Unit-1

# Introduction

## Real Time system

→ A system, which requires a quantitative expression of time (i.e. real time) to describe its behavior is called a real-time system.

→ "Those system in which the correctness of the system depends not only on the logical result of the computation, but also on the time at which the result are produced".

→ Three major components: the controlling system, controlled system and environment.

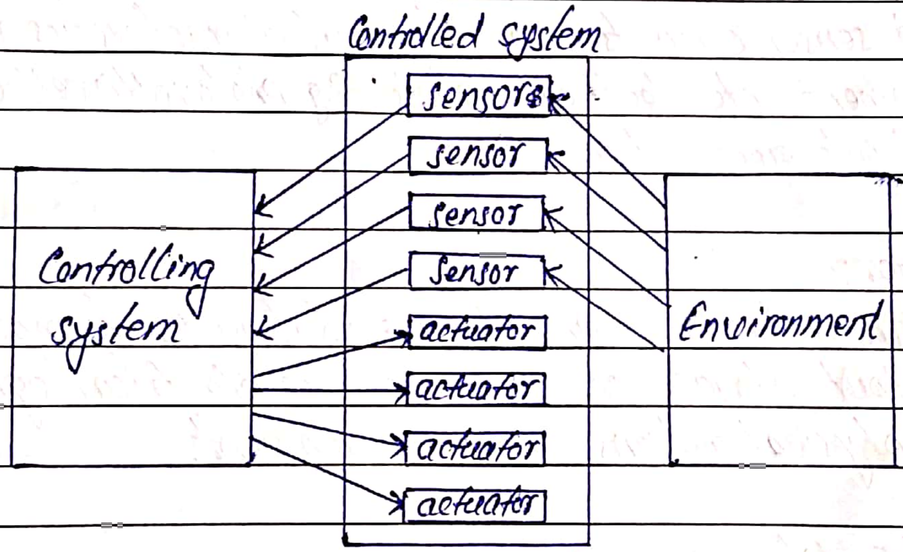
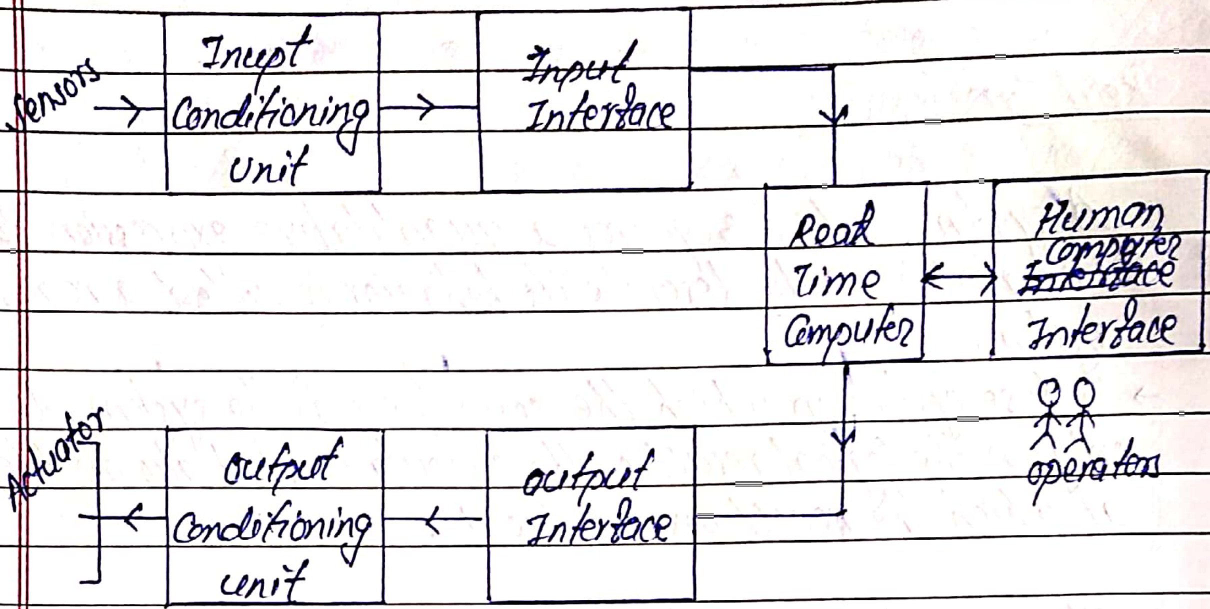



fig: Typical Real time system

Timing constraints are placed on the controlling system and its interactions with the controlled system, in response to changes in the environment. (Hard & soft constraints)

- Avionics computer (Controller) controls aircraft system (Controlled) to maintain desirable flight (environment) characteristics.

## A Basic Model of a RTS




1) **Sensors:**

A sensor converts some physical characteristics of its environment into electrical signals. E.g. photovoltic cell ( converts light into electrical signal )

2) **Actuator:**

An actuator is any device that takes its input from the output interface and converts these electrical signals into some physical actions on its environment.

3) **Signal Conditioning Unit:**

The system consists of 2 types of signal conditioning units:

i) Input conditioning unit
ii) Output conditioning unit

The objective of these conditioning units is to convert or amplify the signals if being used as an input signal or to attenuate the signal by the output conditioning unit if being used as an input to the actuator.

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4) Interface unit:
The system has 2 interface units:
i) Input interface unit: Its objective is to convert analog signals to digital signals.
ii) Output interface unit: Its objective is to convert digital signals to analog signals.

Types of RTS

1) Soft Real Time
2) Hard Real Time } 2nd unit

In terms of interaction;
1) Reactive real time system
2) Embedded real time system

→ Reactive RTS involves a system that has constant interaction with its environment. For e.g. a pilot controlling an aircraft.
→ An embedded RTS is used to control specialized hardware that is installed within a large system. For e.g. a microprocessor that controls the fuel-to-air mixture for automobiles.

Real-Time and Embedded systems

→ A real-time system must deliver services in a timely manner.
- Not necessarily fast, but must meet some timing deadline.
→ An embedded system is hidden from view within a large system.
→ Many real-time and embedded system exist, often without the awareness of their users.

- washing machine, photocopier, mobile phone, car, aircraft, toothbrush, CD player, medical devices etc.

→ Must be able to validate real-time systems for correctness
- Some embedded real-time systems are safety critical i.e. if they do not complete on a timely basis, serious consequences result.
- Bugs in embedded real-time systems are often difficult or expensive to fix.

## Digital Control

Many real-time systems are embedded in sensors & actuators, and function as digital controllers. Digital control system uses digital signals and digital computer to act as a system controller. The objective of digital controller is to control a system, often called the plant (i.e. controlled system), for e.g. an engine, a brake, an aircraft, a patient etc.

Typically, a digital controller requires:

→ A/D conversion to convert analog inputs to machine readable (digital) format.

→ D/A conversion to convert digital outputs to a form that can be input to a plant (analog).

→ A program called control-law computation, which relates the outputs to the inputs
- It computes the control parameter to set the actuator.

The state of the plant is monitored by sensors and can be changed by actuators. The real-time (computing) system estimates from the sensor reading the current state of the plant and computes the control output. Control output is computed based on the difference between the current state and the desired state (called reference input). This computation is called the control-law computation. The output generated by the computation activates the actuators, which bring the plant closer to the desired state.

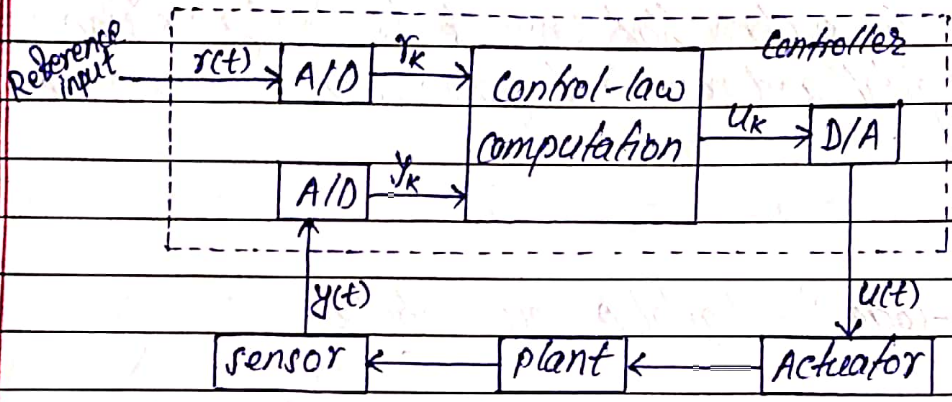



fig: A digital controller

In the figure;

→ The digital controller regulates a controlled system "plant" by comparing the measured state $y_k$ with the desired state $r_k$ and calculating output results $u_k$ to stimulate the "plant".

→ The analog sensor reading y(t), gives the measured state of the plant and the r(t) is the desired state at time t, u(t) is the control output which is calculated as a function of y(t) and r(t).

sampled data system

let e(t) = r(t) - y(t) denotes the difference between the desired state r(t) and the measured state y(t) at time t. The output u(t) of the controller consists of three terms:

- a term that is proportional to e(t),
- a term that is proportional to the integral of e(t),
- a term that is proportional to the derivative of e(t).

Examples:

- Flight control system, robotic arm, Car's cruise (speed) control etc.

# Sampled Data system

- Single-input / single output PID Controller } → Digital controller
  - PID means proportional, Integral & Derivative

⇒ A common approach be developed to design the digital controller that uses the system that converts the analog version of system into a digital and resultant system is called sampled data system.

# Pseudo-code for digital process controller

- set timer to interrupt periodically without period T
- At each timer interrupt

```
{
  do
     Do analog-to-digital conversion of y(t) to get yk
     Compute control output uk based on reference rk & yk
     Make digital-to-analog conversion of uk to get u(t)
  End do
}
```

## Higher level (Hierarchical) Control

→ The controllers in a complex monitor and control system are often organized in a hierarchy.

→ A hierarchical control system is a form of control system in which a set of devices and governing software is arranged in a hierarchical tree. Usually, control is made in many levels, hierarchically.

→ These complex system often consists of multiple sensors and actuators and these sensors and actuators need different sampling periods. Such systems are called multi-rate systems.

There can be multiple control loops and the high-level controller (interacts) interfaces with the operator and monitors the behaviour of low-level controllers. The output of high-level controller acts as the reference input of low-level controller. One or more low-level digital controller directly control the physical plant.

Examples:

1. A patient care system:
   - May consists of microprocessor based controllers that monitor and control the patient's blood pressure, respiration, glucose, sugar level etc.
   - There may be higher level controller (e.g. expert system) which interacts with the operator (a nurse or doctor) and chooses the desired values of these health indicators.

Imp. 2. Air Traffic / Flight control Hierarchy:

Figure below shows example of hierarchy of ~~fig~~ flight control, flight management and air traffic control systems.

fig. →

→ The Air Traffic control (ATC) system is at the highest level. It regulates the flow of flights to each destination airport. It does so by assigning to each aircraft an arrival time at each metering fix (known geographical point; adjacent points are 40-60 miles apart) in the route to destination. The aircraft is supposed to arrive at the metering fix at the assigned time. At any time while in flight, the assigned arrival time to the next metering fix is a reference input to the flight management system.

→ The flight management system chooses a time-referenced flight path that brings the aircraft to the next metering fix at the assigned arrival time. The cruise speed, turn radius, descend/ascend rates and so forth required to follow the chosen time-referenced flight path are the reference inputs to the flight controller at the lowest level hierarchy.

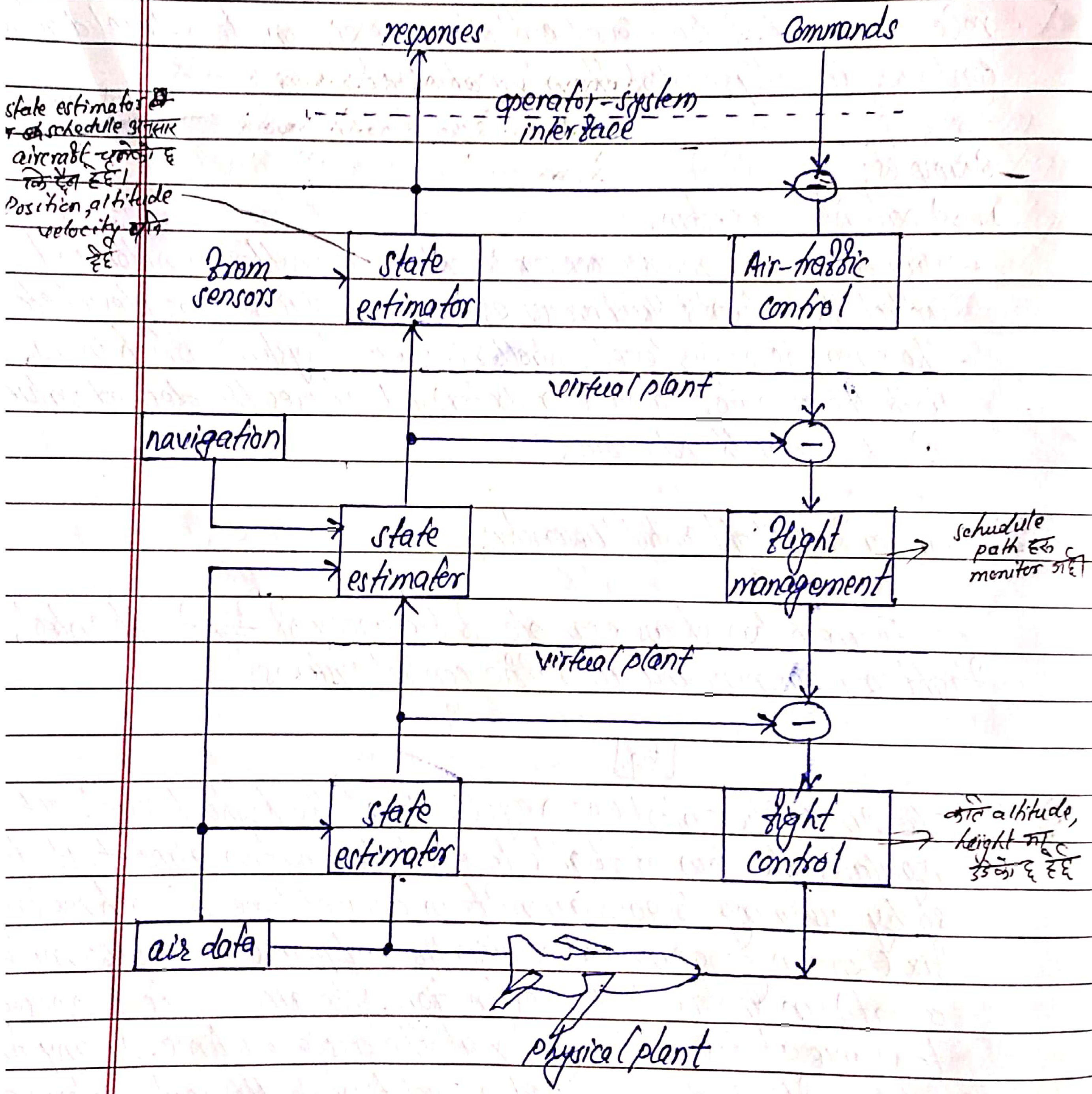



Fig: Air traffic / flight control hierarchy

# Low-level controller vs High-level controller

Computation made by controllers of low levels may be simple and deterministic while high-level controller interacting with operator is more complex and variable (for e.g. expert system). Period of low-level controller ranges from milliseconds to seconds, the period of high-level controllers may be minutes and even hours.

# Guidance and Control

Guidance is the process of calculating the change in position, velocity, attitude, and/or rotation rates of a moving object required to follow a certain trajectory and/or attitude profile based on the information about the object's state of motion.

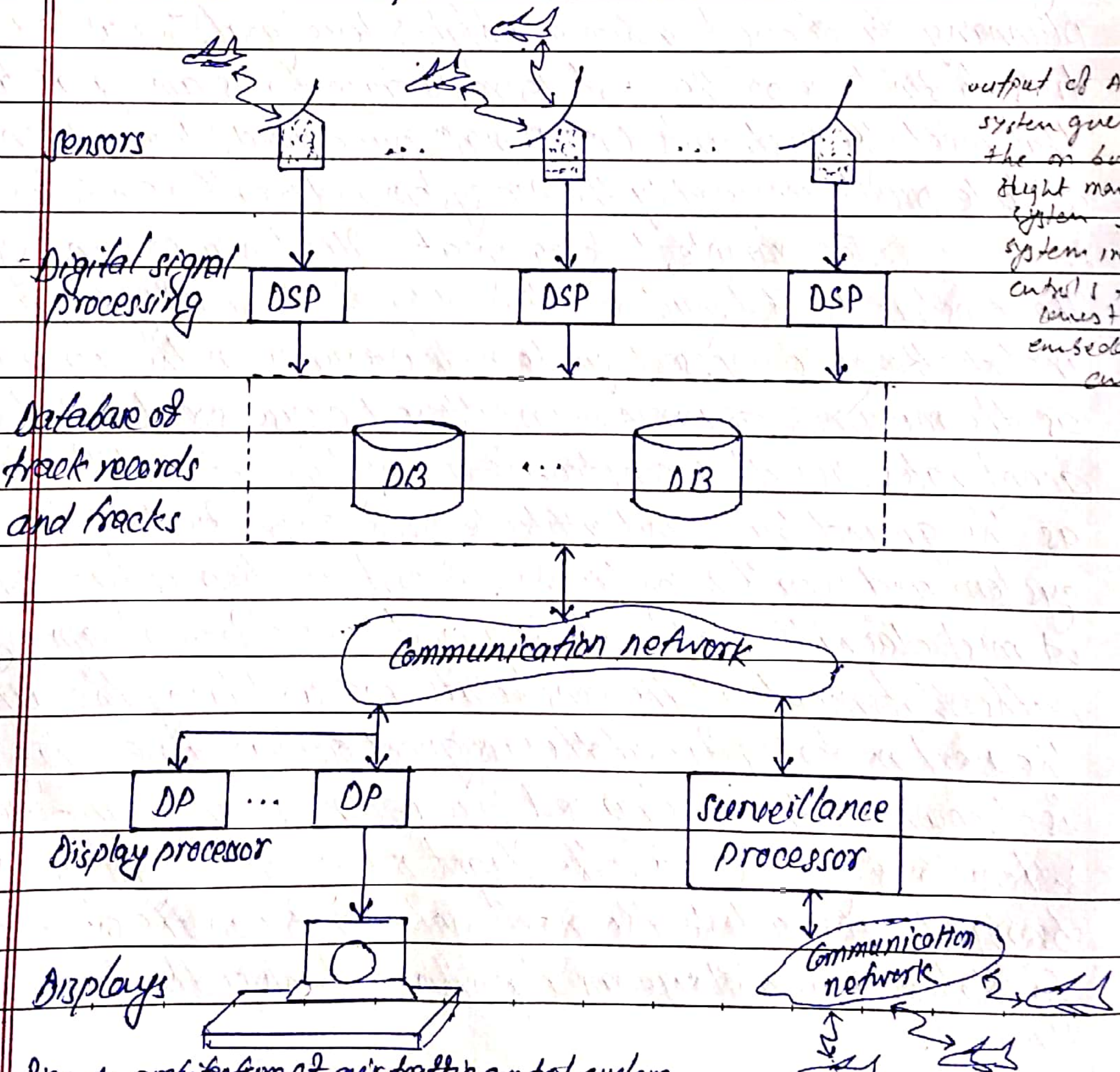
While a digital controller deals with some dynamical behavior of the physical plant, a second level controller i.e. a flight management system typically performs guidance and path planning functions to achieve a higher level goal. In particular, It tries to find one of the most desirable trajectories among all trajectories that meet the constraints (max^m min^m cruise speed, decent/acent rates, attitude profile specified by the ATC system and weather condition).

~~For example, look again at a flight management system.~~ The constraints that must be satisfied by the chosen flight path include the ones imposed by the characteristics on the aircraft, such as the maximum and minimum allowed cruise speed and decent/acent rates, as well as constraints imposed by external factors, such as the ground track and attitude profile specified by the ATC system and weather conditions. A cost function is fuel consumption. A most desirable flight path is a most fuel efficient among all paths that meet all the constraints and will bring the aircraft to the next metering fix at the assigned arrival time. This problem is known as the constrained fixed-time, minimum-fuel problem. When the flight is late, the flight management system try to bring the aircraft to the next metering fix in the shortest time. In that case, it will use an algorithm that solves the time-optimal Problem.

→ Guidance + Control helps to the constrained fixed-time, minimum fuel problem

## Real-time command and Control

~~In Control hierarchy, controllers at the highest~~ The controller at the highest level of a control hierarchy is a command and control system. An Air Traffic Control (ATC) is an excellent example.
The ATC system monitors the aircraft in its coverage area and the ~~and the~~ environment (e.g. weather condition) and generates and presents the information needed by the operators (i.e. the air traffic controllers). Outputs from the ATC system include the assigned arrival times to metering fixes for individual aircraft. These outputs are reference inputs to on-board flight management system. Thus, the ATC system indirectly controls the embedded components in low levels of the control hierarchy.




output of ATC system goes to the on board flight management system so ATC system indirectly control the lowest level embedded compo...

fig: An architecture of air traffic control system

The ATC system gathers information about the state of the aircrafts through the sensors of radars. such radar interrogates each aircraft periodically. When interrogated, an aircraft responds by sending the ATC system its state variables: identifier, position, attitude, heading and so on. These variables collectively are called track record and the current trajectory of the aircraft is a track. The information collected is processed by the DSPs and is stored in the database. This information is picked up and processed by display processor and displayed by the display on. At the same time, the surveillance system continuously analyses the scenario and alters the operators whenever it detects any potential hazard (e.g. a possible collision).

## Signal Processing system

→ Anything that carries information is called as signals. It is a real or complex value function of one or more variables.

→ Most signal processing applications have some kind of real-time requirements. A signal processing application is typically a part of a larger system.

→ signal processing may include digital filtering, video/voice compression and decompression and radar signal processing.

## Radar signal Processing

Radar is an object-detection system that uses radio waves to determine the range, angle or velocity of objects. A radar system consists of a transmitter producing electromagnetic waves in the radio or microwaves domain, an emitting antenna, a receiving antenna to capture any returns from objects in the path of the emitted signal, a receiver and processor to determine properties of the object(s).

The Radar signal processing system consists of an Input/output (I/O) subsystem that samples and digitizes the echo signals from the radar and places the sampled values in a stored memory. An array of digital signal processors processes these sampled values. The data thus produced are analyzed by one or more data processors that not only interface with the display system, but also generate commands to control the radar and select parameters to be used by signal processor in the next cycle of data collection and analysis.

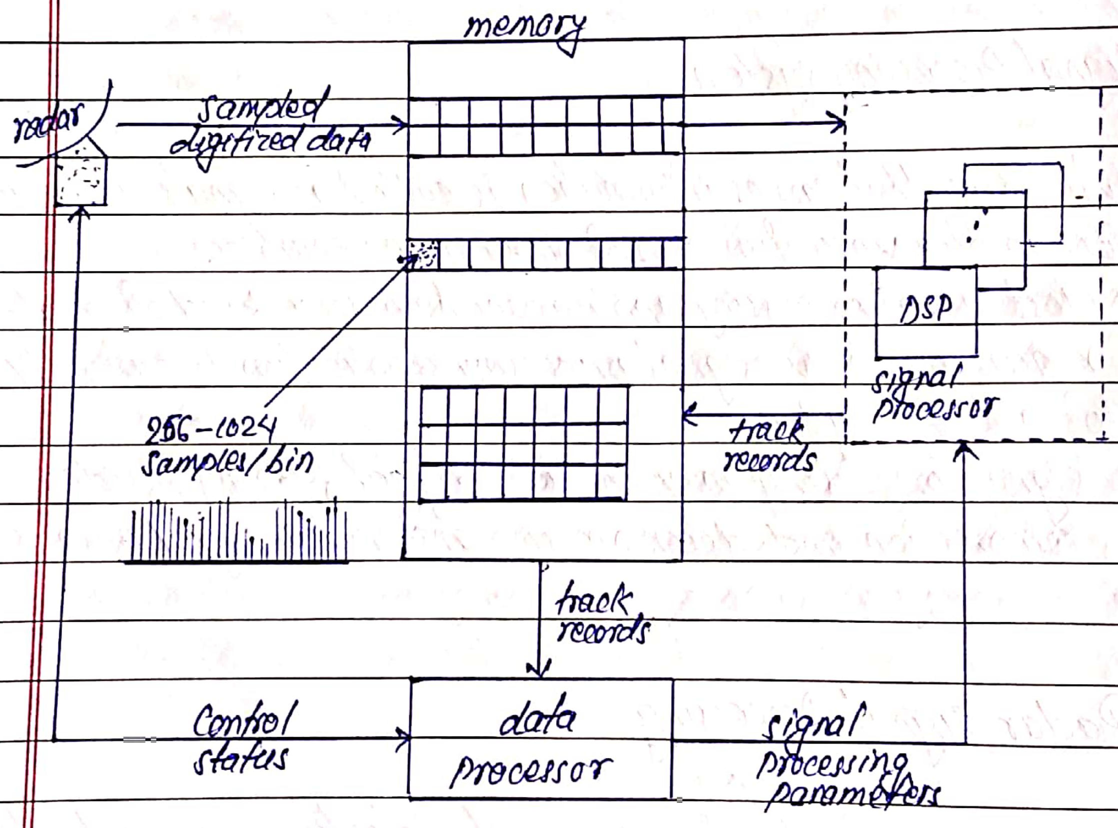



fig: Radar signal processing and tracking system.

To search for objects of interest in its coverage area, the radar scans the area by pointing its antenna in one direction at a time. During the time the antenna dwells in a direction, it first sends a short radio frequency pulse. It then collects and examines the echo signal returning to the antenna. The echo signal consists solely of background noise if the transmitted pulse does not hit any object.

If the signal hits any object at distance "x" and echo arrives after $2x/c$ sec; where $c = 3\times10^8$ m/s. The echo signal collected at this time should be stronger than when there is no reflected signal. If the object is moving, the frequency of the reflected signal is no longer equal to that of the transmitted pulse. The amount of frequency shift (called Doppler shift) is proportional to the velocity of the object. Therefore, by examining the strength and frequency spectrum of the echo signal, the system can determine whether there are objects in the direction pointed at by the antenna and if there are objects, what their positions and velocities are. When objects are detected, signal processor generate a track record for each object and place the record in the shared memory. Each track record contains the position, and velocity of the object.

The following types of measurement can be done by the radar system:

- Position of the target (from the echo delay)
- velocity of the target (from the Doppler frequency shift)
- Reflexivity or "size" of the target (from the echo intensity)

## Basic terms used in Radar Signal Processing

### Tracking:

Tracking is the process of keeping the track of an individual object such as an aircraft under surveillance, a missile etc.

Strong noise and man-made interferences, including electronic counter measure (i.e. jamming), can lead the signal processing and detection process to wrong conclusions about the presence of objects. A track record on a non-existing object is called a false return.

An application that examines all the track records in order to sort out false returns from real ones and update the trajectories of detected objects is called a tracker. The tracker assigns each measured value (position and velocity) to a trajectory. If the measured value assigned to trajectory is an existing one, the measured value assigned to it gives the current position and velocity of the object moving along the trajectory. If the trajectory is new, the measured value gives the position and velocity of a possible new object.

→ Tracking is carried out in two steps:

i) Gating

ii) Data Association

## Gating:

Gating is the process of putting each measured value into one of two categories (established trajectory, new trajectory) depending on whether it can or cannot be assigned to one or more established trajectories. ~~The~~

The value is assigned to an established trajectory if it is within a threshold distance "G" from the predicted current position and velocity of the object moving along the trajectory. The threshold 'G' is called track gate.

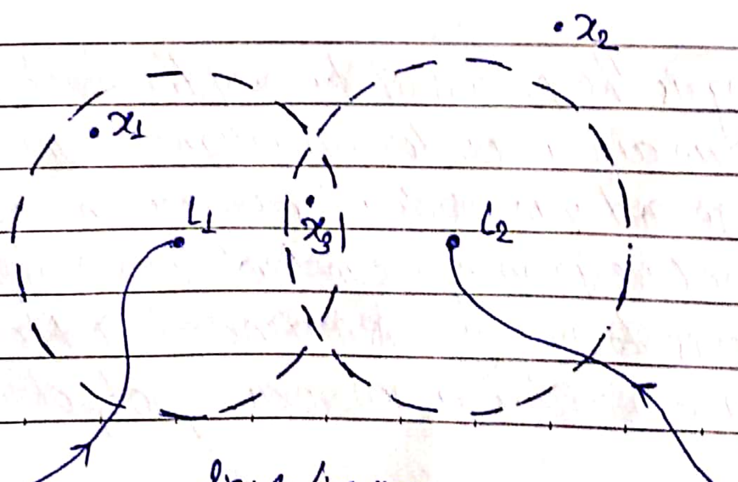



fig: Gating process

At the start, the tracker computes the predicted position and velocity of the object on each established trajectory. In this example, there are two established trajectories $L_1$ and $L_2$, $x_1, x_2$ & $x_3$ are the measured values given by three track records. $x_1$ is assigned to $L_1$ because it is within the distance G from $L_1$. $x_3$ is assigned to both $L_1$ and $L_2$ for the same reason. On the other hand, $x_2$ is not assigned to any of the trajectories. It represents either a false return, or a new object.

## Data Association:

Data association is the process in which every measured value is assigned to at most one trajectory and every trajectory is assigned at most one measured value.

→ The tracking process completes if, after gating, there is a successful data association.

→ This can occur when:

1. The radar signal is strong and interference is low (and hence false returns are few) and,
2. The density of object is low.

→ Sometimes, the assignment produced by gating may be ambiguous, i.e. some measured value is assigned to more than one trajectory or a trajectory is assigned more than one measured value. In this case, data association step is carried out to complete the assignments and resolves ambiguities.

→ The data association algorithm given below can be used to remove the ambiguity.

1. Examine the tentative assignments produced by the gating step.
   a) For each trajectory that is tentatively assigned a single unique measured value, assign the measured value to the trajectory. Discard from further examination the trajectory and the

measured value, together with all tentative assignments involving them.

b) For each measured value that is tentatively assigned to a single trajectory, discard the tentative assignments of those measured values that are tentatively assigned to this trajectory if the values are also assigned to some other trajectories.

2. Sort the remaining tentative assignments in order of non-decreasing distance.

3. Assign the measured value given by the first tentative assignment in the list to the corresponding trajectory and discard the measured value and trajectory.

4. Repeat step(3) until the list of tentative assignment is empty.

In the example in above figure, the tentative assignment produce by the gating step is ambiguous.
step (1a) Does not eliminate any tentative assignment.
step (1b) Find that $x_1$ is assigned to only $L_1$, while $x_3$ is assigned to both $L_1$ and $L_2$. Hence, the assignment of $x_3$ to $L_1$ is discarded from further consideration. After step(1), there still are two tentative assignments, $x_1$ to $L_1$ and $x_3$ to $L_2$.
step(2) leaves them in this order, and the subsequent steps make these assignment. $X_2$ initiates a new trajectory.

## Real Time Applications

Two most common real-time applications are
1) Real-time database
2) Multimedia applications