular operation. In this book, we shall call any physical object to be controlled (such as a mechanical device, a heating furnace, a chemical reactor, or a spacecraft) a plant.

Systems. A system is a combination of components that act together and perform

a certain objective. A system is not limited to physical ones. The concept of the system can be applied to abstract, dynamic phenomena such as those encountered in economics. The word system should, therefore, be interpreted to imply physical, biological, economic, and the like, systems

TERMS AND CONCEPTS

Automation The control of a process by automatic means.

Closed-loop feedback control system A system that uses a measurement of the output and compares it with the desired output to control the process.

Complexity of design The intricate pattern of interwoven parts and knowledge required.

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

Design The process of conceiving or inventing the forms, parts, and details of a system to achieve a specified purpose.

Design gap A gap between the complex physical system and the design model intrinsic to the progression from the initial concept to the final product.

Disturbance An unwanted input signal that affects the output signal.

Embedded control Feedback control system that employs on-board special-purpose digital computers as integral components of the feedback loop.

Engineering design The process of designing a technical system.

Feedback signal A measure of the output of the system used for feedback to control the system.

Flyball governor A mechanical device for controlling the speed of a steam engine.

Hybrid fuel automobile An automobile that uses a conventional internal combustion engine in combination with an energy storage device to provide a propulsion system.

Multiloop feedback control system A feedback control system with more than one feedback control loop.

Multivariable control system A system with more than one input variable or more than one output variable.

Negative feedback An output signal fed back so that it subtracts from the input signal.

Open-loop control system A system that uses a device to control the process without using feedback. Thus the output has no effect upon the signal to the process.

Optimization The adjustment of the parameters to achieve the most favorable or advantageous design.

Plant See Process.

Positive feedback An output signal fed back so that it adds to the input signal.

Process The device, plant, or system under control.

Productivity The ratio of physical output to physical input of an industrial process.

Risk Uncertainties embodied in the unintended consequences of a design.

Robot Programmable computers integrated with a manipulator. A reprogrammable, multifunctional manipulator used for a variety of tasks.

Specifications Statements that explicitly state what the device or product is to be and to do. A set of prescribed performance criteria.

Measurement noise An unwanted input signal that affects the measured output signal.

Mechatronics The synergistic integration of mechanical, electrical, and computer systems.