CHAPTER 6

Unit VI

Robots in Practice

Syllabus Topics

Robot Pose Maintenance and Localization : Simple Landmark Measurement, Servo Control, Recursive Filtering, Global Localization

Mapping : Sensorial Maps, Topological Maps, Geometric Maps, Exploration.

Robots in Practice : Delivery Robots, Intelligent Vehicles, Mining Automation, Space Robotics, Autonomous Aircrafts, Agriculture, Forestry, Domestic Robots.

Syllabus Topic : Robot Pose Maintenance and Localization

6.1 Pose Maintenance and Localization

Q. 6.1.1 Explain localization and its types in brief.
(Refer section 6.1) **(8 Marks)**

- The number of games require direction-finding of the target in a surrounding which mainly consists of locations that are very difficult to differentiate.
- A mobile robot must be aware of its own location so that it can perform various functions on the basis of particular incidents that take place frequently.
- This is also necessary to plan suitable paths or to identify whether the present location is the suitable place to execute some action.

☞ Robot Localization

- Robot localization indicates the robot's capability to set up its own location and direction within the framework of orientation.
- The organization of localization techniques that are used in robotics depends on a few fundamental techniques such as dead reckoning and odometer which are described with the help of two advanced localization technique groups known as probabilistic localization and localization using satellite technology.

☞ Localization classification

The localization can be classified into various forms which are as follows :

Localization classification

1. Relative localization
2. Absolute localization
3. Local localization
4. Global localization
5. Passive localization
6. Active localization
7. Localization in known environment
8. Localization in unknown environment
9. Localization in static environment
10. Localization dynamic environment
11. Localization in natural environment
12. Localization in artificial environment
13. Strong localization
14. Weak localization

Fig. 6.1.1 : Localization classification

(1) Relative localization

- The Relative localization attempts to find out the location of the robot on the basis of alterations of its position from the last dimension.
- If the robot recognizes the starting location, it gradually tracks the final location which can be estimated. The relative localization mainly uses techniques like robot-local sensor data that have sensors mounted on wheels or motors etc.

(2) Absolute localization

- The Absolute localization tries to calculate approximately the location of a robot without applying the data of its earlier location.
- The absolute localization mainly uses techniques that use data from external sensors which provide signals located in the robot work area.

(3) Local localization

- Local localization follows the location of a robot from an initial point.
- The robot uses the information of its previous location and then decides the new location with respect to the adjacent locations of its last position.

(4) Global localization

Global localization does not require any previous information to decide its location with respect to the internal characterization of the operational area.

(5) Passive localization

Passive localization executes data with the help of sensors and calculates robot's location approximately without manipulating the performance of robot.

(6) Active localization

- Active localization can be defined as an element of robot control system that actively manipulates actions performed by robot.
- It can direct the sensors to perform actions like turning around of camera to look behind or even modify the direction-finding plan of the robot.
- It can also perform active routing to produce reasonable outcomes like moving the robot to a place where its sensors are not feasible.

(7) Localization in known environment

The several robot applications which are situated in an earlier known environment can build a plan of the operational area that the robot is capable to concentrate with the help of given plan.

(8) Localization in unknown environment

- The robot working in an unknown environment generally needs to construct a plan to perform its operation.
- The robot simultaneously constructs the plan for operational area and also plans for its own localization.

(9) Localization in static environment

The robot acts in a predetermined, rigid environment where not a single object is moving except the robot which is following a defined path. Such environment is known as static environment.

(10) Localization dynamic environment

- The robot cannot depend completely on a plan representing each and every component related to the environment.
- Such environment is known as dynamic environment. It can rely on other objects which are not defined in the plan that can shift or alter its property.

(11) Localization in natural environment

- Natural environments are not particularly organized or skilled for robots. It remains unaffected with the presence of robot.
- The robot needs to work on the basis of its senses and the abilities of its creator in such area.

(12) Localization in artificial environment

- The environments that are not completely effective but fulfil the requirements of the robots to some extent are called artificial environments.
- The partial versions generally consists of growing localization signals at specific places, generating paths for movement of robots, marking important positions or points by robot-interpretable codes etc.

(13) Strong localization

The identification of exact location of the robot has a lot of special implications that involves predicting the location of the robot either in qualitative or quantitative methods concerning a few worldwide demonstration of space which are defined as **strong localization.**

(14) Weak localization

- The localization in which robots are always familiar with the existing location that has been followed previously is called as weak localization.
- The robot's probable location is calculated approximately on the basis of **Odometry** and **Dead reckoning** that provide a map of the environment and adequate sensing that retains a constant estimate of the location of the robot related to the map.
- This procedure is called as **localization, pose estimation**, or **positioning**.
- **Odometry** makes use of information acquired from the motion sensors to approximately calculate modifications in location eventually. It is also used within robotics by some robots which are either legged or wheeled to estimate their location related to a starting location.
- **Dead reckoning** can be defined as a procedure of evaluating existing location of robot with the help of previously decided location and proceeding towards that location on the basis of recognized or predictable speeds over passed on time and course.
- The common requirement of the problem begins with an early approximation of the robot's position in formation space, given by a probability distribution i.e. P(**x**).
- It makes use of the sensor information **s** in combination with the map to create a refined location estimate P(**x**|**s**) that has an improved probability density related to the actual location of the robot.
- The problem of calculating P(**x**|**s**) is always represented with respect to iterative evaluation process by either using a Kalman filter or particle filter.
- A main problem in these iterative localization processes is the environment of the dimensions that will be utilized to execute the localization.
- It might be feasible to merge dimensions before combining the localization process to acquire an entire dimension of the state as an option for merging the data within the condition of iterative evaluation process.

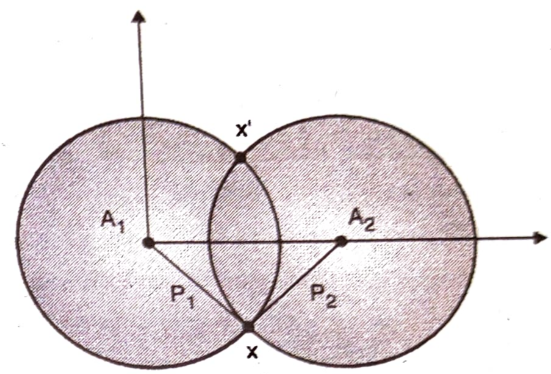
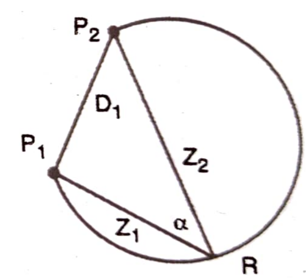
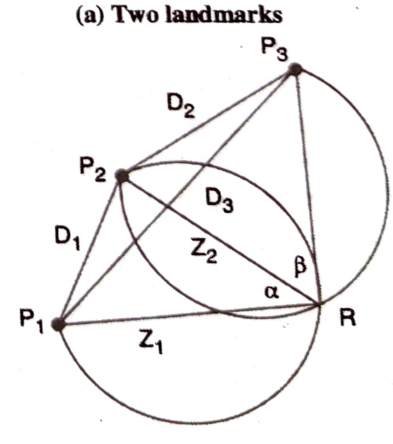


Fig. 6.1.2 : Simple triangulation example

A robot at an unidentified position X finds the distances from p_1 and p_2 with respect to two landmarks A_1 and A_2, the robot can calculate its location instead of its orientation.



(a) Two landmarks



(b) Three landmarks

Fig. 6.1.3 : Triangulation on the basis of behaviour with landmarks

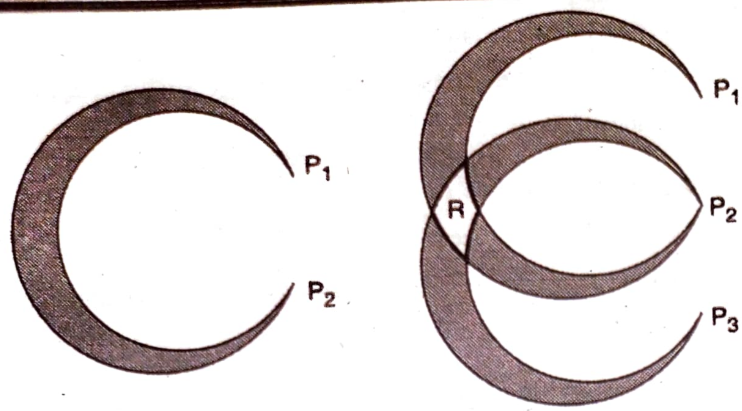


Fig. 6.1.4 : Pose calculation

Pose calculates the related insecurity on the basis of triangulation with the help of inaccurate bearings to (a) two landmarks and (b) three landmarks. Fig. 6.1.4 generated by R.

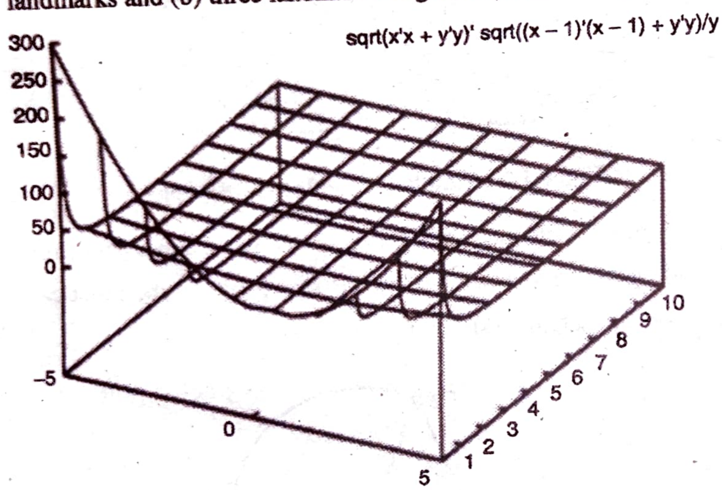


Fig. 6.1.5 : GDOP

- **Geometric Dilution of Precision (GDOP)** for two distance dimensions represents GDOP for landmarks located at two points (0, 0) and (1, 0).
- The error associated with the triangulation develops with distance covered by the targets as well as positions next to the x-axis which does not exist between the two landmarks.

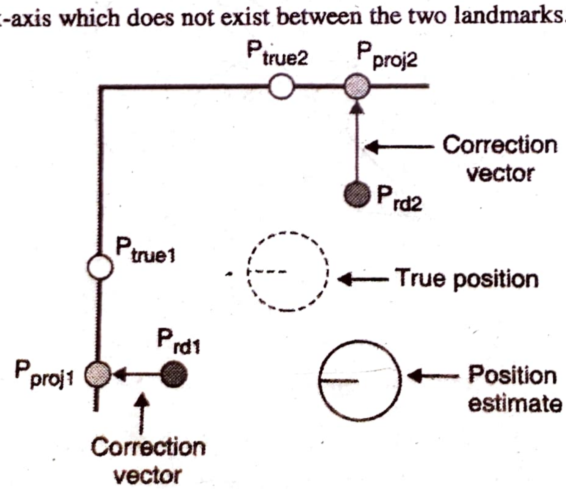


Fig. 6.1.6 : Planning

- Planning against the target line segments by projecting series of data points $p_{rd1,\,2}$ against $p_{proj1,\,2}$, with respect to the target line segment forms, we can determine the error in $p_{rd1,2}$ concerning the true range dimensions $p_{true1,\,2}$.
- The developed points simply give data regarding the error vertical to the target line segment.

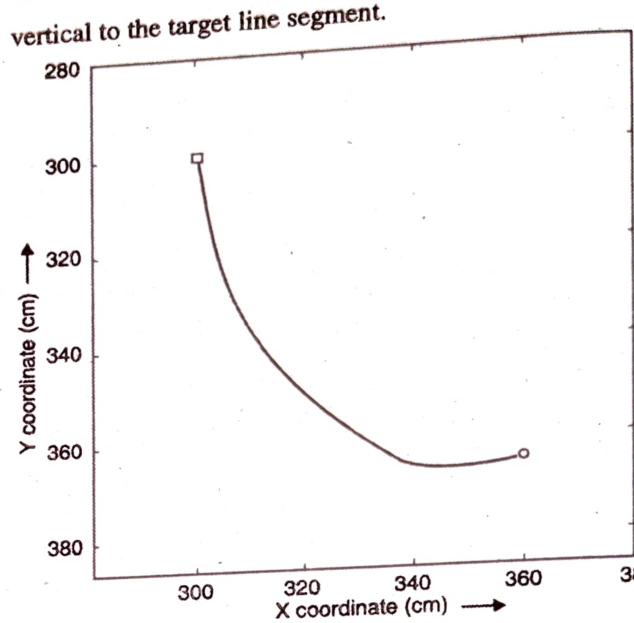


Fig. 6.1.7 : Path of union

- The path of union of the location is estimated from the initial location plotted by a circle to the true location plotted by an asterisk.
- The approximate value does not tend to shift directly to the true location initially, but shifts the exact iterations that can be performed afterwards.

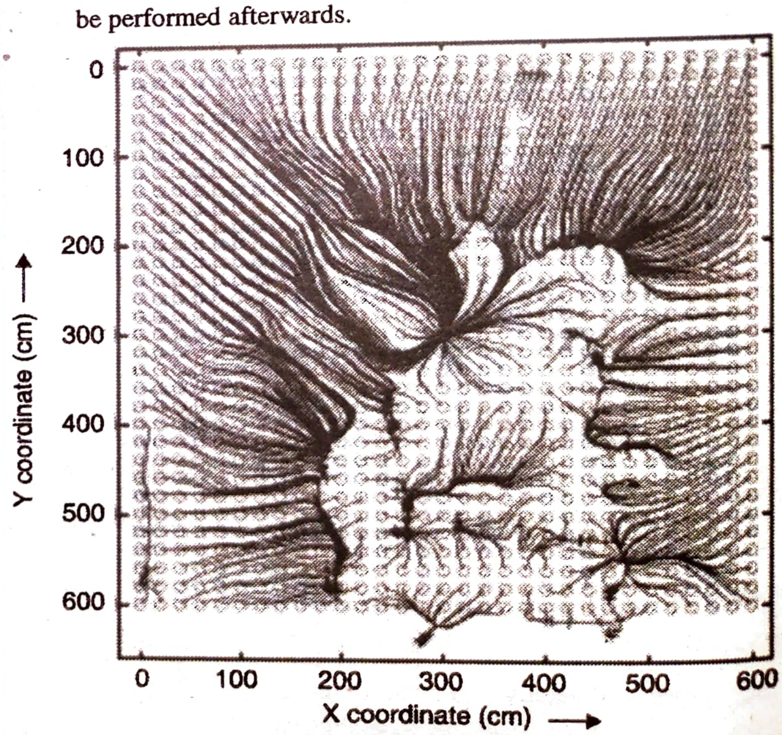


Fig. 6.1.8 : Representation

- Paths of union represented by lines that begin at initial position calculates circles which results into calculation of final position. The exact location of the robot is at the centre of the rectangle.

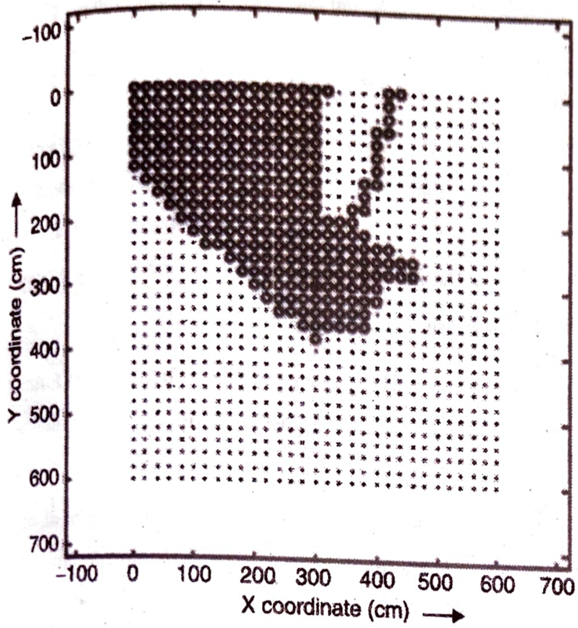


Fig. 6.1.9 : X, Y co-ordinates

- Initial location calculates approximately a value that combines together with the correct location of the robot where each circle shows successful meeting of the true position within 2 cm.
- The filled dot inside the centre is the correct location. The empty circles represent the correct meeting points whereas only dots are related to failure where points do not meet.

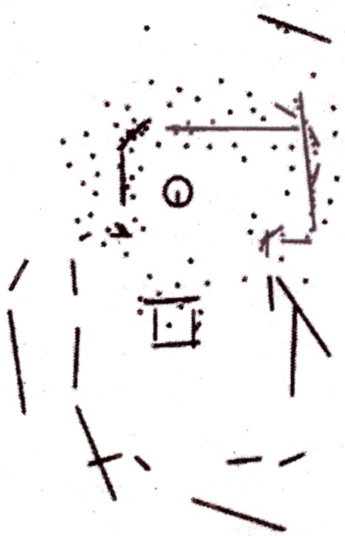


Fig. 6.1.10 : Environment with added noise

- Environment is represented with added noise along with only random range data points observed from the location used by robot.
- If dead reckoning is only useful for location estimation, consecutive errors are supplementary to any progressing complete pose estimate and add up with subsequent actions of the robot.
- This makes the common problem like retaining an exact coordinate system is very complicated or probably impractical in the absence of a few exterior indications for removing the collected errors.
- Long-lasting localization and related tasks like direction-finding and map creation should refer to the outer world for location improvement if situational accuracy is to be retained.
- Generally, this makes use of sensory data for re-adjusting a robot's sense to locate within the environment.
- In certain cases, it establishes actual locating in support of just calculating local position approximately or qualitative data.
- In some conditions it is essential to assume the robot's location without any prior approximation.
- This kind of positioning is defined as **global localization**, in equivalence with global utility reduction; a most favourable solution must be initiated without a consistent initial estimate.

Syllabus Topic : Simple Landmark Measurement

6.1.1 Simple Landmark Measurement

Q. 6.1.2 Write a short note on Simple Landmark Measurement. (Refer section 6.1.1) **(4 Marks)**

- The calculation of approximate locations moves forward on the basis of results related to geometric or trigonometric problems that consist of limitations on the locations of landmarks in the environment.
- Theoretically, the problem is associated to create evaluation of a landmark regarding a fixed sensor.
- The essential differences of the problem occur when the landmarks do not show individual identities which are unknown, when the landmarks are not easy to identify, or when the dimensions are incorrect.

- If there is recognition of a perfectly common definition of a landmark, then fundamentally all techniques for pose evaluation can be defined with reference to landmarks.
- The main aspects that make use of landmarks are the areas through which the landmarks can be identified, the practical relationship among depend on the landmark dimensions with location, and the procedure through which errors are marked.
- Added features that also distinguish a specific location evaluation system are as follows :
  - Identify whether the landmarks are reactive or energetic.
  - Specify the mode of sensors.
  - State the geometric properties of the landmarks such as huge or minute, points or planes, etc.
  - Identify, classify, or determine a landmark.
- An essential issue to be exercised is that landmarks can be used as either synthetic or natural. Artificial landmarks positioned exclusively for the functions of robot localization are generally much easier to identify and can be individually labelled.
- Their most favourable assignment is an attractive issue. The landmarks which occur naturally prevent modification in the environment, but their steady and strong recognition can be a key issue.
- In the end, the scope of the situational check is offered by remarks of a landmark on the basis of sensor as well as geometry of the landmark.
- Planar landmarks generally offer just one-dimensional limits on the robot's pose.

(1) Landmark Classes

Q. 6.1.3 Write a short note on Landmark Classes (Refer section 6.1.1(1)) **(4 Marks)**

- Landmarks can be categorized into following types : **active or inactive, natural or artificial.** Active landmarks are usually senders that produce several signals that are found concerning the environment.
- Active artificial landmarks stay away from various problems usually related to landmarks that are passive in nature.
- Artificial landmarks are normally selected so that they can be seen by the fundamental sensing equipment but may have some confusion regarding natural occurrence of structures.
- Generally, an artificial landmark can be either active or passive that can enlarge the functional range of the fundamental sensor technology as compared to a natural landmark.
- The landmarks can also be described in terms of any sensing representation. Within the framework of robotics there are numerous primary sensing models that execute a specific function for declaring estimations which are as follows :

Video-based sensing

- It makes use of a large range of modes. In its easiest form, it can supply tolerance and possibly series of visually defined landmarks.
- Artificial landmarks can be improved with the help of distinct bar code to both for assisting their recognition and guarantee their individuality.
- The landmarks that occur naturally are generally required for processing highly complex image phases which subsequently depend on target recognition that can be difficult.
- There are various environments that display landmarks which are strong and naturally occurring to construct exceptional visual targets
- For instance, doors and door entrances in passage environments frequently makes very fine and very consistent visual landmarks.
- Laser transmission along with video sensing always requires a unique mention. The retro-reflective landmarks can offer very extensive range ability for detection.
- An active radio signal configs a set of thoroughly created location that estimates landmarks.

Global Positioning System (GPS)

- It is supported by a network of satellites which can be approximately utilized from any exposed open-air location.
- SONAR can be defined as system which is easily available everywhere within low-cost that considers location regardless of its disadvantages in terms of beam distribution, particular reflection and surrounding noise.

- It is used to employ structures that are mostly very large and usually geometric; hence they are occasionally defined as **geometric signals**.

(2) Triangulation and Trilateration

Q. 6.1.4 Write a short note on Triangulation and Trilateration. (Refer section 6.1.1(2)) **(4 Marks)**

- **Triangulation** and **trilateration** are techniques that are used to find solution of limited equations associating the poses referred as a spectator which is dependent on group of landmarks.
- Officially, trilateration makes use of space constraints, while triangulation makes use of perspective (orientation) constraints.
- The term triangulation is used to find solution of limited equations associating the poses referred as a spectator for performing measurements with the help of landmarks regardless of the nature of those landmark dimensions.
- Pose estimation by means of triangulation techniques with known landmarks are recognized since prehistoric times and were developed by the ancient Romans in plotting and constructing roads during the Roman Empire.
- The location or distance of more than one landmark is evaluated with known locations by an agent which can calculate its pose by itself.
- If landmarks and robots both represent a three-dimensional world, then the restricted accuracy related with data of height always results in a two-dimensional problem.
- Estimation of data is occasionally used to authenticate the outcomes.
- If the triangulation problem of a point robot must be measured with six unidentified parameters consisting of three position variables and three orientation variables, then mostly the task is pretended as a two-dimensional or three-dimensional problem by means of two-dimensional or three-dimensional landmarks.
- On the basis of the arrangement of sides (S) and angles (A) respectively, the triangulation problem is defined as "side-side-side" ("SSS"), "side-angle-side" ("SAS"), and so on.
- Every case allows a result without the "AAA" case that the range of the triangle is not controlled by the constraints.
- Actually, a particular sensing technology always revisits either an angular dimension or a distance dimension where the landmark locations are usually acknowledged.
- As a result, both SAA and SSS cases are mainly assembled.
- Generally, the problem can engage a few permutations of algebraic limitations that associate the dimensions to the pose parameters which are usually non-linear, and therefore a result may be reliant on an initial location for evaluation.
- This can be derived as

$$X = F(m_1, m_2, \dots, m_n)$$

where, the vector X denotes the pose variables to be evaluated and $M = m_1, m_2, \dots, m_n$ is considered as the vector of dimensions to be applied.

- For estimating certain cases of locations adjusted by the robot in the plane is represented as follows:

$$x = F_1(m_1, m_2, \dots, m_n)$$

$$y = F_2(m_1, m_2, \dots, m_n)$$

$$\theta = F_3(m_1, m_2, \dots, m_n)$$

- If distance is available to a landmark, then only dimension restricts the robot's location to the curve of a circle.
- A robot located at an unknown position X as shown in Fig. 6.1.2 estimates two landmarks P_1 and P_2 by measuring the particular distances d_1 and d_2 respectively. The robot must be positioned at the junction of the circle of radius d_1 with centre at P_1, through the circle of radius d_2 and centre at P_2. We can suppose that P_1 is at the starting point and P_2 is at (a, 0). A solution given as follows :

$$x = \frac{a^2 + d_1^2 - d_2^2}{2a}$$

$$y = \pm\left(d_1^2 - x^2\right)^{\frac{1}{2}}$$

- In general application, signals are situated on walls, and thus the false solution can be recognized since it would communicate to the robot being positioned on that side of the wall which is incorrect.

- Even if distances to landmarks offer an easy triangulation, majority of sensors and landmarks leads to more difficult conditions.
- A regular real-world condition is relatively tolerant to the available landmark except the distance.
- Let us consider an example of a camera which may identify two small recognized landmarks.
- We can assume that camera can be regulated to acquire the angular partition among the landmarks from their locations on the image.
- With the help of angular partition or **relative bearing** connecting two landmarks with known location limits the robot's point to be positioned on a couple of circular curves.
- If the robot can decide the clockwise details of the landmarks or tag them individually, then the location is restricted to just one of these two circles.
- Supplementary landmarks to which the behaviour is known can supply a third limit and the junction of these limits individually decides the robot location.
- The robot can predict two identified landmarks and calculates the behaviour of each landmark as compared to its own straight-forward direction.
- This gives the variation of behaviour between the paths related to the two landmarks and limits the exact location of the robot to be positioned on a specific section of the circle shown in Fig. 6.1.3(a) the position of points that satisfy the conditional difference is given by,

$$D_1^2 = z_1^2 + z_2^2 - 2|z_1|\,|z_2| \cos(\alpha)$$

where, z_1 and z_2 are the spaces from the robot's existing location to landmarks P_1 and P_2, respectively. The visual ability of a third landmark results into three non-linear limits on z_1, z_2, and z_3,

$$D_1^2 = z_1^2 + z_2^2 - 2|z_1|\,|z_2| \cos(\alpha)$$
$$D_2^2 = z_1^2 + z_3^2 - 2|z_2|\,|z_3| \cos(\beta)$$
$$D_3^2 = z_1^2 + z_3^2 - 2\,|z_1|\,|z_3| \cos(\alpha+\beta)$$

- It can be resolved with the help of standard methods to get z_1, z_2, and z_3. Information of z_1, z_2, and z_3 directs to the robot's location.
- The three landmarks are also useful to prevent any uncertainty if the landmarks are not tagged. There is reasonable noise in the behaviour of the landmark that evaluates or tags.
- This advises the use of added dimensions to either enhance strength or authenticate the dimensions. For easier support, landmarks can be divided into groups, and a reliable estimate from every group can be searched.
- The geometric planning of landmarks concerns that robotic spectator is essential for the accuracy of the result.
- A specific preparation of landmarks may offer high precision when examined from several locations and low precision when examined from others.
- In the range, definite compositions of landmarks may exist with no result at all.
- For an instance, a group of three collinear landmarks examined within two dimensions that behaves like a measuring device can supply good situational precision for triangulation when observed from a point outside the line combining the landmarks.
- Alternatively, if the robot is situated on the line combining the landmarks, then the location can simply be forced to be positioned somewhere on infinite line.
- There are various robotic systems that depend on target triangulation so as to concentrate on the task of pose evaluation.

(3) Triangulation with uncertainty

- The ultimate case of triangulation on the basis of scope or quantity is rather difficult by the fact that actual sensor dimensions have related uncertainty.
- Consequently, the location evaluations created by triangulation systems offer probability sharing for the robot pose.
- The particular deteriorating cases that direct to actual uncertain pose evaluation are related to the enlargement of input error in the route of position evaluation which is a frequent incident as shown in Fig. 6.1.4.
- The association among the correctness of the input dimensions and the precision of the final evaluation of the

required pose variables is dignified by the concept of geometric dilution of precision (GDOP).

- This is a measuring device that states the difference in the yield estimate **x** i.e., the geometric variables comprising the pose with differences in the input factors **S** i.e., sensor data :

$$\text{GDOP} = \frac{\Delta X}{\Delta S}$$

- We obtain the range as **ΔS** that advance to zero which is equal to the Jacobian **J** of the measurement equation.
- The three-dimensional space consists of horizontal geometric dilution of precision (HDOP) and positional geometric dilution of precision (PDOP) which refer to the error awareness of only the horizontal or vertical elements, while the entire GDOP may refer to the awareness of a well-built class of variables.
- In the background of global positioning systems, GDOP is occasionally used to represent the awareness of the scheme of variables that contain both the 3D transformation and the evaluation of the local recipient's time clock error.
- The effortless landmark can be considered in the following case as shown in Fig. 6.1.2.
- The GDOP is given by

$$\text{GDOP} = \mathbf{J} = \begin{bmatrix} d_1/a & -d_2/a \\ d_1(a-x)/y & xd_2/a \end{bmatrix}$$

- The magnitude is planned in Fig. 6.1.5 where the two landmarks are placed respectively at (0, 0) and (1, 0), and **J** is designed over the series x = – 5 to 5, y = 0 to 10.
- **J** develops as the robot shifts away from the x-axis.
- This is normally useful for separation between the two circles which reduces as the robot shifts away from the landmarks.
- The precision of the majority sensors reduces with scope that uses isolated landmarks which needs to avoid the nearby accessible landmarks.
- The small improvement in the GDOP is obvious along the x-axis which is away from the section among the two landmarks.
- The error which occurs in any location estimate develops very rapidly when both landmarks exist on the identical sides of the robot and in order with it.
- Information of the type of the GDOP can be useful to the robot for selecting a particular landmark which is to be applied if several landmark options are accessible and to influence every dimension within a pose evaluation process.
- In realistic conditions robotic systems may face problems in independently recognizing landmarks, or the position evaluation may be unbalanced due to landmark geometry.
- The extremely expert approach to handle with irregularly dependable landmark data is to merge landmark-based location data with position data from dead reckoning.
- This combination of data from two resources has been successful efficiently with the help of Kalman filter.
- Some real-world systems have been developed that can execute consistent pose evaluation and remapping in environments integrating large time change in their landmark design.
- Common approaches authenticate existing models in opposition to current dimensions and remove models having low confidence.

Syllabus Topic : Servo Control

6.1.2 Servo Control

Q. 6.1.5 Write short note on servo control. (Refer section 6.1.2) **(4 Marks)**

- The sensor data which is useful in providing vision to position evaluation is difficult for reversing the imaging make over to improve the positions of points in 3D.
- Basically identifying essential objects is always complicated due to facts such as perspective deformation, image noise, illuminating and shadowing changes and specific reflection.
- The easiest method for using sensor information and particularly vision to associate a robot's pose with a landmark is defined as **image-based servoing** or **visual servoing**, or, for common classes of sensor it is also defined as **sensor-based servoing**.
- Servoing is generally used to enable a robot to shift to an exact target location with the help of practical sensor dimensions which is referred as **homing**.

- This method is depends on storing a particular sensor image $I(q_{goal})$ related with a target location q_{goal} for the robot and using the variation among $I(q_{goal})$ and $I(q_c)$ to shift the robot from its current location q_c to the goal.
- The distance involving the existing robot location from the target location is believed to be monotonically associated to the displacement in sensor space among the target sensor interpretation and the current sensor dimensions.
- This singular relationship generally arises when the robot is quite close to the target location.
- Instead of executing several complex sensor readings to create association, sensor dimensions obtained on-line are openly compared with target sensor dimension with an easy method known as an L_1 or L_2 metric.
- The image can also be describe by a group of intermediary attributes denoted as f(i) and variations can be used to convey the image variation.
- The instances of such attributes range from the pixel variations to landmark locations in the image to energy in various bandpass channels..
- In most cases, the given image attribute vectors are assumed with difference functions which are as follows :

$$E(q_c) = |f(I(q_{goal})) - f(I(q_c))|$$

- The workspace of interest concentrates on locations to be selected which are suitably close to the target location.
- The Jacobian **J** related to sensor image concerning the pose parameters can be denoted as follows :

$$\mathbf{J} = \begin{bmatrix} \frac{\partial f_1}{\partial q_1} & \cdots & \frac{\partial f_1}{\partial q_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial f_m}{\partial q_1} & \cdots & \frac{\partial f_m}{\partial q_n} \end{bmatrix}$$

- The local curve statement means that the Jacobian of E offers a sign that pose changes are associated to changes in E.
- If minute modification in pose of the image creation equation enables a linear estimation to be performed, then the required pose change to generate a desired change in the image dimensions can be calculated as :

$$\Delta q = \mathbf{J}^{-\infty} f$$

- Both the estimations use sensor noises that obtain the target location which involves a repetitive approach. Shifting the robot to q_{goal} shows the low-level strategies below the slope of the difference function from q_c.
- The main problems related to servo control on the basis of sensor are as follows:
  - o The planning from pose to signals which is unusual and revolves around changes in pose.
  - o The attribute space may not be suitably strong or steady.
  - o No measure of location estimate is created, apart from the "home" location.
  - o Servoing is process that states the poses which are previously visited to obtain sample image.
- Alternatively, the method consists of low operating cost, voluntarily executed and builds only easy estimations about the environment.

Syllabus Topic : Recursive Filtering

6.1.3 Recursive Filtering

Q. 6.1.6 Write short note on recursive filtering. (Refer section 6.1.3) **(4 Marks)**

- To achieve position evaluation with the help of external referencing, the inequality among the known and viewed locations of barriers supply an estimate of location to be used in accepting the drift in approximate calculations from inner sensors.
- A Kalman filter is useful in merging pose estimates from dead reckoning and other dimensions in a most favourable manner.
- The environments of mobile robotic are based on the factors which show that a most favourable outcome is often violated.
- Practically, the response functions of actual sensors differ non-linearly with positional variables of the robot.
- To report this non-linearity, an alternative of the Kalman filter which is known as extended Kalman filter (EKF) is attained by linear model of the system.

- The integration of SONAR dimensions involves several supplementary steps as well as linearization of the system of equations.
- If the environment plan is decided, remarks from the sonar sensors can be related with objects in the plan by a communication process which is essentially a similar issue that occurs on the basis of attributes in motion estimation.
- The differences among objects in the map and their monitored positions on the basis of existing estimated robot location give evaluation of the error in the current approximate position which is verified by the precision of the dimensions, precision of the map, and the dependability of the communication.
- Normally the first two factors i.e. sensor error and map accuracy are verified and previously related to assurances which is directly included into the Kalman filter equations.
- Communication is usually handled in a different way. Initial communications can be calculated in a different ways on the basis of dimension types such as circular curves or distinct points and the type of information stored on the plan such as using possibilities or line segments.
- The easiest approach to search the nearest descriptive attribute on the map for every dimension gives existing estimate of the robot location.
- An additional approach is concerned for searching alternative objects to give details about dimension that leads to a "multiple hypothesis tracking" structure.
- The EKF is an influential method that frequently executes well if conditions are appropriate and shortcomings does not exist.
- Basically, the linearization of the system is on the basis of the acceptability of being modelled which is suitable to approximate the error of sources in the system, and perform proper error distribution.
- The real reactions from actual sonar sensors are considerably more difficult as compared to simple models which are practically used to provide multi-path sonar reflections that are highly non-linear.
- This consecutively indicates that there is a possibility of ever-increasing error which pass through an approximate filter.
- The SONAR reactions that are not characterized properly by the basic SONAR model are generally classified as outsider and access function are used to reject them. This creates traditional EKF on the basis of localization that is very sensitive to be selected as a correct function.
- If it is very minute, then high-quality of information is rejected and if it is very bulky, then outsiders damage the estimates.
- Additionally, if there is an error within the input then pose estimate is well-built as compared to the size of the gating function which states that the robot leads to an unexpected collision.
- The difference among actual data and forms can result into elimination of entire sensor information and deviation of the filter.
- In such conditions, the EKF may result into weak estimates and even fail to reach to the correct estimate.
- Additionally, the main concern is the necessity of a simple association among geometric structures and observed dimensions that makes it complicated to apply such techniques in various environments.

Techniques for recursive filtering

- (I) Adaptive Localization at Multiple Scales
- (II) Classification of data points
- (III) Weighted voting of correction vectors
- (IV) Convergence of the estimate
- (V) Multi-scale local correction results
- (VI) Comparative behaviour
- (VII) Quality measures

Fig. 6.1.11 : Techniques for recursive filtering

➜ (I) Adaptive Localization at Multiple Scales

- According to ALMS approach of localization, the process in which a robot establishes pose relating to a mapped environment is executed in various stages.

- In every stage we suppose the presence of a geometric two-dimensional plan of the environment on the basis of lines that represent barriers such as walls in the environment.
- The first stage of location calibration is generated under the restricted assumption that an approximation of the robot's location is accessible and that the robot's direction is identified correctly.
- The pose evaluation problem is perfectly prepared on the basis of area which is explained by the map as per the observed dimensions.
- A superior version of the difficulty is there in which location and direction are corrected at the same time that gives first common estimate which is referred as neighbouring pose correction.
- By means of the local pose corrector and coupled measure of deals among observed and identified landmarks leads to global localization where the robot has no early estimate of its pose which can be prepared as a minor optimization problem.
- The majority of techniques for model-based localization depend on a two-stage approach where models are initially coordinated to practical data, and then the geometric associations among techniques and examinations are used to acquire a location estimate.
- In the condition of ALMS, the corresponding stage involves investigating sensed information points and classifying related to the target line that represents the similar objects which the sensed data signify.
- The statement is made that the nearest line segment to particular sensed data point is probable target for that point.
- Each data point is related with a specific model line.
- The evaluation stage of ALMS is on the basis of a selection procedure which consists of calculating vector dissimilarity among each point and its objective model and deriving a subjective sum of these rectification vectors to give a latest estimate of the robot's exact location.
- The entire process continued until the location is no longer distinguished further.
- If the early comparisons are sufficiently correct, then estimate of both conversion and direction can be calculated with the result of a single non-linear system.

(II) Classification of data points

- The idea of categorization is to compare the various data points with techniques signifying the probable object in the environment which gives response to the actions performed by the sensor.
- The target model related with every point is the model nearest to the point.
- When a small positional error is assumed, the representation of the data points must be closer to the objects.
- These objects assume a strong type that permits the system of equations defining the localization process to be linear during the construction of an extensive Kalman filter (EKF) needed for localization.
- Namely, the system is linear in relation to an operating point which gives the correct robotic location.
- The given approach defines an assumption that some portion of the information is close enough to its correct location to be related correctly, so that method can manage the considerable errors without creating a linear system.
- From every data point and objective line segment, a correction vector is achieved.
- The correction vector gives the vector dissimilarity among the data point and its projection at right angles on top of the infinite line passing by the equivalent line segment.
- This vector symbolizes the offset which is needed to accurately match the point with the infinite line by the model to rectify the error in the point which is at right angles of the line.
- A suitable grouping of given correction vectors is done with the help of each and every dimension which is used to estimate location of the exact position.

- It is essential to make a note of the perpendicular part of error viewed from a particular point which may be accepted by the correction vector.
- This basic location constraint given by each dimension is derived from the geometric constraint that tracks corresponding one-dimensional line model.
- Actually, there is a poor constraint present in the orthogonal path that can be developed with information that exists within the linear attributes in the environment comprising finite length.
- This need of a two-dimensional constraint which is a very huge insecurity in one dimension is equivalent to the opening problem in movement estimation.
- As a general rule, many dimensions from non-equivalent structures will offer adequate constraints to stay away from this problem.
- In various conditions, on the other hand, it can be referred as an issue.
- For example, a robot in the central point of a long, undefined passage that can only accept its position at right angled direction of the main axis of the hallway.
- The motion next to the axis of the passage does not provide any displacement data since each and every part of the wall looks the same and as a result it is difficult to distinguish so as to compute a displacement.

(III) Weighted voting of correction vectors

- The simple averaging across measurements is not a suitable mechanism for merging the correction vectors because of the presence of unknown dimensions which are not related with the accurate model in the map.
- These can occur as a result of incorrect communications, sensor noise and deficiencies in the map.
- In isolation, a strong averaging method is needed.
- An easy gating which uses a step function undergoes, insecurity and deficiency of refined deprivation related to errors in the primary pose estimate.
- It prefers to utilize a continuous function with a relatively long extension. Each correction vector is denoted as follows :

$$v_i = (\Delta x_i, \Delta y_i),$$

- The general error vector $V = (\Delta X, \Delta Y)$ can be considered as follows :

$$\Delta X = \frac{\sum_{i=1}^{n} \omega(\|v_i\|)\, \Delta x_i}{\sum_{i=1}^{n} \omega(\|v_i\|)}$$

$$\Delta Y = \frac{\sum_{i=1}^{n} \omega(\|v_i\|)\, \Delta y_i}{\sum_{i=1}^{n} \omega(\|v_i\|)}$$

where, the weighing parameter ω is defined as

$$\omega(d) = 1 - \frac{d^m}{d^m + c^m}$$

where, c denotes a constant and $\|v_i\|$ is the standard length of the i_{th} correction vector that represents the distance among the i_{th} series of data point and its objective line segment.

- In common terms, points nearest to their objective line segments have superior selection strength in the general error vector as compared to the points located far away.
- This divides the points freely into two groups which are as follows :

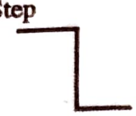
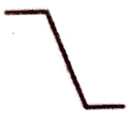
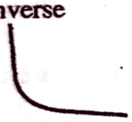
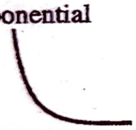
(i) Nearby points,

(ii) Highly subjective points and

(iii) Light weighted isolated points.

- A weighting function is basically required for a simple entry which has insecurity related with a proper step function.
- A sigmoid function is defined as a flexible non-linearity function which offers an entrance that varies slowly.
- This is an unclear threshold that can be offered by a number of functions.
- The little values in the extension are suitable for conditions where the error in the primary pose estimate is huge.
- In these conditions, several data points will be far away from their exact map models to be originally matched so that the long extension of the sigmoid offers a comparatively equivalent weighting between these points.
- It avoids the outsiders from rapidly exercising their authority as a particular threshold is approved.

Table 6.1.1 : Comparison of possible weighting functions.

Function type	Sample expression	Features	Disadvantages
Step 	Step (– d – c)	Constant weight for small d : points close to their paired models are weighted equally and high.	Zero weight for large d, so distant data points can never contribute to the overall error vector; transition is too abrupt.
Piecewise linear 	$1 - \frac{1}{d_{run}}(d - d_{lin})$	Constant weight for small d	Zero weight for large d
Sigmoid 	$1 - \frac{d^m}{d^m + c^m}$	Nearly constant weight for small d, small but non-zero weight for large d (allowing distant points to contribute to the overall error vector), smooth transition.	
Inverse 	$\frac{1}{d}$	Small but non-zero weight for large d.	Too large and non-uniform weight for small d : weighting would be too sensitive to even minor noise or map imperfections.
Exponential 	e^{-d}	Small but non-zero weight for large d.	Non-uniform weight for small d : this suffers from the same effect as the inverse function, except that the weighting is bounded.

➔ (IV) Convergence of the estimate

- Generally, pose evaluation techniques contain non-linear matching procedures tracked by either linear or non-linear evaluation procedures.
- Therefore, several position evaluators simply generate a correct location estimate if they are specified with an adequately perfect initial estimate.
- This is because of the inter-reliance of the results on the categorization and evaluation procedures.
- Accurate evaluation is performed on the basis of exactly relating dimensions and map data.
- As the location estimate for the robot alters, the direct–target communications can differ considerably.
- All points are not correctly organized in the beginning, but only some are required to start shifting to the location estimate in the correct direction.
- Since incorrect communications have a tendency to get casually dispersed and hence the correct ones are readily compensated.
- The path of the location estimate as it meets to the exact location can be observed in Fig. 6.1.7.
- The location estimate revealed by the circle cannot move directly towards the correct location in the beginning represented by the asterisk.
- As the importance is given to the noise immunity as compared to high accuracy at this point.
- As the location estimate gets nearer to the correct location, the more importance is given to accuracy rather than noise immunity so that the path follows a more direct approach.

➔ (V) Multi-scale local correction results

- The union properties of the location evaluator are demonstrated with the help of early location estimates whose error scope was up to 300 cm (10 feet) in the x and y directions respectively from the robot's real position as defined by location calibration.

- Actual locations were calculated physically up to 1/2 cm with the help of a smooth grid on the floor of the experiment area.
- Fig. 6.1.8 displays the meeting of the location estimates as a utility of initial location.
- Every line unites with an early estimate where small circles casing the map to an ultimate estimate.
- The exact robot location is in the midpoint of the map at (x, y) = (300, 300) where several results unite.
- Fig. 6.1.9 displays visibly clear area about the exact location for which the evaluated robot location converges accurately.
- For instance, any early estimate in the uppermost left or within the area of 1m from the true location converges to the proper result.
- The other initial estimates do not converge correctly because of improperly classified dimensions.
- Exact convergence is defined as a final location error which is smaller than 2 cm. Position evaluation errors after coming together generally have a tendency to be smaller than 2 cm in rather well prepared environments.

➜ (VI) Comparative behaviour

- The benefit of the multi-level approach is generally clear when the unknown data exists within a map that may include incorrect techniques.
- Fig. 6.1.10 denotes the map and data which is only seen from the specified robot location along with artificial noise attached to both the data points and model that can result into a partial model of the environment.
- The data is used to calculate location estimation from a variety of early estimates modelling the environment.
- For every initial location estimate, the ultimate error was verified to offer a suggestion to estimate the ultimate pose with different input errors.
- This process was executed with the help of three different corresponding data and localization procedures: by means of both huge and small fixed-magnitude rectangular arrangement windows and an uneven sized window on the basis of ALMS procedure.

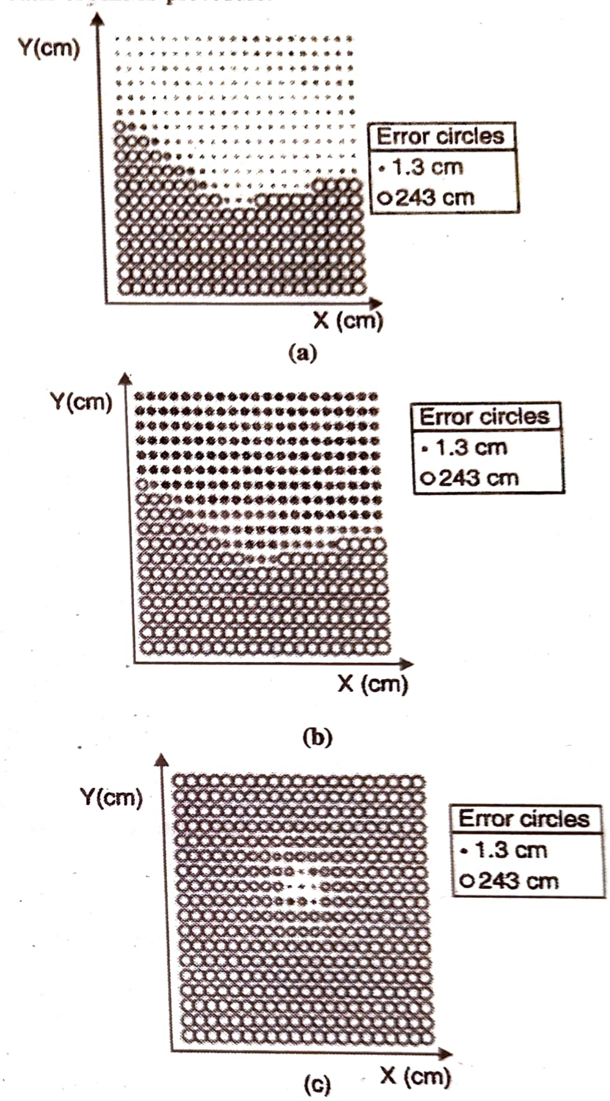


Fig. 6.1.12 : Final position error as a function of initial error

- The Fig. 6.1.12 demonstrates the consequence of the three dimensioning approaches on both ultimate error and the area of joining.
- The radius related to each circle in the Fig. 6.1.12 is relative to the logarithm of the ultimate location estimate error.
- We can observe in Fig. 6.1.12(a) to facilitate the ALMS approach which recommends a large area of joining in addition to very small ultimate error.
- The area of joining for a rigid, extensive classification window and not on the basis of distance loading system is as shown in Fig. 6.1.12(b) which is approximately similar size as shown in Fig. 6.1.12(a), but the ultimate error is nearly an order of well-built scale.

- For the rigid, minor classification window and not on the basis of distance loading system as shown in Fig. 6.1.12(c), the least ultimate error is equivalent to those which are established with the multiple range approach.
- But the area near the exact location for which an early location estimate joins to this value is comparatively less than other approaches.
- The multiple range method on the other hand, involves an augment in computational operating cost in excess of rigid-scale methods.
- This shows that the exchange engaged in selecting a scale dimension that extensively provides a large area of joining with limited precision in the ultimate solution.
- Lesser ranges can offer better precision simply for initial location estimates already suitably closer to the exact result.
- This is expected result, because a huge range will contain more unknowns that contribute to the ultimate result restricting the precision.
- A small scale will effectively ignore unknowns but may also load suitable data points too low if the location error is better than the scale size.

➔ **(VII) Quality measures**

- For deprived initial location estimates, it is feasible that the estimation generated by location calibration is not the exact location of the robot.
- It is necessary to defend an actual system from the severe consequences of such an error that secures the location estimate.
- To be precise the detected dimensions are reliable in unconditional terms.
- The multiple results can be compared on the basis of the type in which it is observed by sensor data.
- This proposes two theoretically different forms of error estimate which is used to measure performance.
- The initial residual error among examined and accepted models is detained by a **mean-squared error** estimate.
- The second type of evaluate which is appropriate to the number of identified models really utilized in the ultimate pose estimate that is referred as **classification factor**.
- The exchange among the number of techniques used and the density or complexity of the entity models is transmitted to the view of **minimal length encoding**.
- The mean-squared error measure is very simple:

$$E_{mse} = \frac{1}{n} \sum_{i=1}^{n} \|p_i - \ell_i\|^2$$

- Where, p_i is i_{th} of n series data points, ℓ_i is p_i's objective line segment technique and $\|p_i - \ell_i\|$ is the space from a point p to the nearby point on the line segment.
- It determines the average difference among data and techniques.
- The objective has a global effect on exact pose of the robot which assumes that at least a large amount of data points are nearby to their objective models which outputs a small value related with an exact solution.
- The inverse of E_{mse} states a global maximum at the exact pose of the robot.
- There is a complexity with this utility used single-handedly: it is vulnerable to unknowns which surely influence the outcomes although the pose estimate is very perfect.
- Ever since it is not identifying the number of existing unknowns in the range of sensor data which contain possible series of data that perform a wide range of functions that decide whether a particular pose is very complicated only on the basis of this function.
- On the other hand, it can be useful to compare two optional solutions.
- The classification factor E_{cf} is an amount that depends on the portion of all data points that are well defined.
- This is acquired by calculating the portion of all data points which are confined in some predetermined distance threshold x of their related model.
- According to the assumption a model can engage only a small portion of the environment because a nearby relation among a dimension will takes place by chance and rarely.
- The E_{cf} can designate the excellence of a pose estimate which approaches unity firstly when the pose estimate is nearby to the exactly one and secondly for a related but inaccurate location that exists in the environment.

- Ignoring the remaining part of the E_{cf} measure is better that gives a nearby value to unity when the location estimate is exactly correct to the true location and close to zero when the estimation of error is large.
- Since a gating function uses an unexpected, similar to step area threshold which performs numerous deficiencies that show uneven performance as errors surpass the threshold value.
- It deals with a "flexible" sigmoid which cannot be developed as a threshold to guarantee refined deprivation of the result as a purpose of the input error.
- The **classification factor** is thus defined as shown in the Fig. 6.1.12 :

$$E_{cf} = \frac{1}{n}\sum_{i=1}^{n}\left(1-\frac{d^m}{d^m+c^m}\right),$$

where, $d = \sqrt{\|p_i - \ell_i\|}$ is the distance between p_i and ℓ_i i.e., among dimension and model; c is the adjacent size; and m is the sigmoid sharpness.

- The area must be huge so as to hold factual errors in the models on the basis of sensor error.

Syllabus Topic : Global Localization

6.1.4 Global localization

- Global localization is obtained with the help of series of actions that can be created as a Markov localization problem which integrates data over the time so as to resolve the global localization problem.
- In every step of the localization process data is necessary to be guaranteed undoubtedly from the current location to potential locations in the environment.
- An essential action in the process of executing either local or global localization consists of equating the group of existing inspections with a few created maps.
- Standard matching techniques can be generally classified as follows :
  - **Data-data matching :** The existing raw data directly matched with assumed raw data.
  - **Data-model matching :** The observed data is matched with additional conceptual models that are stored in the map on the basis of relationship shared between data and models.
  - **Model-model matching :** The models stored in the map are matched with the models created from existing observations.
- All methods which are useful to achieve success contain a specific domain of applicability mainly depends on the attributes of both sensor and data acquirement method.
- Generally, equating the raw data can decrease the dependency on previous statements regarding the environment have a tendency to be weak except the matching method which is very refined.

Syllabus Topic : Mapping

6.2 Mapping

Q. 6.2.1 Explain the term Mapping in detail. (Refer section 6.2) **(8 Marks)**

- Maps act as an infinite sponsor of interest for any human being with eyes to observe or with two ears to listen and understand the value of imagination.
- Tags for unknown areas of a map are located by map-producers.
- A map states that it must be carefully followed and strongly trusted. For independent robots, the facility to freely create plans of the environment cannot appear like a condition for various tasks.
- At times it is supposed that a robot must be capable of deciding an earlier availability of a map which is unfortunately a rare case that performs architectural plans or associated form of maps failing constantly.
- The various features of an environment are not expected to emerge on a map like peripheral and transitory objects.
- Maps generally represent structural aspects in a few abstract areas may be with meaningful labels.
- While a mobile robot should be able to associate its existing location openly to its own observations concerning its environment.

- Maps prepared for individuals always based on the understanding skills of a person by means of the map and on their skill to create operational conclusions, abilities frequently missing in additional systems.
- The advance sensory attributes of objects, if explained in maps can provide application to a human observer.

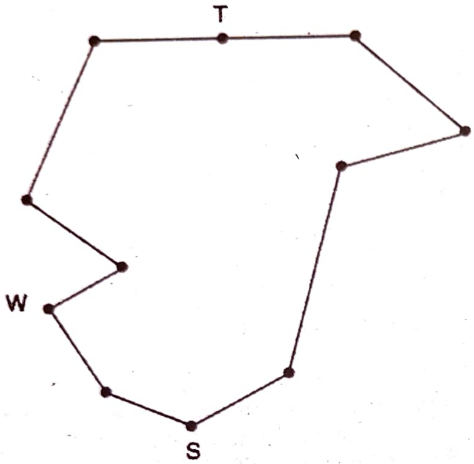


Fig. 6.2.1 : A Street defined by nodes S and T

- The pair of nodes S and W does not describe a path, because there are points on the right-side that cannot observe any point on the left-side.

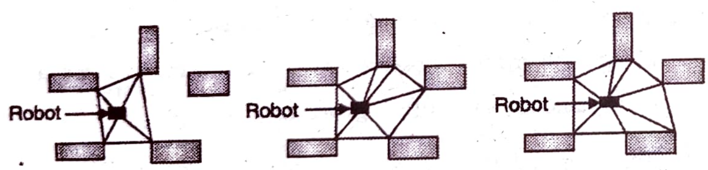


Fig. 6.2.2 : Phases in the geometric discovery

- Fig. 6.2.2 Phases in the geometric discovery of space contain three cases in the discovery of space with the help of an algorithm.
- Under peripheral control, the robot shifts and constructs a geometric representation of open space.

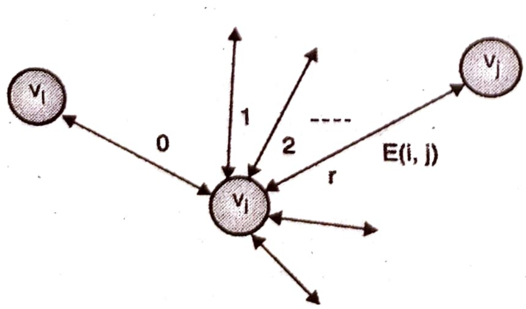


Fig. 6.2.3 : Edge ordering

- Maps can acquire several forms, but represent two particular representational types that are mainly applicable to mobile robotics which are as follows :

(1) **Metric maps** : They are based on an unlimited reference outline and geometric estimates of the location of objects in space.

(2) **Topological maps** : They also referred as relational maps which just clearly symbolize connectivity data generally in the form of a graph.

- Each of this type of demonstration acknowledges various definite explanations.
- A lot of real demonstrations contain both topological and measuring device module.
- For instance, metric maps indicating the clear possession of space or **geometric maps** indicating specific tagged objects regularly include connectivity data.
- Metric maps emerge to be the most spontaneous such as a tourist's map that represents a city.
- The mobile robots may be the clearest form of map which is a metric map in formation space that executes all possible movements.
- Topological maps as compared to metric maps confine qualitative and relational data while do not emphasize on inappropriate or unclear details.
- Consequently, topological maps include a very clear relation to tasks and the meaning of the problem.
- A common subway map or direction-finding instructions are referred by humans in excess of considerable areas of space.
- A number of creators have recommended that only metric maps are not well-matched for indicating large-scale space.
- So as to utilize the benefits of both metric and topological demonstrations, it is regularly suitable to consider the creation of one representation with the help of studies from a further less conceptual representation.
- Additionally, it considers local explanations before extensive interactions.
- This guides naturally to a hierarchical levelling of consecutive representations of map information which is described in the following five layers :

Levels of Map

1. Sensorial
2. Geometric
3. Local relational
4. Topological
5. Semantic

Fig. 6.2.4 : Levels of Map

→ 1. **Sensorial**

The signals which represent raw data or domain conversions are referred as sensorial signals.

→ 2. **Geometric**

The signals which represent 2D or 3D objects gathered from sensor data are referred as geometric signals.

→ 3. **Local relational**

The relations which represent operational, structural, or meaningful relations among geometric objects that are located at individual positions are local relational.

→ 4. **Topological**

The extensive relational associations that attach objects and positions across the complete environment.

→ 5. **Semantic**

The operational tags related with the elements of the map.

- The most predictable maps represent the use of space in either 2D or 3D.
- A clearly different group of maps showing particular application to robots is called as **perceptual map**.
- They openly associate observed sensor dimensions to spatial location without routing to an intermediate explanation in terms of substantial objects.
- This kind of demonstration is voluntarily imagined in the background of olfaction but is evenly applicable to previous sensing techniques.
- Map discovery is a necessity for a lot of sensible mobile robotics functions.
- The existing maps are incorrect in environment, and nearly every environment is busy in progressive changes.
- Consequently, a mobile robot system needs to be capable of holding transformations in their environments.
- If they have to preserve maps, they must be capable of renewing them.

6.2.1 Sensorial Maps

Q. 6.2.2 Write short note on Sensorial Maps.
(Refer section 6.2.1) **(4 Marks)**

- The maps which support direct sensor observations suggest the chance of combining the environmental symbolization as openly as feasible with the sensors which the robot utilizes to observe the environment.
- The fundamental idea is to perform sensor dimensions attached with odometry data and then use a method like servo control that identify attributes in the sensor reactions so as to follow the map.
- As a robot travels all the way through its environment it gathers sensor observations.
- The odometry perfectly assumes following a small duration of time that a robot gathers from a set of dimensions.

  $\{I_i (x_i, y_i, \theta_i)\}$
- The continuous approximation to I_i can be calculated with the help of $I(x, y, \theta)$ so that servo control can use techniques to follow the map.
- The complexity with this kind of approach is that one should identify sample in the group of possible dimensions and create the constant I from the dimensions $\{I_i(x_i, y_i, \theta_i)\}$.
- Instead of using I for constructing a direct mapping from sensor observations to pose, the dimensions I_i can act as a primary dimensions signified in the map.
- The robot ultimately creates a graph-like representation of location that represents edge of the graph match to the paths, while the vertices of the graph match to junctions.
- The representation is on the basis of creating a visual landscape of the left and right areas of the path as the robot shifts.

- The robot discovers by making closed circles in the environment and then finds closed circles by recognizing that the existing 2D landscape is equivalent to a previously identified landscape.
- Landscapes can also be developed in a less well controlled environment.
- The vertices in this case are described by an attention operator motivated by techniques of human optical attention, and those vertices are selected which may be most motivating to humans as a minimum previously semantic level.
- A method defined as **alpha-backtracking** is used to exchange supplementary travel by discovering robot in opposition to the finest of the sample positions selected for the topological representation.

6.2.2 Geometric Maps

Q. 6.2.3 Write short note on Geometric Maps. (Refer section 6.2.2) **(4 Marks)**

- Geometric maps can be a well-organized report of the environment, such that the sensor offers appropriate data so that environment defines a well-match to the geometric technique to be used.
- The examination of an unidentified environment results into creation of a geometric map from that discovery, and associated problems which are studied broadly in the area of computational geometry.
- Discovery associates to a range of related potential.
- This includes exploring a specific purpose or target position to find a route with particular properties that cover free space, and study regarding the use of space i.e. mapping.
- A broad set of problems handle exploration in unidentified or moderately known environments.
- Such problems are of more significance as they are strongly associated to environment discovery in common.
- There are some algorithms which are generated for direction-finding in an unknown environment.
- These algorithms notice the location of the target or barriers in the environment, in the path of direction-finding and therefore are physically classified as a type of discovery algorithm.
- The algorithm is described as a well-designed and spontaneous to frequently shift the robot in the direction of a straight line relating the starting location and the target when featured with a difficulty.
- Considerably, they display that this algorithm is most favourable in definite conditions so that general environments are not probably bounded.
- The dissimilar geometric representations may lead to various investigations and explore algorithms.
- For instance, a street can be referred as a polygon which has a start S and goal T on the border line of the polygon divides edges into two groups i.e. left and right.
- Every edge on the left-side is seen from several points on the right-side which are commonly weak to be seen.
- The polygons can be divided into a "right" and "left" side by dividing into two chains separated at the initial and final locations.
- A number of researchers have measured the difficulty of travelling from S to T without a preceding map of the polygon.
- The robot is supposed to be capable of examining the side tag to which any particular segment belongs to the wall.
- A generalized street can be defined as a polygon such that each point on the border line is able to be seen from some point on some chord which is a well-built group of polygons as compared to streets.
- It can be voluntarily established than the most favourable path from S to T which must be travelled from chord to another.
- It only performs horizontal movements so that it can travel anywhere on the polygon, and induces the use of distance metric.
- By carefully coordinating movements with spiral exploration to recover turning points in order that the robot resides between the suitable "sides" of the polygon.
- The algorithm generates a path whose distance from S to T is most favourable as calculated by the L_1 metric.

- A direction-finding for travelling from a starting position to an unknown target location surrounded by a class of polygons is defined as rectilinear generalized streets (G-streets).
- The task of repeatedly building a geometric map has also been measured as a practical task.
- This system uses the COPIS sensor to build a geometric illustration of the open space about the robot.
- With the help of perfect odometry, the robot builds a polygonal object that corresponds to the open space about itself.
- Every time the robot travels an evident vertical line is followed and their locations are recomputed by means of triangulation.
- Vertical lines which cannot be related with formerly observed environmental configuration are proposed as new configuration and are supplementary to the map which obtains two different observations of a new attribute so as to get a location estimate.
- Each and every map object is linked in a radial manner so as to develop a representation of open space.
- It is believed that the space inside the polygon created by connecting the edges in a radial manner is empty.
- Fig. 6.2.2 demonstrates the process of discovery. Dashed lines join the robot which is represented as a dark rectangle with logical configuration, and the open space polygon is depicted with solid lines.
- As the robot travels, more sensor dimensions are prepared and a well-built region is discovered.
- This specific approach has some restrictions.
- It is complicated to identify whether each and every space has been discovered, the system cannot explain very difficult free spaces.
- The discovery procedure is determined by a peripheral operator where the system does not make a decision of the location discovery.
- Geometric maps are possibly the most frequently used type of map in self-governing robotics.
- Therefore it is not unexpected that a large amount of the work in independent mapping depends on acquiring geometric maps.
- Algorithms can be approximately divided into two groups which are as follows :

  (1) They plan an environment without managing and preserving a pose estimate contained by the map, and

  (2) They explain mapping and localization at the same time.
- These two fundamental approaches are measured next.

Fundamental Approaches of Mapping

1. Mapping without Localization
2. Simultaneous Localization and Mapping
3. Loop Closing

Fig. 6.2.5 : Fundamental approaches of mapping

➔ (1) Mapping without Localization

- The fundamental plan is to build a useful grid with the help of sensor dimensions as the robot travels all the way through the environment.
- Some executions concerned two corresponding illustrations: first one for confidence that a cell is vacant, a subsequent for the degree of confidence that a cell is occupied.
- The preservation and useful illustrations are usually carried out by Bayesian probability revise system.
- A probabilistic technique of the sensor is necessary that associates various possible dimensions to the construction of environment that may provide growth to them.
- Whenever a sensor is used, it needs to identify different dimensions which can probably be described according to the environment.
- The sensors which consider the condition of a line-of-sight are defined as idealized lasers that determine the distance by the side of the line of sight.
- But when the sensor revisits a specific distance evaluation(r), it cannot reproduce the exact distance (z) accurately due to alteration caused by electrical noise, visual noise, or other sources.

- The probability p(r|z) of a specific range evaluation(r) for an real distance (z) to the closest obstacle is calculated as :

$$p(z|r) = \frac{p(z)p(r|z)}{p(r)}$$

where, the probable value of z for a particular evaluation (r) is the value which exploits a subsequent estimate.

- The normalization expression p(r) can be calculated as :

$$p(r) = \int_{z\text{-min}}^{z\text{-max}} p(x)\, p(r|z)\, dx$$

- A useful grid can define areas of the world as residing on the isolated set of potential states, each one with a permanent probability, calculated by the practical sensor data and any previous principles :

$$p(W|R)$$

where, W is considered as the world state and R is considered as the group of useful readings.

- A split depiction that performs the grouping of old and new data by using the Bayes rule is easier.
- Each one of the two incomplete illustrations can be used to accumulate specific types of evidence.
- Before the map is used, the certainties from the two partial maps can be considered as useful to create a single possibility of occupancy; for instance,

$$\frac{1}{2}[p_{occupied} + (1 - p_{empty})]$$

- In the background of planning, possession can be considered as an unidentified environment.
- The useful grid is primarily a set that returns without any understanding of the possession of the world.
- As the robot gets dimensions, aspects of the grid are restructured by the Bayes rule :

$$p(W|R) = \frac{p(R|W)\, p(W)}{p(R)}$$

- Which offers the subsequent distribution p(R|W) defining the performance of the sensor that returns a particular dimension for a specified state of the world.
- p(W) explains the earlier beliefs related to specific configurations of the world. p(R) explains the possibility of a specific sensor dimension across the entire probable configurations of the world are calculated as :

$$P(R_i) = \sum_j P(R_i \mid W_j)\, P(W_j)$$

- The world model W which makes best use of this subsequent distribution is then relating to Bayesian decision-theory which is one of the most "sensible" explanations of the environment.
- This is defined as a maximum a posterior (or **MAP**) estimation.
- The deficiency of particular model statements makes the method very common.
- Possession grids offer a consistent framework for merging data from several sensors.
- This benefit, however, is experienced by the necessity for correct probabilistic techniques of sensor presentation.
- Additionally, the local quantization inbuilt in the useful representation can either craft it ineffective with respect to memory consumption or restrict the reliability of the map obtained.
- A supplementary issue is that since the beginning of individual dimensions is unused in the planning process, it is very complicated to build an perfect geometric representation from an useful demonstration.
- This difficulty is combined by the necessity to maintain the individual unit size restricted.
- The useful representation can be calculated to restrict the robot by associating the current grid with an incomplete grid acquired from latest sensor data.
- The ideal space sensors and possibility representations are potential systems for developing use of grids in the structure of environmental maps.
- A system which makes use of trinocular stereo system and improvised probability permutation rule to construct the use of grid for the environment.
- A significant assumption of this approach is the statement of identified position surrounded by the world.
- The added positional errors in excess of time can damage the use of grid as it is being created.
- So to avoid this problem correction of incremental location errors is implemented at the same time map is also being

assembled which is complicated since the map contains low assurance.

- An impressive substitute for both the map and localization is to resolve them simultaneously.

(2) Simultaneous Localization and Mapping

- The difficulty of constructing a map of an unidentified environment while estimating growth of one's location inside it is defined as simultaneous mapping and localization (SLAM).
- It is essentially maintained on the basis of a representation of location while creating a strong representation of what is practical.
- While the secondary problems of attribute recognition, detection, and planning are essentially important to the SLAM problem.
- It is always closely associated to data sorting that updates the location estimate and a related uncertainty model.
- This uncertainty model is coupled with a co-variation matrix describing error in the parts of the state.
- In the background of SLAM, on the other hand, the state comprises of both the robot pose and the map itself that can result into a large co-variation matrix and a difficult update problem.
- Synchronized localization and mapping may be described in a Bayesian structure that states the objective of estimating the posterior density function related to the environmental map Θ and pose s_t.
- The understanding of interpretation performed by the robot $z^t = \{z_1, z_2, \ldots, z_t\}$, control inputs $u^t = \{u_1, u_2, \ldots, u_t\}$, and data associations $n^t = \{n_1, n_2, \ldots n_t\}$.
- Where, u_t and n_t determine the mapping between characteristics in θ and the readings z_t.
- The SLAM posterior is represented by

  $p(s^t, \theta \mid z^t, u^t, n^t)$
- Basically this entails relating the conditional probability of position and map provided by the robot's sensor dimensions, regulate motions, and data relationships.
- The determination of the "best" map needs selection of the best result to $p(s^t, \theta | z^t, u^t, n^t)$.
- It is noted that "best" condition stand for the maximum posterior value of P.
- By using Bayes rule, we can substitute $p(s^t, \theta | z^t, u^t, n^t)$ as

$$p(s_t, \theta \mid z^t, u^t, n^t) = \eta p(z_t | s_t, \theta \mid z^{t-1}, u^t, n^t)\, p(s_t, \theta \mid z^{t-1}, u^t, n^t)$$

- Where, η is denoted as a normalizing term.
- The term $p(z_t | s_t, \theta \mid z^{t-1}, u^t, n^t)$ can be made simpler to $p(z_t | s_t, \theta, n^t)$ by considering the dimensions z_i and z_j as variables that are independent of each other for $i \geq j$ and that the dimension at present step is self-sufficient of the control input.
- The term $p(s_t, \theta | z^{t-1}, u^t, n^t)$ can be made easier by using the Markov assumption and the assumption of total probability :

$$p(s_t, \theta \mid z^{t-1}, u^t, n^t) = \int p(s_t | s_{t-1}, u_t)\, p(s_t | s_{t-1}, \theta \mid z^{t-1}, u^t, n^t) ds_{t-1}$$

- This enables the SLAM posterior to be considered as

$$p(s_t, \theta \mid z^t, u^t, n^t) = \eta p(z_t | s_t, \theta, n^t) \int p(s_t | s_{t-1}, u_t)\, p(s_{t-1}, \theta \mid z^{t-1}, u^t, n^t) ds_{t-1}$$

- The two fundamental approaches can be demonstrated by SLAM, considering the following toy example.
- Assume we have a directionless location that indicates robot operation on the plane.
- Let $X = [x, y]$ be the location of the robot.
- There exist a huge number of distinctive signals in the environment, and every signal i is rigid and has position $p_i = [p_x^i, p_y^i]$.
- The control input at every time step is a alteration in the (x, y) position of the robot (x, y) and is damaged by a number of zero mean plant noises (v_x, v_y).
- For every time step the robot gets relative x and y offsets to some group of signals $(p_x^i - x, p_y^i - y)$.
- The next two segments expand Kalman and particle filter results for this problem :

(A) Kalman filter approach

Q. 6.2.4	Explain Kalman filter approach in detail. (Refer section 6.2.2)	**(8 Marks)**

- This approach is initiated by describing plant and dimension models that explain the problem with the help of considerations.
- The estimation of the combined probability of robot and signal state is given as:

$$x(k) = [x\ y\ p_x^1\ p_y^1\ p_x^2\ p_y^2 \cdots p_x^n\ p_y^n]^T$$

- It is noted that several signals needs to be estimated which will develop as a function of time.
- According to Kalman model the given equation is as follows:

$$x(k+1) = \Phi x(k) + \Gamma u(k) + v(k)$$

- Where, Φ denotes the identity matrix,
- Γ denotes the identity matrix,

$$u(k) = [\ x_k(k),\ x_y(k), 0, \ldots, 0]^T, \text{ and}$$

$$v(k) = [v_x(k), v_y(k), 0, \ldots, 0]^T$$

- We have,

$$x(k+1) = \Phi x(k) + \Gamma u(k) + v(k)$$

$$\begin{bmatrix} x(k+1) \\ y(k+1) \\ p_x^1(k+0) \\ p_y^1(k+1) \\ p_x^2(k+1) \\ p_y^2(k+1) \\ \cdots \\ p_x^n(k+1) \\ p_y^n(k+1) \end{bmatrix} = \begin{bmatrix} x(k) + \Delta x(k) + v_x(k) \\ y(k) + \Delta y(k) + v_y(k) \\ p_x^1(k) \\ p_y^1(k) \\ p_x^2(k) \\ p_y^2(k) \\ \cdots \\ p_x^n(k) \\ p_y^n(k) \end{bmatrix}$$

- The robot travels to that location according to the given command but every motion is being damaged by the noise process.
- The signals remain immobile.
- This is a linear plant representation and must be used to evaluate the state of a robot as it performs the movements.
- The robot can logically relate its displacement with the group of visible signals.
- At time k assume that the robot is able to logically relate with some subgroups of the entire signals which are visible and new signals may also be revealed.
- Suppose that not only signals but pre-viewed signals are also logically related.
- With the help of linear Kalman filter the following equation can be obtained:

$$z_i(k) = \Lambda_B x(k) + w_i(k)$$

- Where, Λ_B denotes the derived measurements from the system state, and

  $w_i(k)$ denotes the noise function.
- For the fundamental system, the dimension from signal i is basically the couple of values represented by $p_x^i(k) - x(k)$ and $p_x^i(k) - y(k)$ respectively,

$$\Lambda_B = \begin{bmatrix} -1 & 0 & 1 & 0 & 0 & 0 & \ldots & 0 & 0 \\ 0 & -1 & 0 & 1 & 0 & 0 & \ldots & 0 & 0 \\ -1 & 0 & 0 & 0 & 1 & 0 & \ldots & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 1 & \ldots & 0 & 0 \\ & & & & & & \ldots & & \\ -1 & 0 & 0 & 0 & 0 & 0 & \ldots & 1 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 & \ldots & 0 & 1 \end{bmatrix}$$

- This simple linear Kalman result of the SLAM problem demonstrates several issues related to the approaches which are as follows :
  - An available real system is never considered as linear.
  - Therefore, instead of using a linear Kalman filter with its most favourable assurances of, the EKF can be used which establishes issues associated to convergence.
  - The filter guesses an identified communication between signals.
  - The signals can be recognized from one instance to another.
  - Such a clean information alliance is not likely to exist in practice.
  - If the convergence concerns related with EKF, then any difference in the information is likely to show considerable difficulties.
  - The set of signals are not likely to be identified at starting of system.

- o As a result a few non-linear processes will have to be functional to decide if a potential signal is actually one of the signals that are visible previously and recognize a new signal if necessary.
- o The additional cost related with a Kalman filter can be drawn if a matrix needs to be inverted whose size is equivalent to the size of the system condition.
- o The system state size is comparative to several landmarks, if the quantity of landmarks raises, the additional cost of the process also boosts.

(B) Particle filtering approach

Q. 6.2.5 Explain particle filter approach in detail. (Refer section 6.2.2) (8 Marks)

- A particle filtering approach towards SLAM apply particle filter to symbolize the SLAM posterior $p(s_t, \theta | z^t, u^t, n^t)$ accurately.
- Even if such an approach is impressive from a abstract point of view, it initiates difficult issues associated to appropriately sampling the circulation.
- Thus, most convenient particle filter on the basis of SLAM approaches work to lessen the difficulty of the condition being represented.
- Let us consider the problem in its purest state temporarily.
- The SLAM posterior at the moment k is signified by a group of samples S_k^i, that is, the distribution stands for $p(s_t, \theta | z^t, u^t, n^t)$.
- The essential function of the filter pursues the method defined as follows :

Re-sampling phase

The sample distribution denoted by S_k^i follows the procedure of re-sampling to guarantee that the particles offer a better illustration of $p(s_t, \theta | z^t, u^t, n^t)$.

Prediction phase

Every particle ultimately progresses in forward direction, reproducing $p(s_t | s_{t-1}, u_t)$. This engages a probabilistic representation of the plant noise.

Update phase

Sensor dimensions are familiar with revising the weights related with every particle indicating map and location pairs i.e. $p(z_t | s_t, \theta, n^t)$.

- Each of these functions offer particle filter counterparts as per the terms which allows the calculation as follows:

$$p(s_t, \theta | z^t, u^t, n^t) = \eta p(z_t | s_t, \theta, n^t) \int p(s_t | s_{t-1}, u_t)\, p(s_{t-1}, \theta | z^{t-1}, u^t, n^t) ds_{t-1}$$

- As viewed previously, this is expected to be unrealistic, and so a series of different methods are applied to reduce the difficulty of the problem.
- Possibly the most influential of these is the application of Rao-Black wellized particles.
- Rao-Black wellization is a method that impairs a difficult insecurity maintenance problem into two components.
- It depends on the information that one can decrease the state space of a combined state with the help of product rule $p(x, y) = p(y|x).p(x)$.
- Thus, if $p(y|x)$ can be signified logically, then only $p(x)$ requires to be tested experimentally.
- Generally, this means that the entire variation of the element being estimated can be deduced.
- A general method in SLAM which is associated to the state evaluation problems utilizes a particle filter to symbolize $p(x)$ and some other methods for $p(y|x)$, directing to the Rao-Black wellized particle filter (RBPF).
- If $p(y|x)$ is symbolized logically, then union of a particle filter can occasionally be completed with less estimates consequently.
- An additional common difference of the RBPF is to symbolize $p(y|x)$ with the help of a Kalman filter.
- This is the most essential ideas of the Fast-SLAM algorithm that plans SLAM in terms of robotic path and relate Rao-Blackwellization to symbolize the map in terms of numerous Kalman filters.

(3) Loop Closing

Q. 6.2.6 Write a short note on loop closing (Refer section 6.2.2) (4 Marks)

- According to SLAM, local errors can be regulated with the help of an efficient state estimator, but error can still exist during a long path.
- Thus, if a robot's trajectory interconnects itself with a lengthy loop in between, then it is complicated to decide only location where the crossing happens.
- The location which determines this crossing is known as loop closing.
- Loop closing is an essential difficulty in SLAM as it refers an algorithm by means of two clear options with significant consequences are as follows :
  (1) The place which is at present being visited is similar to some locations that are previously visited; in this situation, data must be included between that earlier visit and currently build up a particular consistent representation.
  (2) The place varies from few earlier visited locations which are self-governing and spatially distinct illustrations that are required to be constructed.
- In Kalman filtering, the approaches related to SLAM display loop closing within the procedure of determining communications among planned landmarks.
- If a particular theory of Kalman filter illustrations and possible breakdowns are related with the faulty data relations that are established with Kalman filters they may result into inaccurate choices in terms of loop closing to have disastrous results.
- In particle filtering, the approaches related to SLAM display multiple theories that enables loop closing to be measured as an option for not closing the loop.
- On the other hand, if a particle filter depends on the approach which consists of just limited amount of particles, then issues also exist.
- The decision to "close the loop" or to "influence the closing loop" is more seriously compared to a critical element of various SLAM approaches.
- The critical nature provides loop closing which requires a huge and dynamic research that attempts to develop an efficient strategy to decide whether the loop must be closed or not.
- The importance is given to the decision being made for achieving the target that searches a decision function which is forceful to sensor and model noise in the system.
- It is evident that if the components like sensor, characterization are more dependable then on the basis of loop-closing judgment a particular modality is more desirable.
- At the same time the basic approaches related to loop closing can be defined as follows :
  (1) map-to-map,
  (2) map-to-sensor,
  (3) sensor-to-sensor
- The nature of the above three categories depends on the basis of the decision taken for closing the loop which is prepared.

6.2.3 Topological Maps

Q. 6.2.7 Write a short note on Topological Maps. (Refer section 6.2.3) **(4 Marks)**

- To ignore the evident problems in retaining a long-lasting metric map of an environment with the help of an optional class of representations is used on the basis of graphs.
- Topological maps avoid the probably huge storage overheads related with metric maps. In addition, they have attractive visible resemblance with human spatial perception.
- Only topological representations which do not have any distance data symbolize a "worst-case" situation for location sensing schemes.
- Topological maps define the given environment like a graph which joins specific places in the world that are represented by nodes with edges personifying their convenience.
- The map which is based on a graph is given by G = (N, E) with group of X nodes N and group of Y edges E.
- The nodes are denoted by $N = \{n_1, \ldots, n_x\}$ and the edges by $E = \{e_1, \ldots, e_y\}$, and edge e_{ij} is represented by $e_{ij} = \{n_i, n_j\}$.
- If the instruction of v_i and v_j is important, since it is present in some models so as to previously assume that paths are having single path which shows that there is a possibility of directed graph.

- The relation of $Y < X(X - 1)$ for graphs not including edges that exist between a node and itself, at the same time for planar graphs which do not have any crossing edges but gives restriction on the number of edges by using relation $Y < 3X - 1$.
- An actual environment has been projected with the help of several schemes that determine a topological environment illustration which is often depends on provisional statements concerning the types of real environments that are permissible.
- The standard example makes use of a topological representation to symbolize the corridors and junctions of a perfect office environment.
- Even if withdrawal methods are useful in obtaining a topological illustration of a metric environment, then entire topological illustrations are not withdrawals.
- Practically, a topological illustration can be described for an uninterrupted environment on the basis of landmarks or other attributes.
- One probable description of a graph vertex is on the basis of a local uniqueness measure.
- In this condition, some group is assumed on the basis of sensor functions for the local environment.
- For instance, the radius of the smallest amount of circle which can be marked within a group of viewed range dimensions that are useful in describing a node in the topological illustration.
- The vertices of the graph are those positions which make best use of the value of more than one function.
- To associate the graph more strongly to a map of real space, the description of an edge can be enlarged slightly to enable a clear requirement of the order of edges occurring on each highest point of the graph.
- This limits the implanting of the graph, i.e., its potential design on a plane.
- This ordering is acquired by detailing the edges in a systematic way with some paradigm in initial direction.
- An edge $E_{i,j}$ is incident on nodes n_i and n_j which is allotted with labels x and y respectively.
- The label x stands for directing edge $E_{i,j}$ regarding some reliable details of edges at v_i, and the label y stands for directing edge $E_{i,j}$ regarding some reliable details of edges at v_j.
- The labels x and y can be measured as general paths which starts from vertex v_i till the nth vertex is traversed by the edge $E_{i,j}$ to vertex v_j.
- A lot of environments are currently concentrating in mobile robotics which are based on land that may be considered as unplanned 2D environments recognized by landmarks that are actually giving the description of any particular position that may not be exclusive.
- The term signature makes use of particular visible characteristics related with a position i.e. a node.
- If these signatures are suitably unique, either for the reason that the look of the node is unique or related with odometry dimensions that make the signatures unique, then nodes can be distinct and graph illustration is implemented which can be created independently.
- For instance, the TOTO robot generates a topological map or graph as it discovers its world.
- As landmarks are discovered, they develop into nodes in the graph together with their qualitative assets like left wall, right wall, corridor and related compass behaviour.
- An accuracy maintenance procedure is raised to make sure that the similar landmark does not become numerous nodes in the graph.
- This approach demonstrates a number of essential factors of topological mapping and engages considerable processing which is dependent on domain.

(1) Marker-Based Exploration

- In the worst condition, the availability of a restricted disambiguating signature may not be possible.
- The discovery of a random untagged graph not including metric data or exclusive signatures prevents developing a distinct map for every environment.
- Namely, it cannot be created when a vertex has been visited one or more times, and hence it is not feasible to disambiguate among potential optional maps.

- If the robot is able to perform some method for disambiguating vertices, then it can probably discover the environment.
- For instance, if the robot is provided with a container of spray paint or a substantially long rope that the robot can use as it travels through the environment, then the robot can spot every location as it is surpassed, and this can be useful to supply every vertex with a distinct signature.
- Possibly the simplest spotting method involves enhancing the robot with more than one distinct pointers or indicators that the robot can fall, lift up, or identify if they are at the robot's existing location
- It defines a finite-state automation that can discover a target in log-space time by means of two pointers and a compass.
- The discovery algorithm functions by constructing an identified sub-graph of the world, discovering unidentified edges incident on the identified sub-graph, and thus additionally appending to it.
- The algorithm suggests the robot to perform O(N3) movements among positions in the worst case, where N refers to the number of decided positions in its environment.
- These positions relate to nodes in the graph-like map which is created during the movements signify the edge navigation.
- This discovery algorithm works on an improved graph-like illustration of the world.
- The world is described as an implanting of a graph G which is undirected.
- The graph surrounding is achieved by enlarging the description of a node to enable the explicit requirement of the order of edges occurring upon every vertex of the graph implanting.
- This ordering is acquired by specifying the edges in a organized way as defined earlier.
- In reference with the simple illustration of the environment, it is also believed that the robot has extremely restricted sensing and mobility choices.
- The robot can travel from one node to another by navigating an edge, it can lift up an indicator which is situated at the existing node, and it can leave an indicator it contains at the existing node.
- The robot in generally contains "K" number of indicators at its clearance.
- Suppose that the robot is present at a particular node n_i which has entered with the help of edge $E_{i,j}$.
- In a particular move, it goes away from node n_i to node n_j by navigating the edge $E_{i,j}$, which is situated at "r" number of edges after $E_{i,j}$ in relation to the edge order at node n_j.
- This is specified with the help of transition function represented as $\delta(n_i, E_{i,j}, r) = n_j$ given as follows :
- If $\delta(n_i, E_{i,j}, r) = n_j$ and $\delta(n_j, E_{i,j}, s) = n_k$

  then $\delta(v_j, E_{j,k}, -s) = v_j$
- This involves a series of moves which are reversible and iterative.
- It is also believed that if $\delta(n_j, E_{j,k}, t) = n_i$ then $-$ s does not exist and if $\delta(n_j, E_{j,k}, t) = n_j$, then redundant or disintegrated paths does not exist.
- A particular move is therefore defined with the help of order r of the edge through which the robot leaves the existing node, where r is described regarding the edge through which the robot travelled such node.
- A special case is noted for a planar implanting of a graph where detailing of edges is performed in a clockwise manner to satisfy the preceding theory.
- An indicator operation is completely defined by representing every "K" indicator whether it is lifted up, leaved down, or not operated upon.
- This is given with the help of a K-tuple $\Omega^K = (op_1, op_2, \ldots, op_K)$,
- Where, op_k can be defined as an element which has a value from the group {lift up, leave, null}, on the basis of which operation are performed on indicator k.
- Let us consider a simple action X which is defined as a indicator operation followed by a move that is given by,

$$X = (b, \delta),$$

where, b is related to Ω^K.

- The robot executes some action on the indicator in the existing node and then travels to a new location.
- The robotic perceptions are of two types which are as follows :

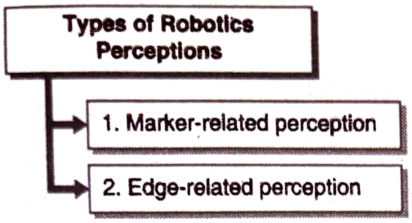


Fig. 6.2.6 : Types of Robotics Perceptions

(1) Marker-related perception

- Suppose that a robot is present at node n_i which arrives by means of edge $E_{i,j}$.
- The robot represents the marker-related perception with the help of a K-tuple denoted by $B_s = (bs_1, bs_2, \ldots, bs_K)$, where bs_k shows a value from the group {present, not–present} in relation to the presence of indicator k is located at node n_i.

(2) Edge-related perception

- The robot can decide the comparative locations of edges incident on the node n_i in a reliable way, for instance, by means of a clockwise list starting with $E_{i,j}$.
- Consequently, it can allot an integer tag to every edge incident on n_i, signifying the order of that edge relating to the edge list at n_i.
- The tag 0 is allotted randomly to the edge $E_{i,j}$ which helps the robot navigation through the node n_i.
- The instruction is local because it is on the basis of edge $E_{i,j}$.
- Arriving at the similar node from two distinct edges will show the way to two local instructions where both complement each other with respect to a permutation.
- It is noted that if the graph is used as level surface and a clockwise list of edges, then two variations will be simple circular transformations of each other.
- The sensory data which robot obtains when situated at node n_i that can be described as a pair of marker-related perception at that particular node and the command of edges incident on that node relating to the edge alongside which the robot goes through the node.
- If the robot traverses the similar node twice, it should associate the two different local instructions generated and combined by them into a particular global instruction, for instance, by searching the tag of the final edge of the second instruction regarding the first instruction.
- The discovery algorithm preserves a discovered sub-graph S and a group of unknown edges U, which originate from nodes of the discovered sub-graph.
- Each stage of the algorithm consists of choosing a group E of k unknown edges from U and authorizing the node n_2 at the unknown end of every edge $e = (n_1, n_2)$ in the group E.
- Authenticating a node n_2 confirms that it is not matching to any other node in the discovered sub-graph.
- This is performed by introducing one of the k indicators at n_2 and visiting the entire nodes of the recognized sub-graph S alongside edges of graph, searching for the indicator.
- It is noted that the other node n_1 incident on e is previously in the sub-graph S.
- If the indicator is established at node n_i of the discovered sub-graph S, then node n_2 is similar to the previously identified n_i.
- In this condition, edge $e = (n_1, n_2)$ must be allotted with an index regarding the instruction of edge to node n_2.
- To decide this, the robot avoids the indicator at n_1 and returns to n_2 along the smallest path in the discovered graph S.
- At n_2, it travels to the node alongside every incident edge. The robot returns back to n_1 since it will instantly identify the existence of the indicator.
- It is noted that the index of e related to the edge instruction of n_1 is recognized with the help of construction.
- Edge e is then attached to the sub-graph S and deleted from U.
- If the indicator is not present at one of nodes of S, then node n_2 is not included in the sub-graph S and hence should be attached to it.
- The unknown edge e is also inserted to S that has now been enhanced with the help of one edge and node.
- The insertion of the node n_2 to the sub-graph results into addition of entire edges incident upon it to be allocated with

an index related to the edge e through which the robot traversed the vertex and the recent edges are inserted to the group of unknown edges U.

- It is noted that no other edge of the recent node n_2 has been inserted earlier to the sub-graph or else n_2 will already be present in the discovered sub-graph.
- This index transfer sets up the edge instruction local to n_2.
- The algorithm concludes when the group of unknown edges U is vacant.
- Graph exploration is referred as a very expensive process if it consists of accessibility of only one indicator.

6.2.4 Exploration

- A last issue concerned with robot mapping is the difficulty of discovery.
- A general approach entails movement through the identified free space in the direction of environmental areas that are the most "unidentified".
- Such areas are defined as the border line of the robot's existing map.
- As the sensors are situated on the robot, movements in the direction of unidentified areas make them recognized, hence expanding the recognized environmental area.
- At any moment various parts of the robot's map will consist of frontiers and heading for the neighbouring frontier, which may not be the most efficient in conditions of environmental discovery.
- One more approach is to make use of some kind of random-walk–like algorithm that states that the robot performs straight-line movements till it is encounters a barrier at a particular point which is selected in a specific arbitrary direction.

Syllabus Topic : Robots in Practice

6.3 Robots in Practice

Q. 6.3.1 Explain properties of an environment. (Refer section 6.3)	**(4 Marks)**

- Even if various mobile robot systems are investigational in behavior, the systems dedicated to particular useful applications are being expanded and organized.
- The functions performed by mobile robot systems are generally described with the help of some properties of environment which are as follows:
  - o The environment that is hostile which instead of a robot sends a human being that is either very expensive or very hazardous. The environment consists of nuclear, chemical, marine, battleground and space environments.
  - o The environment which is isolated in order to send a human operator which is too complex or takes more time. Several examples suggest environments which are fully unreachable to humans like microscopic environments as well as various additional environments containing mining, space and forestry that shows certain properties.
  - o The environment which supports certain tasks that have a very difficult duty cycle or a very high weakness factor.
  - o The environment which supports certain tasks that greatly oppose human beings.
- In addition, areas where the robot is useful can enhance effectiveness, strength, or security etc. represents candidates that are needed for development of investigational systems which may consequently turn out to be practical.
- Basically, the choice to execute a robotic solution in a particular task frequently results into a conclusion which is economical, well-organized, or easy that can be useful to a person for completing a task.
- However, functional applications are carried out by independent robots, and, as the prices related to robotic systems reduce and their abilities enhance, then more markets are expected to be generated.

6.3.1 Delivery Robots

- A large number of manufacturing, business, and medicinal applications need to transport and deliver product among widely scattered locations.

- If the environment has to be specially made in order for making the delivery job simpler, then automation systems needs to be easy like an assembly line which may be applied to solve the problem.
- A few application domains like hospitals are differentiated with the help of a large number of objects from fundamental areas such as grocery, cloth, files, medication etc. which are circulated to a large number of locations like wards or rooms where patients are allocated with individual beds.
- At present these functions are carried out by the staff, and the well-organized operation of delivery by the staff is very complicated.
- A mobile robot can provide proper solution to the problem of delivery in a hospital that faces many complex technical problems.
- The hospital environment is very complicated to represent since people move around in the environment in random ways through a large number of doors and elevators which are followed.
- Instead of these technical complications, several research and manufacture robotic systems are generated so as to deal with the problems related to delivery in hospitals.

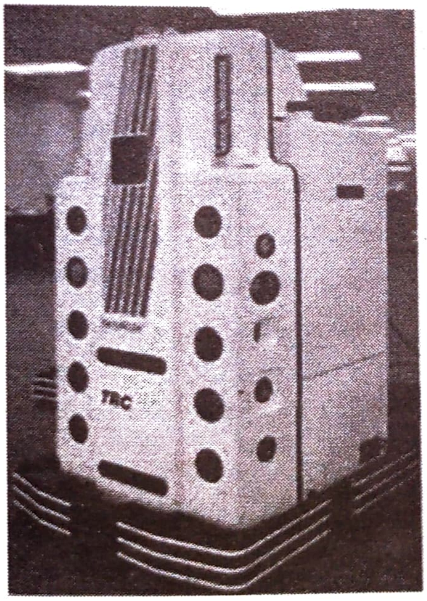


Fig. 6.3.1 : Helpmate robot

- The Helpmate robot with the help of a metric plan follows path through the hospital and depends on sonar and video sensors for its movement to keep away from blockages.
- These robots are useful in operating doors and elevators with the help of wireless communication channels.
- The FIRST robot stands for Friendly Interactive Robot for Service Tasks which is considered to concentrate on similar tasks.
- It depends on well positioned targets that are checked with the help of laser to perform the global locating task and deals with local positioning data with the help of gyroscope along with odometry.
- The environment is represented in an organized manner to define the targets consisting of nodes and paths connecting nodes identified during a functional training stage.
- Delivery robots are not restricted to transport of small items in hospital or workplace environments.
- For instance, the **Automated Guided Vehicle (AGV)** is used as an application for cargo handling which is planned to shift regular cargo containers in shipping harbors.
- The vehicle is used to do adjustments with regular cargo containers and makes use of two guided wheel assemblies i.e. one at the front and the other at the back, to move cargo containers within the storage area.
- The vehicle depends on radar sensors and previously situated radar signals so as to carry out point-to-point routing in this well-known environment.
- Laser sensors are responsible for keeping away accidents. A large number of mobile robots are arranged for jobs related to delivery.
- The Multiple Autonomous Robots for Transport and Handling Applications (MARTHA) is a project generated as a system which allocates a group of independent robots to perform synchronized tasks to transport material.
- Each robot locally executes as a communicating device which enables reliable interaction with any other robot or transmit messages to all robots that are nearby.
- A central planner which is represented as a central station combines with circulated plan effecting units in every robot.
- The global planner takes care of long-lasting goal fulfilment on the basis of a topological characterization of the environment.

- While the scattered local planners takes care of mapping execution at a metric level which consists of conflict avoidance, conflict resolution and describing errors.
- The settlement of resource constraints contain free space for a large set of robots that integrate planning model which is expanded to perform authorizing and including new plans for other robots in the system.
- This functions with the help of a planning protocol which works on the basis of graph that develops temporal precedence constraints solving differences. Localization is executed with the help of individual visual landmarks.

6.3.2 Intelligent Vehicles

Q. 6.3.2 Explain Intelligent Vehicles in brief
(Refer section 6.3.2) **(8 Marks)**

- Vehicles are widespread in all over the world. They act as transport strength of various financial systems and a significant financial asset utilized worldwide to offer essential transportation through roads for carrying personal objects, military equipments, and commercial transfer.
- So the key aspects like vehicles, roads and highways are always obstructed and utilized inadequately.
- This can be recognized as a fact that the drivers frequently do something for their own interest without taking care of general efficiency expenses and do not take decisions which are of long-term interest.
- In addition to this, the methods of communication and the value of shared data among drivers is ineffective and extremely error-prone.
- Finally, the driving ability explains significant inconsistency which is combined by the fact that driving can be exhausting and results into weakness and carelessness.
- As a result, the transport systems hardly ever come to a conclusion theoretically within reach of the traffic throughput prior to get overcrowded.
- There is a significant necessity to enhance the highway systems and vehicles so as to supply improved throughput, and the price of adding extra lanes is quite expensive, so several groups are inspecting the functions of mobile robot to supply improved traffic throughput.
- Apart from simply expanding the traffic facility, intelligent vehicles can recommend considerable assurance for risk deduction.
- The execution of a given vehicle depends upon the proper functioning of the driver where human error results into frequent accidents and deaths per year.
- It is relatively feasible that an independent vehicle may offer safety to a great extent as compared to a human operator.
- Additional features of transports which are related to people and objects through the roads can also be resolved by robotic solutions.
- Roads are planned for a vehicle having regular size, and transport of large number of goods.
- Several functions of mobile robot technology are suggested to concentrate on certain conditions.
- While a range of models are recommended that symbolize various classes of developed methods which are as follows:
  - o Driving associates, which offer supplementary data and sensors to the driver to improve the performance of human driver with respect to both protection and effectiveness.
  - o Convoy systems can be defined as a line of vehicles that generally recommend development of automated delivery convoys where the guiding vehicle is operated by a human driver but the succeeding vehicles in the convoy drive by themselves.
  - o A self-directed driving system totally removes the operator from the loop which individually drives the vehicle.
  - o A self-directed highway system considers the entire highway as an organization that manages set of vehicles separately.
  - o A self-directed urban system concentrates on problems associated to urban transport by applying independent vehicle technology.
- The difference between various levels of performance can be explained in detail with the help of following points :

Levels of Performance

- 1. Driving Assistants
- 2. Convoy Systems
- 3. Autonomous Driving Systems
- 4. Automated Highway Systems
- 5. Autonomous Urban Systems

Fig. 6.3.2 : Levels of Performance

➜ (1) Driving Assistants

- Vehicle manufacturers desire to create secured and sophisticated vehicles.
- The general path of this growth is symbolized with the efforts taken by Volvo.
- The main objective of Autonomous Intelligent Cruise Control (AICC) project by Volvo to build up an intelligent "driver assistant" which acquires speed desired by the driver, the condition of approaching traffic signals, and the speed and desired location of other vehicles on the road into consideration to propose a suitable speed to the driver.
- The European PROMETHEUS venture examined the growth of warning assistance by driver which observed several different approaches to supply extra data to the driver of a car without affecting the environment.
- A major drive of this effort is the growth of systems which recognize road signs at nearby distance that either indicates the driver or controls the car directly.
- Several cars are currently ordered with a variety of driving assistant equipments as an alternative.
- Generally, parking sensors are available on the basis of either ultrasound or laser through several manufacturers and equipments are also available.
- In the same way, supportive cameras and enclosed video systems are offered for various vehicles.
- Global positioning system (GPS) is considered as a standard automotive technology which is currently used for path scheduling and route tracking.
- For instance, Toyota and Lexus included models that consist of automatic parallel parking that has sensors which enables a car to get parked without human control.
- Volvo has advertised a series of special driving assistant equipments like active cruise control for automatic break, accidental lane change recognition, and observing driver that provides an evaluation of present automotive sensor equipments which contain sensors that are useful for driving assistants.

➜ (2) Convoy Systems

- Convoy systems include both general and military functions. During highway maintenance procedure a guiding vehicle is always tracked by a trailing vehicle that protects the passengers in the guiding vehicle from accidents resulted by traffic which does not allow the service vehicle to reach in time.
- Even the driver of the trailing vehicle is also prone to risk, and thus a system is required to get the driver out of the trailing vehicle so that the safety of entire system is enhanced.
- The Department of Transportation in Minnesota uses a shadow vehicle which is regulated by radio that a walker operates remotely alongside the highway which restricts the functional speed of the complete convoy.
- So as to overcome these restrictions, the Department of Transportation in Minnesota is generating and estimating an independent trailing vehicle.
- It works on a line-of-sight theory that use vision to follow a specific target on the guiding vehicle, and combines this data with the recognition of a directed radio beam produced by the guiding vehicle and differential GPS which uses the guiding vehicle as a mobile base station.

➜ (3) Autonomous Driving Systems

- Instead of only providing data to the driver, another approach is also available for the robot to drive the vehicle openly.
- Even if several problems are needed to be concentrated so as to expand an independent driving vehicle, the real problem of tracing the road is most likely expected to get consideration.
- The essential job is to recognize the road surface in order to drive the car efficiently.

- Another essential job is to identify the proper structure through which the lanes are marked, so that suitable directions can be estimated.
- If a solution is provided to find the location of the road and a method for driving the car along the road, then remaining job is to ignore other users of the road.
- If the road followed, then problem should be detected with immediate effect and precise, so that the road follower in order to avoid an obstacle does not result into removal of the vehicle from the road.
- Solutions on an average use hardware which has special functions and sensors so as to deal with these conditions.
- A large number of different autonomous driving systems exist that are available currently to perform certain operations to ensure improvement worldwide which calculates the existing state of art in autonomous driving and encourage investigation in the area.

➜ (4) Automated Highway Systems

- Instead of just handling a particular vehicle, another approach is also available that considers the requirements of the total highway system and performs functions to activate it.
- The Intelligent Vehicle/Highway System which is known as IVHS is the one that examines various methods which can apply robotics to vehicles.
- This surveyed the growth of systems that cover the series from offering smart sensors to the driver so that it can have total control of the vehicle.
- If the price of including and retaining supplementary road lanes is more, then the method uses robotics to enlarge automotive highway density which is very impressive, but rather uncomfortable traditionally.
- Presently, the difficulties of autonomous highway driving give an impression of mostly political and social problems instead of technical problems.
- The technology provides a kind of programmed highway which is previously available, but issues related to legal responsibility, user assurance, and cost acknowledgment can avoid its delivery for a moment.

➜ (5) Autonomous Urban Systems

- The driving model for an autonomous urban system is to eliminate private vehicles from the central part of urban regions and offer a convoy of vehicles controlled by humans which are openly available.
- The vehicles are expected to be planned for providing easier control, environment friendly and skilled to perform range of autonomous functions that help in gathering the vehicles from where they have been departed and helping them to arrive at their respective central depots.
- Even if extensive operations of autonomous urban systems are not available actually, but various **automated road vehicles** are being arranged.

6.3.3 Mining Automation

- Approximately each nation with a large volume capacity of mining industry considers a study program related to mining automation.
- Additionally, equipment producers also consider a study program to examine the ability of independent or programmed mining actions.
- A probable benefit to the beginning of mining automation consists of :
  - o Provides better protection to the workers.
  - o Obtains superior production from the mine.
  - o Retains lesser equipment maintenance price.
- Normally, mining is performed with the help of two modes which are as follows :

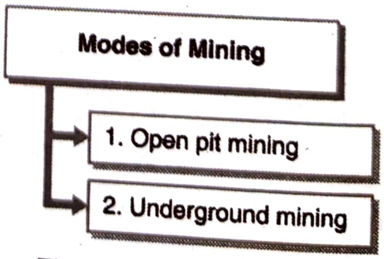


Fig. 6.3.3 : Modes of mining

➜ (1) Open pit mining

- Open pit mining is categorized by huge, bulky and costly equipment known as a dragline.
- Draglines are big devices similar to cranes which are useful in gathering overload and dump it in a particular location.

- These machines need significant ability to manage the required spaces that makes use of visual control with the help of an operator which is very complicated.
- Automatic dragline systems most likely represent the biggest robots in the world.
- Moving draglines cover small spaces with the help of large feet.
- Due to huge size and the complexity of control, various efforts are taken to generate devices which help the operator in scheduling tasks.

➜ (2) Underground mining

- Underground mining is categorized by the conditions which are required for performing hazardous tasks in a rigid environment.
- Several underground tasks require proper placement of a tool which is related with a particular object or configuration in the environment.
- The independent or mechanical systems are constructed to perform risky operations such as locating explosives, recognition and elimination of rocks, digging and placing bolts that support roof etc.
- Due to the possibility of risky rockfall, isolated underground mining is generally performed in recent mines.
- In several operations, the operator instead of controlling the vehicle directly prefers standing away from the site and controls it remotely.
- The temporary aim of mining technology is to construct an operational system that allows the operator to maintain a safe distance away from the vehicle.
- The associated problems represent the task of finding the actual location of the vehicles present in the mine and creating a consistent, high-frequency communication network in mine so as to maintain proper functioning.

6.3.4 Space Robotics

- The external space is an approximately perfect functional environment to stimulate the utilization of autonomous systems.
- It is a very costly and dangerous mission to project presence of a human being on the Moon which is distant planetary body.
- It is always desirable to discover our nearby planetary neighbours, with the help of automated systems instead of human beings.
- Before suggesting an independent or subordinate system for interplanetary discovery, it is essential to understand that robotic systems may not be able to provide similar level of flexibility as compared to mission conducted by humans.
- The missions conducted by Space Robotics are as follows :

Space Robotics Missions
- 1. NASA/JPL
- 2. Soviet

Fig. 6.3.4 : Space Robotics Missions

➜ (1) NASA/JPL

- The United States has employed a long-lasting sequence of unmanned robotic inter-terrestrial surveys with the help of NASA and JPL programs.
- The Ranger series in the beginning of the 1960s suffered a crash landing on the moon and was unable to communicate with the environment.
- The Surveyor systems executed successful landings on the moon.
- The robots of Surveyor were stable and collected samples with the help of a robotic arm. A project was organized to explore Mars in 1975 known as Viking project.
- The Mars Pathfinder mission was initiated in 1996, which deployed a tool package on Mars in 1997 that included a Sojourner rover which is also known as Microrover Flight Experiment (MFEX).
- The pair of wheels in the rover was movable in required direction.

- Basically, the vehicle was controlled in a programmed way with the help of intense location points chosen physically on the basis of control centre of the earth.

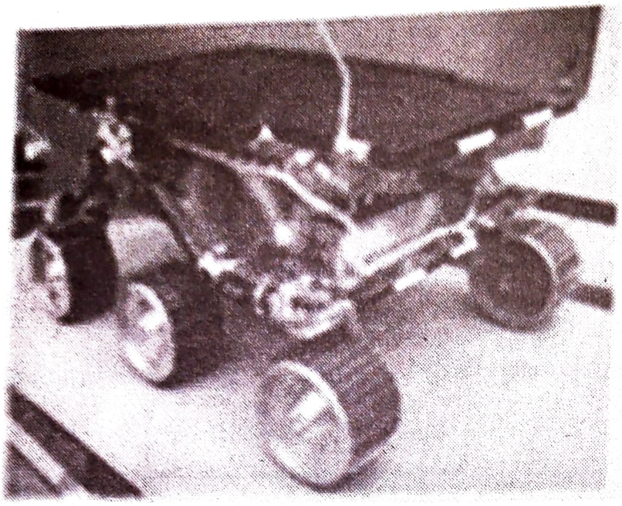


Fig. 6.3.5 : Displays a view of the rover

- Along with Sojourner, there were two more rover missions that achieved successful completion on Mars which are follows :

  (I) MER-A Sprit and

  (II) MER-B

- The above two rovers basically depend on the six-wheeled design.

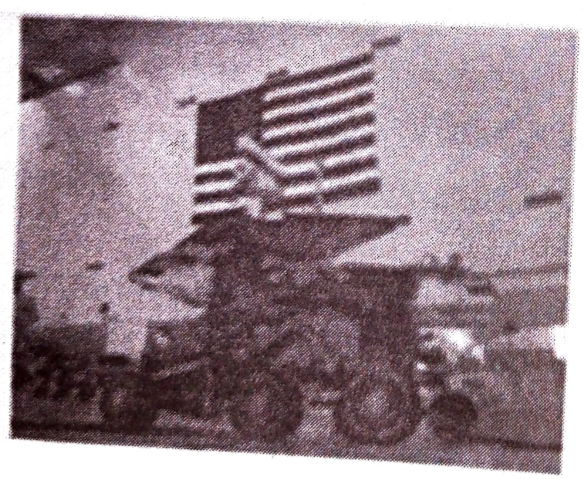


Fig. 6.3.6

- The MER platform is well-built as compared to Sojourner.
- All the three Mars rovers initiated to function with the help of command related orders by the rover.
- The rover starts processing these commands and acknowledges with respect to the reply.
- This restricts the upper limit of action/instruction sent for each communications package.
- The future rover missions are expected to have a vehicle that will offer a superior rank of self-governance which performs functions like gathering samples and transporting them back to the initial site for ultimate return to Earth.

➔ **(2) Soviet**

The Soviet Union initiated two Moon walker robots that are eight-wheeled in voluntary vehicles which perform driving on the Moon.

6.3.5 Autonomous Aircraft

- The military application is possibly the most useful application domain for autonomous aircraft which supports applications such as military drones, exploration aircraft, projectiles, ground support and attack platforms.
- It also supports civilian applications such as analysis, assessment, and communication functions.
- Military applications performed by autonomous aircraft have affected the aircraft to be considered as global exploration device like Global Hawk and battle missions like Reaper.
- Strategic weapons are also generated for the missions like Silver Fox.
- These devices are commonly controlled with the help of tools having different levels of complications present on the project which automatically decreases the complexity of operator task performance and takes care of communications failures.

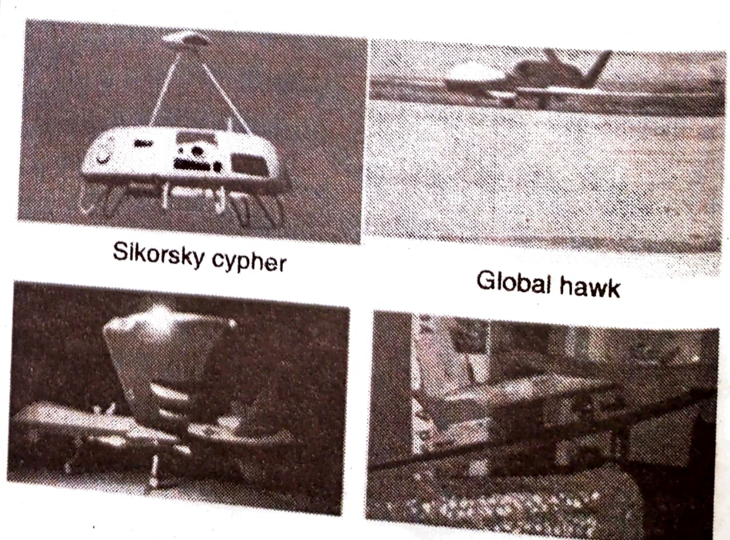


Fig. 6.3.7 : Selected autonomous aircrafts

6.3.6 Agriculture/Forestry

- The autonomous systems which are related to agriculture and forestry should overcome the particular functional limitations as compared to limitations found in business or organizational environments.
- The environment is rigid and probably missing either smooth ground surfaces or even a distinct ground level surface.
- The environment is difficult to be represented, and evolves as per maintenance provided with the type of climate which is suitable to the machines.
- Alternatively, the tasks concerned to agriculture are difficult and can be rather risky.

(1) Forestry Maintenance

- To acquire a high output from industrial forests, it is essential to carry out weeding and withdrawing operations which requires visiting the forest for performing initial sowing seeds and eliminating competing plants that grow around the required commercial trees.
- This entire operation is very costly since the forests are likely to be isolated which can be risky since the equipment needed to perform thinning of the forests is relatively powerful.

(2) Greenhouse Robots

- Greenhouses are generally useful for rigorous agriculture tasks like cultivating seedlings and enhancing plants.
- A common built-up greenhouse is in rectangular form with dimensions 100 m × 20 m.
- In a greenhouse, plants are organized in rows with slender corridors that offer access.
- The complimentary growth circumstances available in a greenhouse can result into development of pests and other unwanted organisms.
- These undesirable organisms are controlled with the help of chemical products like pesticides, fungicides, etc which are related to the closed environment that provide a potentially risky surroundings to the human gardener.
- The devices required to decrease human contact in a greenhouse at the time of spraying these chemical products are very essential.
- The AURORA robot is considered as an unmanned robot which follows the map around greenhouse corridors with the help of economical sensor systems.
- It makes use of sonar sensing to track the corridors, while it occasionally gets caught and needs operator involvement externally.

(3) Lawn- cutting Robots

- The concept of efficient domestic lawn cutting robots does not exist in reality, since they are created for well-built, huge areas such as football grounds and golf courts.
- This robot drives on the basis of a vehicle that uses GPS, a gyroscope, and dead reckoning to cut a lawn with the help of a previously planned cutting sequence.
- The vehicle is deficient in sensors that can identify and ignore obstacles and for that reason it is inappropriate for domestic lawns, even if it assumed to be efficient in controlled environments.

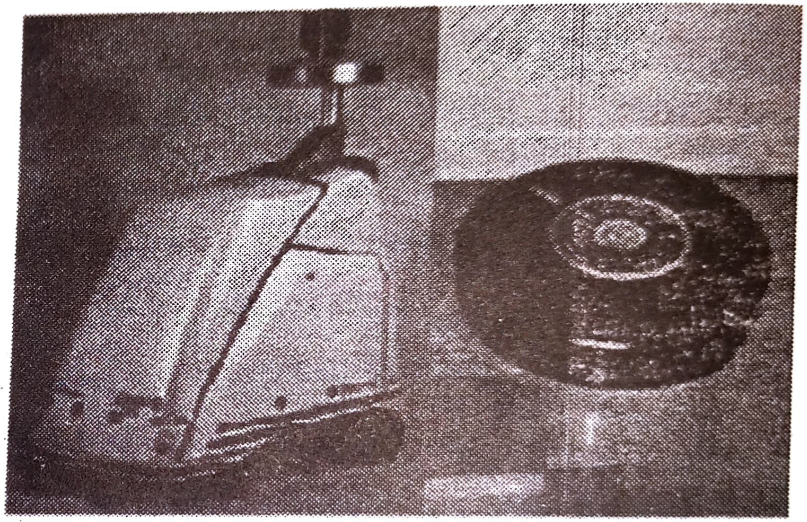
(4) Harvesting Robots

- Harvesting is considered as an activity which is completely dependent on labour in agriculture.
- Generally, the material which is required for harvesting can be damaged or spoiled due to improper handling, and large amount of time and money is invested in producing fruits and vegetables.
- The harvesting of fruit mainly creates a problem if they are situated at greater heights of the trees which make use of ladder to gather fruits.

6.3.7 Domestic Robots

- The concept of efficient domestic robots does not exist in reality, but a large number of cleaning robots are present for performing various applications.

- The companies like Cyberworks and Robosoft produce various cleaning robots for functions such as floor polishing, street cleaning, and vacuuming as shown in Fig. 6.3.8(a).
- Even if these robots could be installed in common environment, then cost exchange generally restricts their function to operational environments like cleaning rooms in which it is not cost efficient like a human cleaner.
- The Robosoft is an independent vacuum cleaner as shown in Fig. 6.3.8(a) was created to be utilized as an isolated controlled device.
- The family of household robots known as Roomba which is shown in Fig. 6.3.8(b) were created exclusively for household applications.
- These robots are improved with the help of various accessories that restrict the devices to a certain part of the floor space; the robot can work in a variety of modes to clean enclosed environments.



(a) Robosoft (b) Roomba

Fig. 6.3.8

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