Chapter One

Introduction to Control Systems.

Introduction.

Automatic control has played a vital role in the advance of engineering and science. In addition to its extreme importance in space-vehicle systems, missile-guidance systems, robotic systems, and the like, automatic control has become an important and integral part of modern manufacturing and industrial process. For example, automatic control is essential in the numerical control of machine tools in the manufacturing industries, in the design of autopilot systems in the aerospace industries, and in the design of cars and trucks in the automobile industries. It is also essential in such industrial operations as controlling pressure, temperature, humidity, viscocity, and flow in the process industries

These Advances in the theory and practice of automatic control provide the means for attaining:
- Optimum performance of dynamic systems.
- improving productivity
- relieving the drudgery of many routine repetitive manual operations.

In manufacturing processes it ensures that certain parameters, such as temperature, pressure, speed or voltage take up spesfic constant values recognized as the optimum, or are maintained in particular relationship to other variables. In other words, the duty of control engineering is to bring these parameters to certain pre-defined values (set-points), and to maintain them constant against all disturbing influences.

Engineering is concerned with **U**nderstanding and **C**ontrolling the materials and force of nature for the benifit of humankind. Control System engineers are concerned with understanding and controlling segments of their enviromental, often called system, to provide useful economic products for the society. The twin goals of understanding and control are complementary becouse effective system control requires that the system be understood and modeled.

Modern Control engineering has links with almost every technical area. Its spectrum of application ranges from electrical engineering, through drives, mechanical engineering, right up to manufacturing process. Control Engineering is based on the foundations of feedback theory and linear system analysis, and integrates the concepts of network theory and communication theory. Therefore control engineering is not limited to any engineering discipline but is equally applicable to aeronautical, chemical mechanical, enviromental, civil, and electrical engineering. Any attempt to explain control engineering by referring to specialized rules for each area would mean that the control engineer has to have a through knowledge of each special field in which he has to provide control. This is not simply not possible to with the current state of technology.

Today, Control Engineering has application in almost every area of Technology. The most main areas of Control Engineering are:

1 - Industrial Process Control

Industrial process control covers the control of tempreture, pressure, flow-level, etc --- in many different industrial application.

2- Drive Control (speed Control)

This group includes speed control of motors on different machines such as in plastic manufacturing, paper Production or textile machinery. Specially designed controllers are normally used for these application since they have to remain stable during fast disturbances in the range of twenth tenths of seconds.

3- Control of Electrical Variable

This refers to stabilization of Electrical parameters, eg. Voltage, current, power or even frequency.

This type of equipment is used in power generation or to stablize Characterstic Values in supply networks.

4- Position Control

Involves the positioning of tools, workpieces or complete assemblies, either in two or three dimensions.

eg. anntena, positioning of guns on ship and tranks, CNC machines.

5- Course Control

Referes the control of the course of ships or plane. (Autopilots)

Here the controller has to satisfy special demands, such as high processing speed and operational safety, combined with low weight.

The most important tasks of Control Engineers are

1. Determining the process variable

2. Checking ~~wether whether~~ Automatic Control offers significant advantages

3. Determining the measurment site

4. Assessing the disturbance

5. Selecting the manipulator

6. Selecting a suitable controller

7. Installation of the controller in accordance with applicable regulation

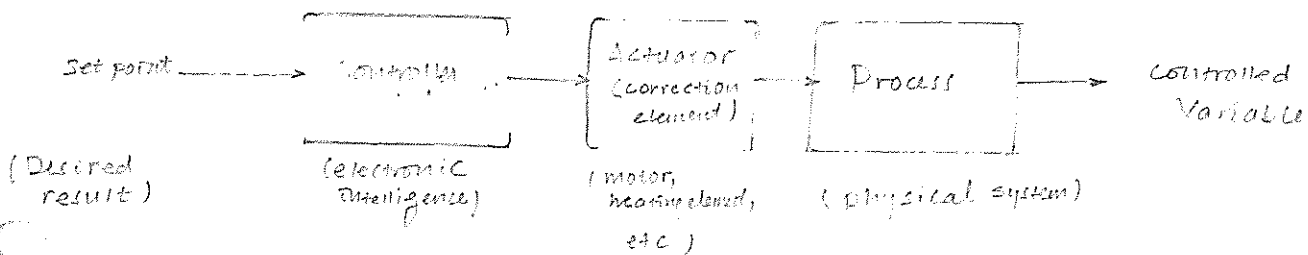8. Starting up adjusting parameters, optimizing an unsatisfactory control loop.

Control System.

A control system is an interconnection of components forming a system configuration that will provide a desired system response. i.e a control system is by which any quantity of interest is maintained or altered in accordance with a desired manner.

The basis for analysis of a system is the foundation provided by linear system theory, which assumes a cause-effect relationship for the component of a system. Therefore a component or process to be controlled can be represented by block, showing input-output relationships, cause-effect of relationship of the process

Input ⟶ Process ⟶ Output
(cause)   (effect)

Process to be Controlled.
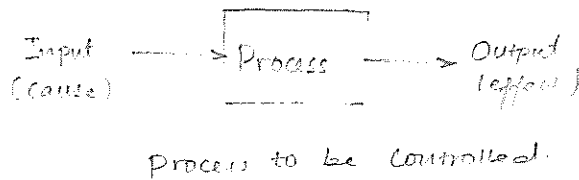
Every Control System has (at least) a Controller and an actuator (also called a final control element). Shown in the block diagram below, the controller is the intelligent part of the system and is usually electronic.

Set point ⟶ Controller ⟶ Actuator (correction element) ⟶ Process ⟶ Controlled Variable

(Desired result)   (electronic Intelligence)   (motor, heating element, etc)   (physical system)

A block diagram of a control system.

The input to the controller is called the set point, which is a signal representing the desired system output. The actuator is an electromechanical device that takes the signal from the controller and converts to it into some kind of physical action. examples of actuators, electric motor, electrically controlled valves or heating elements --- The last block, process, having an output labeled Controlled Variable, represents the physical process being affected by the actuator, and the controlled variable is the measurable result of that process. eg. If the actuator is an electric motor that rotates an antenna, then the process is "rotating of the antenna" and the controlled variable is the angular position of the antenna.

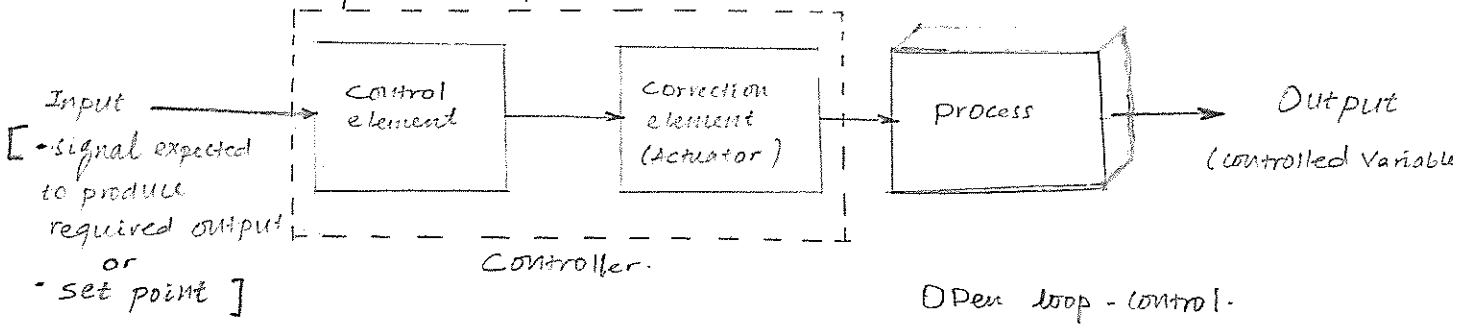Control Systems can be broadly divided into two Catagories

A) Open-loop Control system

B) Closed-loop Control system.

A) Open-loop Control system.

In open-loop Control system, the controller independently calculate exact voltage or current (actuating signal) for the actuator to do the job and sends it. With this approach, however, the controller never actually knows if the actuator did what it was supposed to, because there is no feedback. This system absolutely depends on the controller knowing the operating characteristics of the actuator.

→ Here the output of the plant has no effect on the control action, in other words:

In an open-loop Control system the output is neither measured nor fed back for comparison with the reference input. (or desired Values)
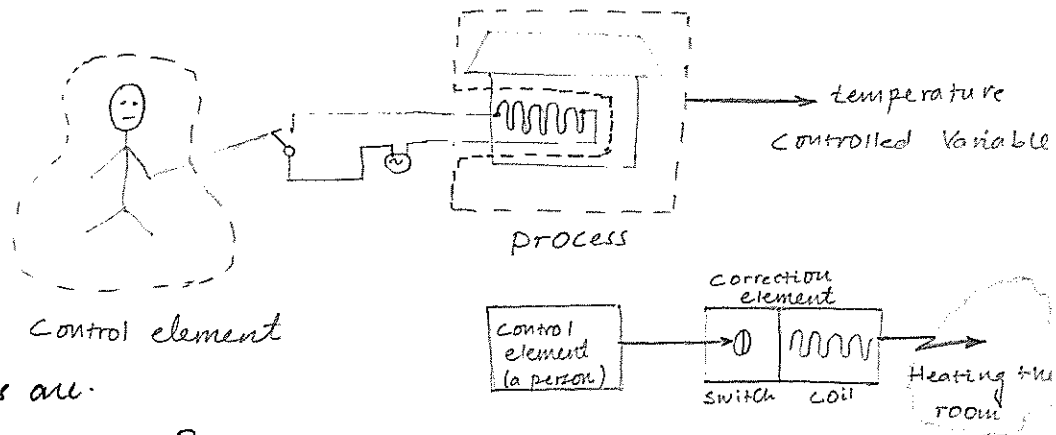
Input —————
[-signal expected to produce required output
or
- set point]

| Control element | Correction element (Actuator) | Process | Output (controlled Variable |

Controller.

Open loop - control.

The subsystems are

1. Control element :- this element determines what action is to be taken in view of the inputs to the control system
(Governed by some control algorithm)

2. Correction element (Actuators) - this element responds to the input from the control element and initiates action to change the variation variable being controlled to the required Value.

3. Process :- the process or plant is the system of which a variable (eg. temp, speed, position, pH, course, ---) is being controlled.

The first and the second subsystem (control Element and correction element) are combined to into an element called Controller.

Examples of Open-loop system.

An electric heater which is used to heat a room.

temperature
controlled Variable

process

Control element

Correction element

Control element (a person)

switch   coil

Heating the room

The subsystems are:

1- Controlled Variable :- Room temperature

2- Control element :- A person making the decission based on Exprience of temperature produced by switching ON/OFF the switch of the heater.

3- Correction element :- The switch and the heater/fire.

4- Process - the room.

Another example of open-loop system is a washing machine. Soaking, washing and rinsing in the washer operate on a time bases. The machine does not measure the output signal, that is, the cleanness of the clothes being washed.
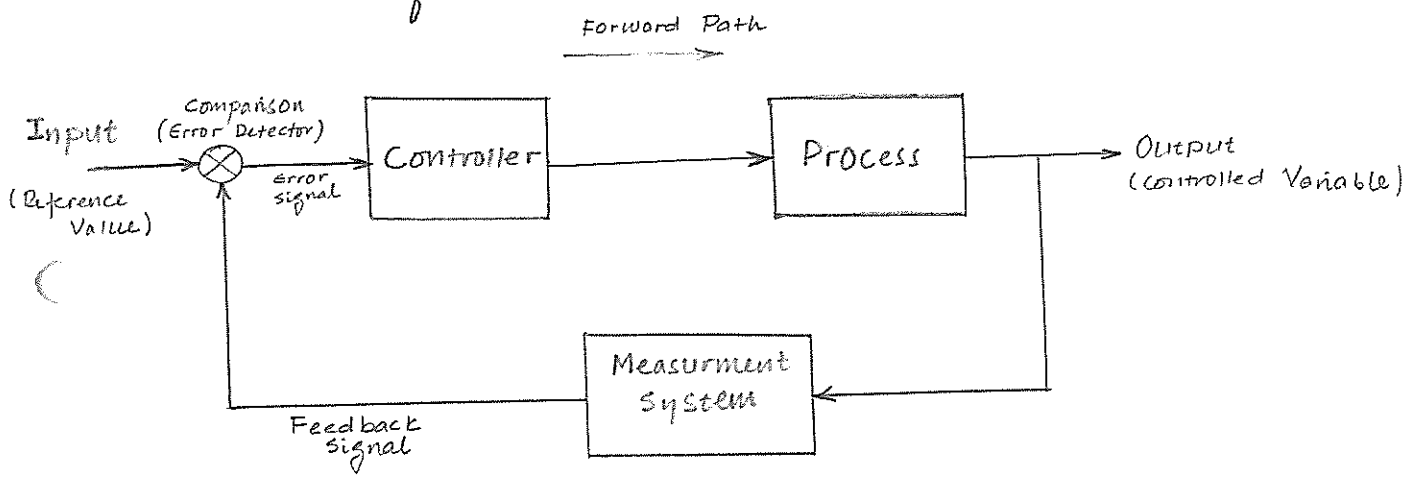
Two Outstanding features of open-loop control systems are

1- Their ability to perform accurately is determined by their calibration. To calibrate means to establish or reestablish the input-output relation to obtain a desired system accuracy.

2- They are not troubled with problems of instability.

B) Closed-loop Control Systems.

In contrast to an open-loop control system utilizes an additional measure of the actual output of to compare the actual output with the desired output response. The measure of the output is called the feedback signal.

A feedback control system is a control system that tends to maintain a prescribed relationship of one system variable to another by comparing functions of these variables and using the difference as a means of control.

Forward Path

Input
(Reference Value)

Comparison
(Error Detector)

Error signal

Controller

Process

Output
(Controlled Variable)

Measurment System

Feedback signal

closed loop feedback control system

A feedback control system often uses a function of a prescribed relationship between the output and reference input to control the process. Often the difference between the output and of the process under control and the reference input is amplified and used to control the process so that the difference is continually reduced.

The output of the process (controlled variable) is constantly monitored by measurment system (sensors). The sensors samples the system output and converts into signals (usually electrical) that it passes back to the controller. Because the controller knows what the system actually doing, it can make any adjustment necessary to keep the output where it belongs. This signal from the controller to the actuator is the forward path, and the signal from the sensor to the controller is the feedback (which "closes" the loop). The feedback signal is substracted from the set point at the comparator. By subtracting the actual position value of the controlled variable (as reported by the sensor) from the desired value (as defined by the set point), we get the system Error.

The self correcting feature of a closed-loop control makes it preferable over open-loop control in many applications, despite the additional hardware required. This is because closed-loop systems provide reliable, repeatable performance even when the system components themselves (in the forward path) are not absolutely repeatable or precisely known.

The presence of feedback typically imparts the following properties to a system (which we will see them in the coming chapters)

1. Increase accuracy. For example, the ability to faithfully reproduce the input
2. Tendency towards oscillation or instability
3. Reduced sensitivity of the ratio of output to input to variation in system parameters and other characteristics
4. Reduced effects of nonlinearities
5. Reduced effects of external disturbances or noise.
6. Increase bandwidth.
   The bandwidth of a system is a frequency response measure of How well the system responds to (or filters) variation (or frequencies) in the input signal.

remove the Error signal and is often called an actuator.

4. Process element -

The process element or plant in the system of which a variable is being controlled.

5- Measurement element

This produces a signal related to the variable condition being controlled and provides the signal Fed back to the comparison element to determine if there is an error.

The necessary feature of a closed-loop system is a feedback loop, this is the means by which a signal related to the actual condition being achieved is Fed-Back to be compared with the reference signal.

A familiar example of a closed-loop control system is driving an automobile. A simple block diagram of an automobil steering control system is shown below.
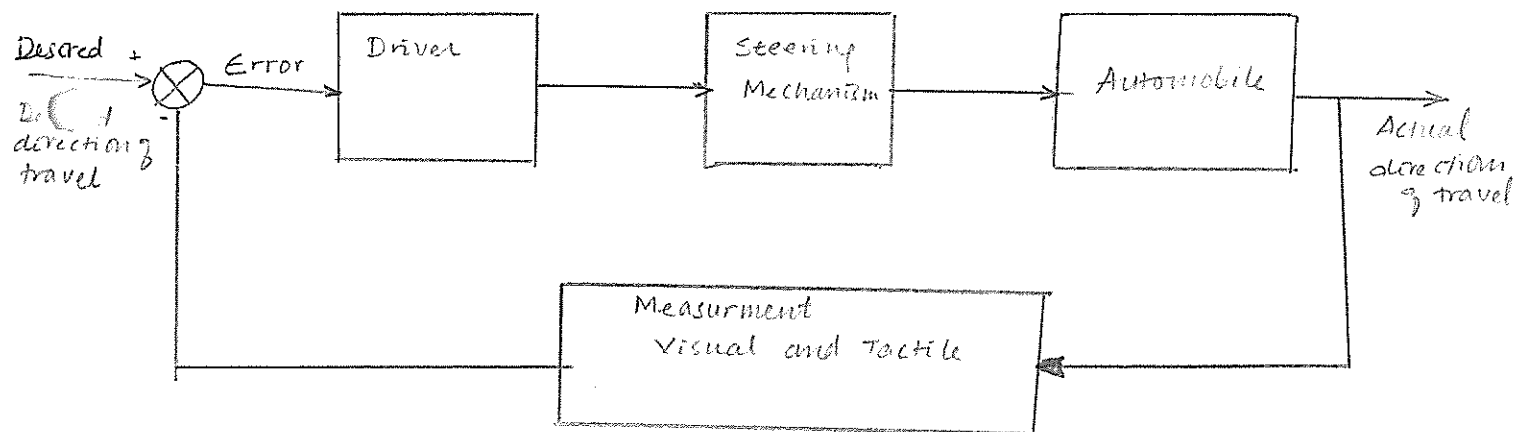
The desired direction of the travel is compared with a measurment of the actual direction of travel in order to generate a measurme. measure of the error. The error is indicates to correct the actual direction of travel

The measurement of actual direction of travel is obtained by visual and tactile (body movement) feedback.

The error signal represents the difference between "where the plant controlled Variable --" and "where you want plant's controlled Variable to be".

The controller is always working to minimize this error signal. A Zero error means that the output is exactly what the set point says it should be.

A Closed-loop system consists of basic subsystems as shown below.

Feedback System block diagram depicting a basic closed-loop control system.
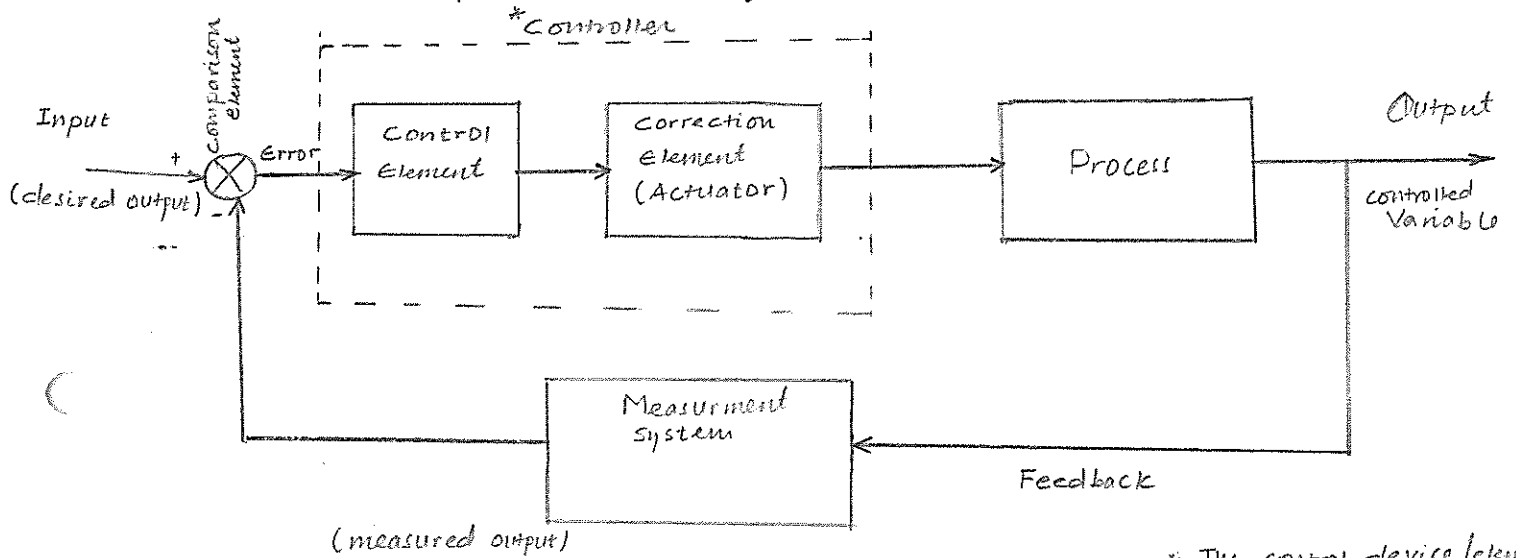
* The control device /elem often called controller

The subsystems are

1- Comparison element (Error Detector)

This element compares the required or the reference Value of the Variable being controlled with the measured Values of what is being achieved and produce an error signal, which indicates how far, the values of what is being achived is from the required Value.

$$\text{Error signal} = \text{Reference signal} - \text{Measured Value signal.}$$

2- Control Elements -

This elements decides (after running some control Algorithm) what action to take when it recives an Error signal. The term Controller is often used for an element incorporating the control element and the correction Unit.

3- Correction Element /Actuator

This element is used to produce a change in the process to

Classification of Control Systems.

There are various ways of classifying control systems. Depending on

- the number and type of component (which decides the form and of mathematical model) { → Linear / → Non-linear

- type of signal (•contious or •discrete)

- number of input and output quantity { •single output-single input (SISO) / •multiple output multiple input (MIM

1. Linear and Non-linear Control System.

A system is called linear system if it obeys the principle of superposition and homogenity.

Superposition

When a system is subjected to an exitation (input) $x_1(t)$, it will provide a response (output) $y_1(t)$ and if it is subjected to another input $x_2(t)$, it will respond respons by $y_2(t)$ output. For a linear system, it is necessary that the exitation $x_1(t) + x_2(t)$ results in a response $y_1(t) + y_2(t)$

⇒ This is called superposition.

Homogenity

A system with an input x that results in an output y. Then it is necessary that the response of a linear system to a constant β be

$$\bar{y}_1(t) = \beta x_1(t)$$
$$\bar{y}_2(t) = \beta x_2(t)$$

where $y_1(t) = x_1(t)$
$y_2(t) = x_2(t)$

=) $\bar{Y}(t) = \bar{Y}_1(t) + \bar{Y}_2(t)$ =) $Y = y_1 + y_2$

$= \beta x_1(t) + \beta x_2(t)$

$= \beta (x_1(t) + x_2(t))$

$= \beta (y_1 + y_2)$

$= \beta y(t)$

=) This is called Homogenelity.

A system is called Non-linear if it does not satisfy the principle of superposition and Homogenity.

2- Linear time-invariant system and linear time-varying systems.

Mathematical models of most physical systems are described by differential equations.

A dynamic systems that are composed of linear-time-invariant lumped-parameters described by linear-time-invariant differential equations are called Linear-time-invariant-system.

Note   A differential equation is linear time-invariant of the coefficents are constants or functions only of the independent variable

A dynamic system that are represented by differential equation whose coefficent are functions of time are called linear-time-varying systems.

Eg.   An example of time-varying control system is a space-craft control system where the mass of the space-craft changes in time due to fuel consumption.
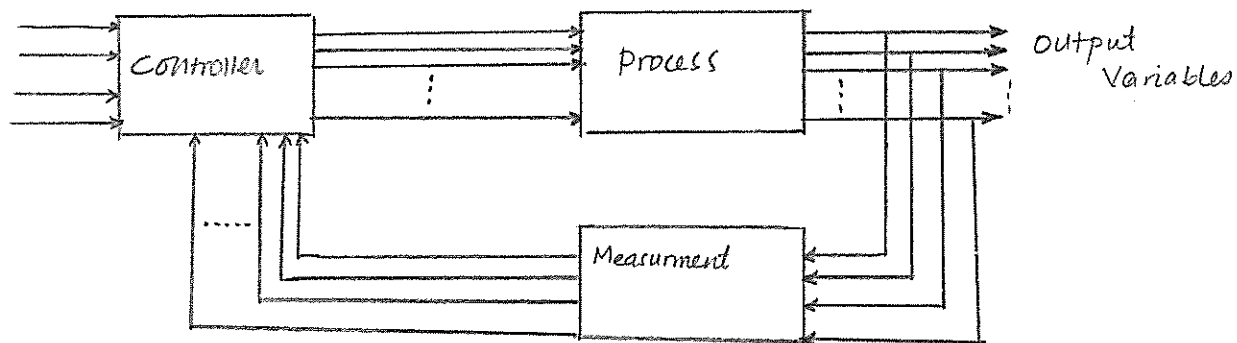
3.   Single-Variable and multivariable control system.

A control system in which there is only one input and one output quantity, is called single variable control system.

reference
input

controller → plant → output (single)

measurment
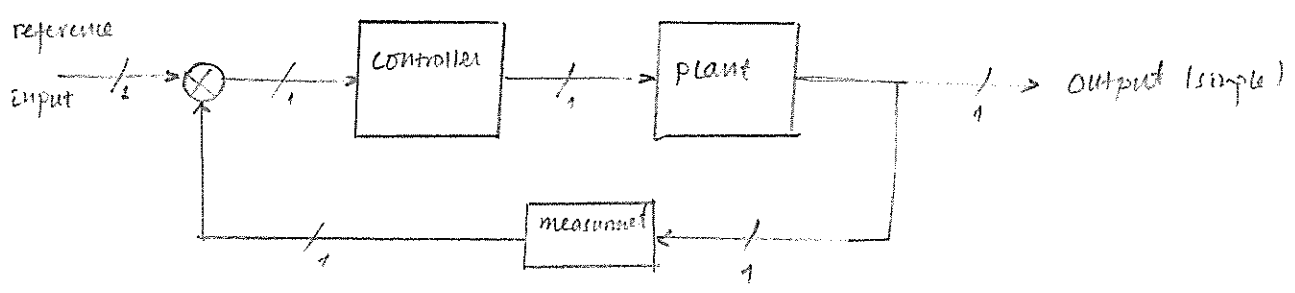
In many practical applications more than one variable of interest are encountered. Such systems with several variables under control are called Multivariable control system.

Multivariable control System

4. Continous-time and Discrete-time control System.

If a system associated with the various parts of a control system are all continous functions of time-variable, such system is called Continous-time-control System.

If the signals at one or more points of a control system are available at discrete intervals (ie in the form a pulse train or binary data or sampled data form) Such system is called Discrete-time or Sampled-data System. A block diagram representation of sampled data control System is shown below.
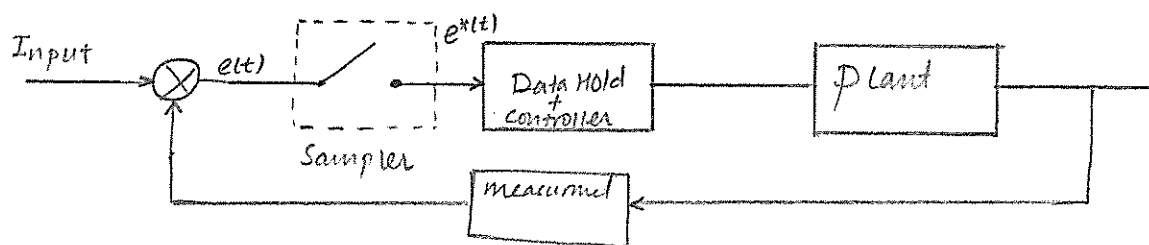
Discrete control System

Main Control Strategies.

Every control system must guarantee first the stability of the closed-loop behavior. The possibility to fulfill different specifications varies from the model considered and the control strategy chosen.

Here it is a brief listing of the various different methodologies/strategies within the sphere of control engineering. Oftentimes, the line between these methodologies are blured, or even erased completely.

Classical Controls

Control methodogies where the ODEs (ordinary Differential Equations) that describes a system are transformed using Laplace, Fourier, or Z Transforms, and manipulated in the transform domain.

Modern Control

Methods where high-order differential equations are broken into a system of first-order equations. The input, output, and internal states are of the system are described by vectors called "state variables".

Adaptive Control

Adaptive control uses on-line identification of the process parameters, or modification of controller gains, thereby obtaining strong robustness proporties. The controller changes its response characterstics over time to better control the system.

Robust Control

Robust control deals explicitly with uncertainty in its approach to controller design. Here, arbitrary outside noise/disturbance are accounted for, as well as internal inacuracies caused by the heat of the system itself, and the environment. Controllers designed using robust control methods tends to be able cope with (small) differences between the true system and the nominal model used for design

Optimal Control

In a system, performance matrice are identified, and arranged into a "Cost function". The cost function is minimized to create an operational system with the lowest cost. Together with PID, LQG widely used control technique in the industry, ea esp. process control.

Nonlinear Control.

The youngest branch of control engineering, nonlinear control encompasses systems that canot be described by linear equations or ODEs, and for which there is often very little supporting theory available

Intelligent Control

Intelligent control uses uses various AI (artificial intelligence) computing techniques/approches like neural network, Bayesian probability, fuzzy logic, machine learning, evolutionary computation and genetic algorithm to control a dynamic system.

Stochastic Control

Stochastic control deals with uncertanity in the model. In typical stochastic control problems, it is assumed that the there exists random noise and disturbance in the model and the controller design must take into account these random deviation.

Examples of Control Systems.

1- Computer Numerically Controlled (CNC) machine tool

Many system operate under computer control, a CNC machine tool
is shown below in the figure.

Information relating to the shape of the work-piece and hence the motion
of the machine table is stored in a computer program. This is relayed
in digital format, in a sequential form to the controller and is compared
with digital feedback signal from the shaft encoder to generate a digital
error signal. This is converted to an analogue control signal which,
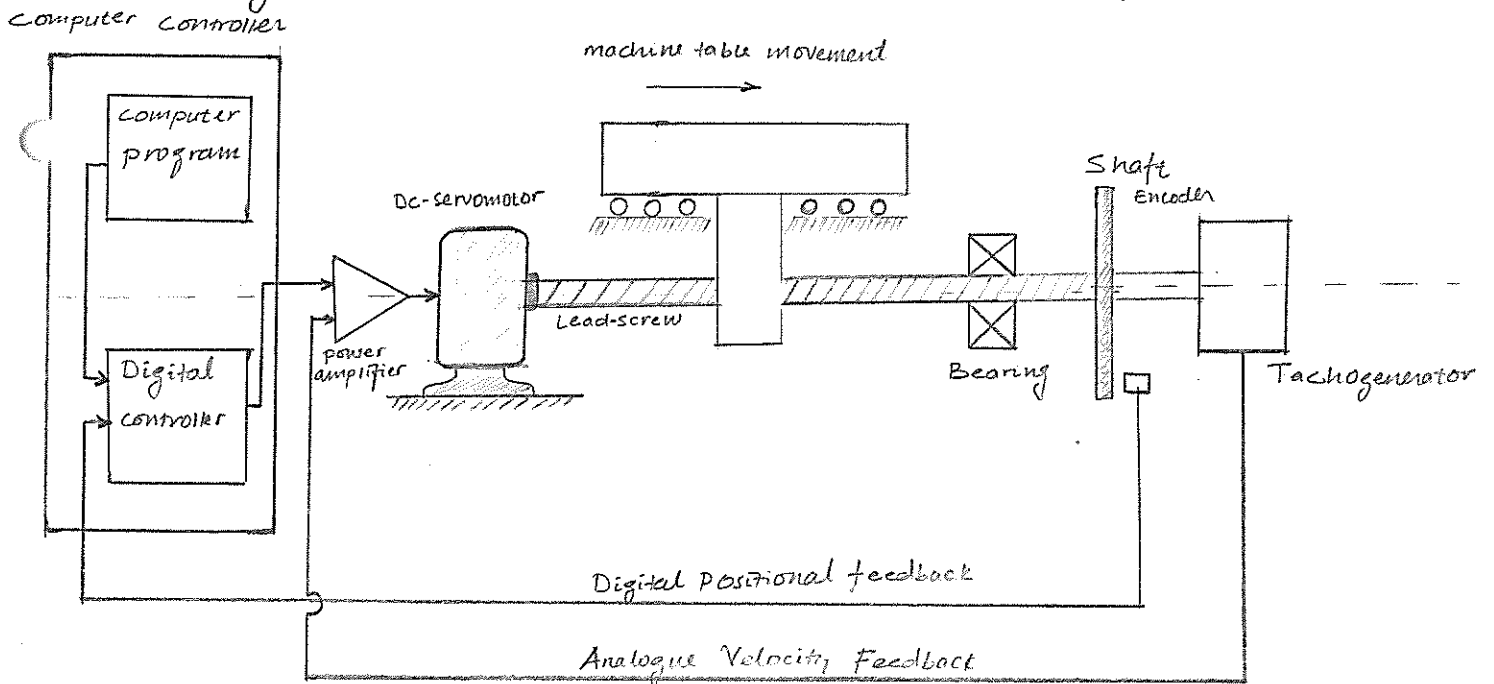
Computer numerically controlled machine tool.
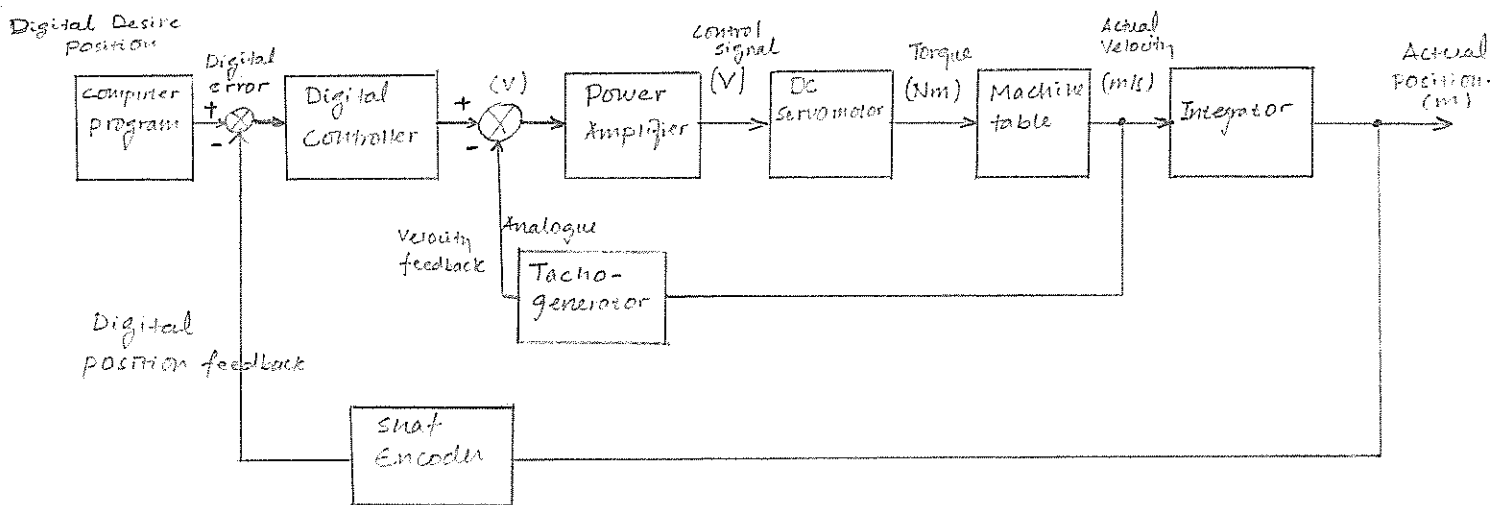
Block diagram of CNC machine-tool control system.

When amplified, drives a d.c. servomotor. Connected to the output shaft of the servomotor (in some cases through a gearbox) is a lead-screw to which is attached the machine table, the shaft encoder and a tachogenerator. The purpose of this latter device, which produces an analogue signal proportional to velocity, is to form an inner, or minor control loop in order to dampen, or stablize the response of the system.

The Control Systems Engineering Problems.

Control System engineering consists of analysis and design of system configuration.

Analysis is the investigation of the properties of an existing system. The design problem is the choice and arrangement of system components to perform a specific task.

Two methods of for Design

1 - Design by analysis

2 - Design by Synthesis

Design by analysis is accomplished by modifying the characteristics of an existing or standard system configuration, and design by Synthesis by defining the form of the system directly from its specification.

Control System Models or representations.

To solve a control system problem, we must put the specifications or description of the system configuration and its components into a form of amenable to analysis or design.

(Modeling will be dealt in the next chapter)

Control System Design

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

The first step in the design process consists of establishing the system goals. For example, we may state that our goal is to control the position and trajectory of a manufacturing assembly robot arm accurately.

The second step is to identify the variables that we desire to control (eg. position and trajectory of robot arm).

The third step is to write the specification in terms of the accuracy we must attain. This required accuracy of control will then lead to the identification of sensors to measure the controlled variable.

Knowledge of system ~~Summary~~ <u>Knowledge of System and requirements</u>

In order to design and implement a control system the following essential generic elements are required.

a) ~~A~~ Knowledge of the desired Value: It is necessary to know what it is you are trying to control, to what accuracy, and over what range of values. This must be expressed in the form of a performance specification. In the physical system this information must be converted into a form suitable for the controller to understand (analog or digital)

b) Knowledge of the output or actual value: This must be measured by a feedback sensor, again in a form suitable for the controller to understand. In addition, the sensor must have nessary resolution and dynamic response so that the measured value has the accuracy required from the performance specification

c) Knowledge of the controlling device: The controller must be able to accept measurements of desired and actual values and compare compute a control signal in a suitable form to drive an actuating element. Controllers can be a range of devices, including mechanical levers, pneumatic elements, analogue or digital circuits or microcomputers.

d) Knowledge of the actuating device: This unit amplifies the control signal and provides the 'effort' to move the output of the plant towards its desired value.

e) Knowledge of the plant: Most control strategies required some knowledge of the static and dynamic characteristics of the plant. These can be obtained from measurements or from the application of fundamental physical laws, or combination of both.
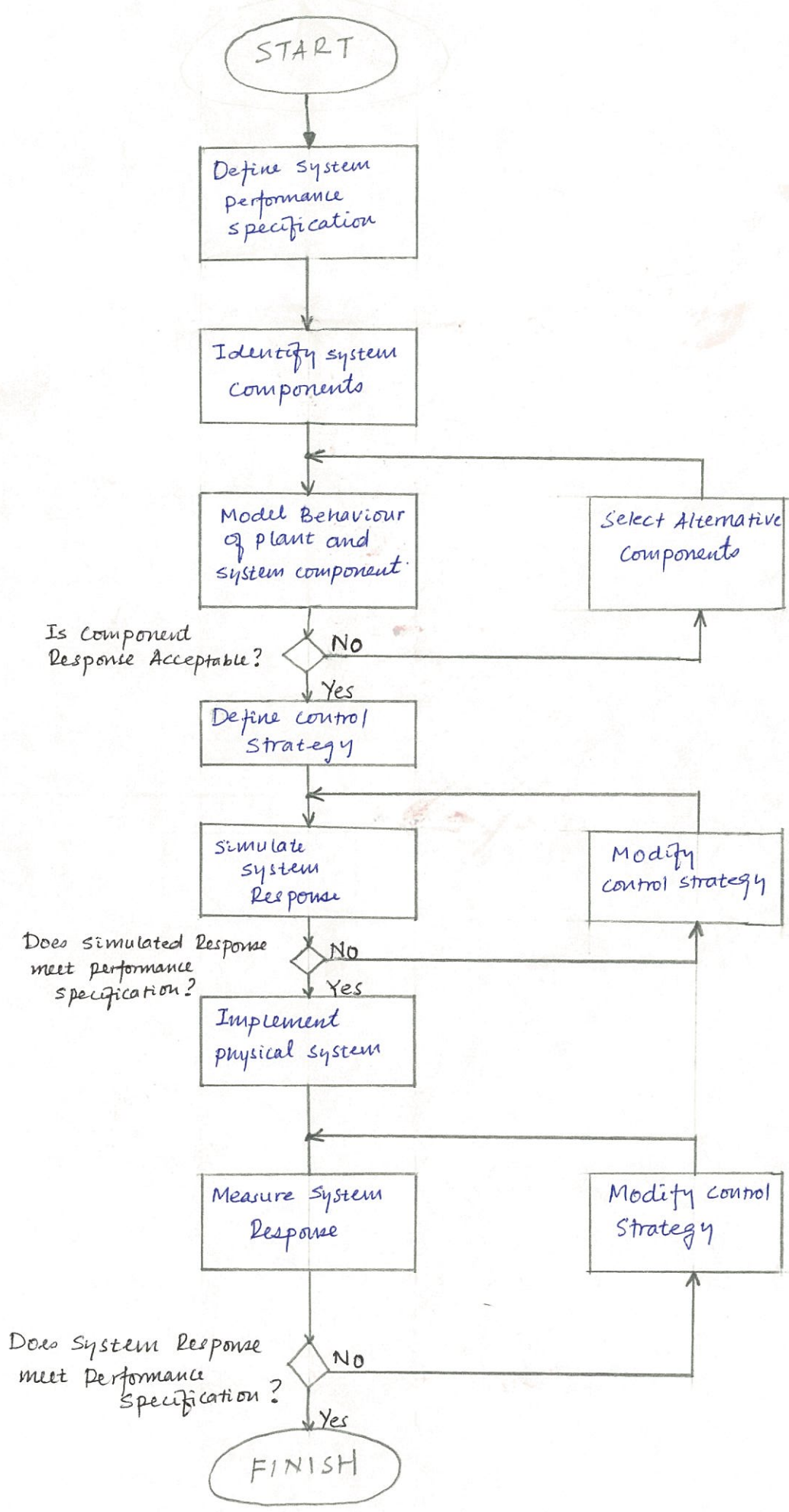
Control system Design

With all of this knowledge and information available to the control system designer, all that is left is to design the system. The first problem to be encountered is that the knowledge of the system will be uncertain and incomplete.

Measurements of the controlled variables will be contaminated with electrical noise and disturbance effect.

However, there is a standard methodology that can be applied to the design of most control system. The steps in this methodology are shown in the next page figure.

The design of a control system is a mixture of technique and exprience. This methodology explains some tried and tested approaches. Exprience, however only comes with time.

START

Define System
performance
Specification

Identify system
Components

Model Behaviour
of plant and
system component.

Select Alternative
Components

Is Component
Response Acceptable?   NO

Yes

Define control
Strategy

Simulate
system
Response

Modify
control strategy

Does simulated Response
meet performance
Specification?   No

Yes

Implement
physical System

Measure System
Response

Modify control
Strategy

Does System Response
meet Performance
Specification?   No

Yes

FINISH

Steps in the design of control System.