CHAPTER 5

Unit V

Robotics

Syllabus Topics

Robotics : Fundamentals, path Planning for Point Robot, Sensing and mapping for Point Robot, Mobile Robot Hardware, Non Visual Sensors like : Contact Sensors, Inertial Sensors, Infrared Sensors, Sonar, Radar, laser Rangefinders, Biological Sensing. Robot System Control : Horizontal and Vertical Decomposition, Hybrid Control Architectures, Middleware, High-Level Control, Human-Robot Interface.

5.1 Robotics - Introduction

Q. 5.1.1 Write note on Robotics.
(Refer section 5.1) **(4 Marks)**

- Robotics is an interdisciplinary branch of engineering and science that includes mechanical engineering, electronics engineering, computer science, and others.
- Robotics deals with the design, construction, operation, and use of robots, as well as computer systems for their control, sensory feedback, and information processing.
- These technologies are used to develop machines that can substitute humans and replicate human actions.
- Robots can be used in any situation and for any purpose, but nowadays many of them are used in dangerous environments (including bomb detection and deactivation), manufacturing processes, or where humans cannot survive.
- Robots can take any form but some are made to resemble humans in appearance.
- This is said to help in the acceptance of a robot in certain replicative behaviours usually performed by human being.
- Such robots attempt to replicate walking, lifting, speech, cognition, and basically anything a human can do.
- Many of today's robots are inspired by nature, contributing to the field of bio-inspired robotics.
- The concept of creating machines that can operate autonomously dates back to classical times, but research into the functionality and potential uses of robots did not grow substantially until the 20th century.
- Throughout history, it has been frequently assumed that robots will one day be able to mimic human behavior and manage tasks in a human-like fashion.
- Today, robotics is a rapidly growing field, as technological advances continues; researching, designing, and building new robots serve various practical purposes, whether domestically, commercially, or militarily.
- Many robots are built to do jobs that are hazardous to people such as defusing bombs, finding survivors in unstable ruins, and exploring mines and shipwrecks. Robotics is also used in STEM (Science, Technology, Engineering, and Mathematics) as a teaching aid.
- Robotics is a branch of engineering that involves the conception, design, manufacture, and operation of robots.
- This field overlaps with electronics, computer science, artificial intelligence, mechatronics, nanotechnology and bioengineering.
- Science-fiction author **Isaac Asimov** is often given credit for being the first person to use the term robotics in a short story composed in the 1940s.

- In the story, **Asimov** suggested three principles to guide the behaviour of robots and smart machines.
- **Asimov's** Three Laws of Robotics, as they are called, have survived to the present:
  1. Robots must never harm human beings.
  2. Robots must follow instructions from humans without violating rule 1.
  3. Robots must protect themselves without violating the other rules.

5.1.1 History of Robotics

- The word robotics was derived from the word robot, which was introduced to the public by Czech writer **Karel Čapek** in his play R.U.R. (Rossum's Universal Robots), which was published in 1920
- The word robot comes from the Slavic word rabota, which means labour/work.
- The play begins in a factory that makes artificial people called robots, creatures that can be mistaken for humans - very similar to the modern ideas of androids.
- **Karel Čapek** himself did not coin the word. He wrote a short letter in reference to an etymology in the Oxford English Dictionary in which he named his brother **Josef Čapek** as its actual originator.
- According to the Oxford English Dictionary, the word robotics was first used in print by Isaac Asimov, in his science fiction short story "Liar!", published in May 1941.
- In 1942, the science fiction writer **Isaac Asimov** created his Three Laws of Robotics.

Syllabus Topic : Fundamentals Problems

5.2 Fundamental Problems

> **Q. 5.2.1** Discuss the fundamental problems in Robotics.
> (Refer section 5.2) **(4 Marks)**

- Before proceeding to real Robotics, first we will discuss some computational tasks which are related with an autonomous system.
- Here we are going to see some computational problems.
- The abstraction of autonomous robot in a simple form is the point robot. The robot is abstracted by point robot as a single point operating in a specific environment typically a continuous Cartesian plane.
- In this formalism, it is possible to represent robot as a point $(x, y) \in R^2$. Plane is the operation domain of robot.
- The state of the robot is explained in detail by the point (x, y) and is called as pose or configuration of robot.
- In the process of moving the robot, its state is updated from value (a,b) to different value (c,d).
- The operation of robot is based on plane but the entire domain is not get available for the robot.
- The group of poses which are valid is known as free space of robot. Some spaces may be invalid and some may not be occupied by the robot.
- This concept is represented in term of partitioning configuration of robot on two different classes :
  (i) Free space represented as C_{free} and
  (ii) Occupied space represented as $R^2 - C_{free}$
- As per above discussion, some questions get raised regarding mobile robots :
  - Can we relocate robot from one configuration to another while remaining within C_{free} ?
  - If robot has local measurement of C_{free} , then what is the way for robot to determine its state?
  - If robot knows the whereabouts regarding the C_{free} , then what is the way for the robot to determine it?
  - What is the way for robot to determine its pose and C_{free} if it does not have knowledge of both?

Syllabus Topic : Path Planning for Point Robot

5.2.1 Path Planning for Point Robot

> **Q. 5.2.2** Write note on Path Planning for Point Robot.
> (Refer section 5.2.1) **(8 Marks)**

- The movement of robot is in a sequential manner from *S* to *T* Fig. 5.2.1 (a) to (f). The direct path is denoted by dashed lines and the path followed by the robot is denoted by solid lines.
- Now observe the environment illustrated in Fig. 5.2.1. The starting configuration of robot is S = (a, b), and we want to shift it to configuration T = (c, d).

- To plan the path from S to T we have to decide a path which joins S and T which should be in the context of the free space.
- Usually there is need of a continuous curve in C_{free} having first end at the starting point (a, b) and another at the end (c, d).
- It is important that the start and end (goal) must be in C_{free} for the existence of path but what is the way to determine the existence of path?
- This is a difficult problem because there is need of searching through continuous space for the existence of a continuous path.
- There are some mechanisms of finding paths such as the shortest path or the straightest path.
- There are number of options to solve path planning problem, out of which many depends upon solving approximations to the problem.
- Now we are going to see an easy solution for the problem called as the Bug2 algorithm.

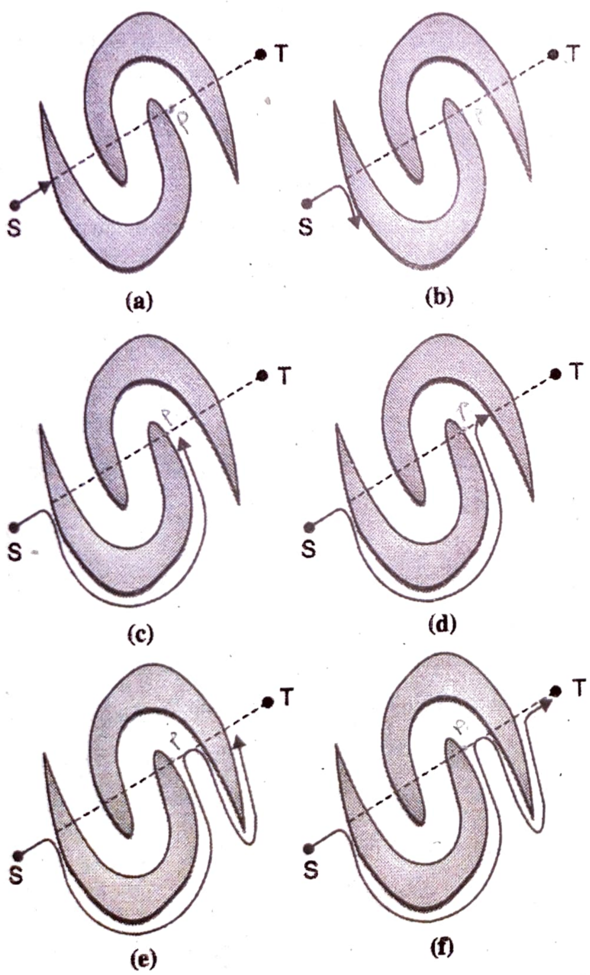


Fig. 5.2.1 : Bug algorithm example

- Consider the current position of robot is at *S* and we want to move it to *T*.
- Then if there is existence of direct path means straight line, then robot should prefer it.
- If the path is obstructed, then it is necessary for robot to go through straight line from *S* to *T* until any obstacle is not encountered.
- Say this point as *P*. Then the robot should go around the obstacle unless it is able to continue to move to the goal position *T* along the line *ST*.
- The robot travel all the way around the obstacle until it gets a point on the obstacle on the line *ST* from which it will be possible to leave the obstacle in the way of *T* which is closer to *T* as compared to the point *P* at which it begins travelling to avoid the obstacle.
- If there is no any existence of such point, the robot determines there is no path exists between *S* to *T*.
- The Bug2 algorithm assures to search a path to the goal location if it is reachable.
- The Bug2 algorithm is as follows :

```
Visualize a direct path ST from the start S to the goal T.
While the goal T is not achieved, do
begin
    while the path ST to the goal is not obstructed, do
    begin
        move towards the goal along the path ST,
        if the path is obstructed then
            begin
                mark the current location as P
                circumnavigate the object until the robot
                either,
                (a) hits the line ST at a point closer to T
                    than P and can move towards T, in
                    which case the robot follows ST,
                (b) returns to where P in which case T is
                    unreachable
            end
        end
end
```

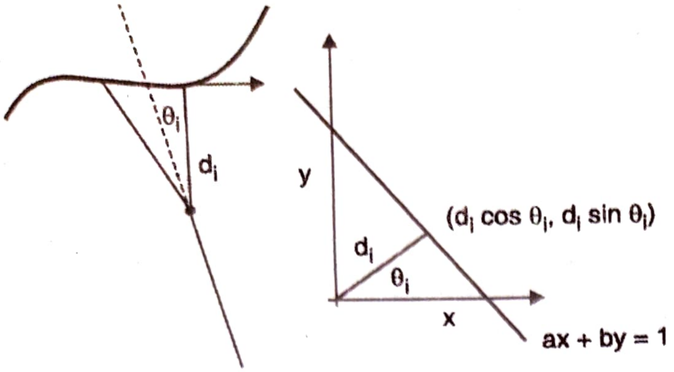


Fig. 5.2.2 : Equipping a point robot with a sensor

(a) The robot gets range measurements d_i in various directions (given by θ_i).

(b) It is possible to integrate these measurements for the purpose of estimating the orientation of the object in front of the robot.

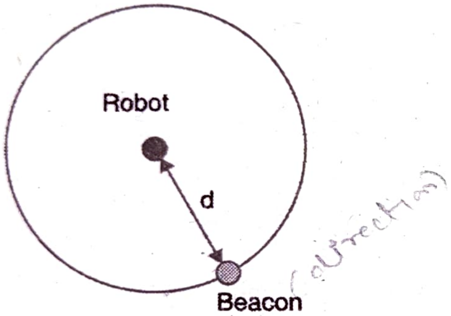


Fig. 5.2.3 : Range information

- When a robot concludes that there is a distance *d* from a beacon, it positions the beacon to a circle by referring the robot at its centre having radius as *d*.
- The completion of Bug2 algorithm is considered in that it is sure to search a path to the goal if there is existence of such a path and if such path does not exist then reports failure.
- However there is no assurance from Bug2 algorithm for finding a specifically efficient (short) path. To understand this, see that the robot always returns to the line *ST* for the purpose of moving towards the goal.
- Here it is observed that robot required to 'know' complete information regarding its environment and its capacities within this environment so as to execute an algorithm like this.
- It needs knowledge about its location in the world and be able to maintain current estimate of this as it moves.
- It required the information about location of goal in this representation.
- It must be capable to mark a location in this representation (*P*) and conclude if it is necessary to there.
- The robot should have capacity to sense the existence of an obstacle and to be able to refer this information for the purpose of circumnavigating it.
- It is should be possible for the robot to immediately change its trajectory in space.
- This dependency regarding the perfect knowledge of the robot's position as well as ability to precisely detect obstacles along the path generates complex problems for Bug algorithms while operating with real robots.

Syllabus Topic : Sensing for Point Robot

5.2.2 Sensing for Point Robot

Q. 5.2.3 Explain Sensing for Point robot.
(Refer section 5.2.2) **(8 Marks)**

- There is need of some standard mechanism for robot to sense its surrounding environment which helps it to handle the navigation and localization realities.
- Consider single range sensor is available for robot which is able to point to any direction and returns the distance to first encountered object and if there is no obstacle in the path, then it returns infinity
- Also consider that the global orientation (position) of robot is well-known.
- This sensor is very powerful and can be considered as a theoretical abstraction of a frequently used sensor called as laser point scanner.
- It is possible for robot to point this sensor in any direction to which it wants to move so as to ensure the clarity of space ahead.
- This sensor can be used by the robot which is using the Bug2 algorithm for determining the local shape of an obstacle to decide further movement along the boundary of the obstacle.
- Consider in a static environment, the robot is still and fires its sensor in several directions.
- A set of measurements $\{(\theta_i, d_i)\}$ is gained by the sensor.

Fundamental point
- mapping
- sensing
- path planning

- By taking the reference of this sensor, the robot is able to get measurements in a certain collection of orientations in the moving direction of the robot and calculate the local distance.
- Now set robot's current location as origin of a coordinate system and define θ as the angle between the moving direction of the robot and the sensor direction.
- Then sensor readings correspond to surface readings at $(d_i \cos(\theta_i), d_i \sin(\theta_i))$.
- Now consider the equation of the surface :

$$ax + by = 1$$

- Here the solution for (a, b) will be :

$$\begin{bmatrix} d_1 \cos(\theta_1) & d_1 \sin(\theta_1) \\ d_2 \cos(\theta_2) & d_2 \sin(\theta_2) \\ \cdots & \cdots \\ d_n \cos(\theta_n) & d_n \sin(\theta_n) \end{bmatrix} \begin{bmatrix} a \\ b \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ \cdots \\ 1 \end{bmatrix}$$

- If there is no error in measurements, then it can be considered as an over constrained but consistent system. It is possible to solve it by simply selecting any two measurements.
- Practically conversely, there may be some noise in the estimation process, and a process which leads to integrate such noisy measurements is necessary. Writing

$$A = \begin{bmatrix} d_1 \cos(\theta_1) & d_1 \sin(\theta_1) \\ d_2 \cos(\theta_2) & d_2 \sin(\theta_2) \\ \cdots & \cdots \\ d_n \cos(\theta_n) & d_n \sin(\theta_n) \end{bmatrix}$$

$$X = \begin{bmatrix} a \\ b \end{bmatrix},$$

and

$$B = \begin{bmatrix} 1 \\ 1 \\ \cdots \\ 1 \end{bmatrix},$$

- Then this expression can be written more compactly as

$$AX = B$$

- To solve this we can use standard least-squares minimization techniques [e.g., $X = (A' A^{-1} A' B)$].
- As soon as we got the equation of the surface near the line of motion, this can be used to guide the motion of the robot.
- We have to remember that it is essential to only select data measurements which are regarding a single surface in front of the robot.
- When this type of sensor is provided, it is possible to get some data required to execute the Bug2 algorithm.
- It is easy for the sensor to conclude the distance to the object which is placed in front of the robot and, for suitably clear surfaces, can decide the route to which the robot can track for the purpose of circumnavigating the object.
- Remember that objects which have sharp convexities will needs another sensing as well as navigation strategies so as to navigate effectively around such objects.
- The sensors individually have particular constraints and properties for the purpose of interpreting the sensor data.
- Some kind of sensors like the simulated sensor which is considered here gets range information. Other sensors get some extra indirect information like bearing.

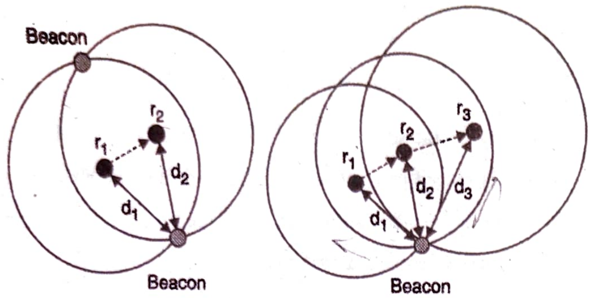
Syllabus Topic : Mapping for Point Robot

5.2.3 Mapping for Point Robot

Q. 5.2.4 Explain Mapping for Point robot. (Refer section 5.2.3) **(8 Marks)**

- Consider that a point robot functions in plane where a number of stationary beacons exists that produce unique signals which let the robot to receive range but not direction.
- Then what will be the way for robot to construct a map of the locations of these beacons?
- It is necessary to remember that the range information given by the sensor is enough to localize the location of a beacon to a circle on the plane (see Fig. 5.2.4), but it is not enough to let the robot to localize the beacon to a single point.
- The localization of beacon is possible if the robot is moved.
- While the robot moves and resenses the beacon another bunch of constraints is gained. This is shown in Fig. 5.2.3. All the constraints restrict the location of the beacon to a circle.
- For the beacon, two probable positions can be gained by the intersection of two circles on the plane.

- The further movement of robot leads to identification of an addition circular constraint, and the position of the beacon is condensed to a single point.



(a) After one motion (b) After two motions

Fig. 5.2.4

- As the movement of robot starts (denoted by the dashed line) and senses the beacon another time Fig. 5.2.4(a), it gains an extra collection of constraints as to the location of the robot.
- The probable location of the robot is restricted to circle by each and every set of constraints. The point where these two circles get intersected limits the location to one of two locations.
- When the robot moves a second time Fig. 5.2.4(b), a third constraint is appeared. The point where these three circles get intersected gets a single point as the location of the beacon.
- While the movement of robot is continued, it is possible that some beacons may appear in the range of sensor and some may go out of the range of sensor.
- Subsequent to two motions of the robot which results into unique locations in space, on the other hand, the actual location of each and every beacon which remains in robot's range will be mapped.
- It is imperative to see that for the working of technique, robot should consistently estimate its motion for the purpose of integrating the constraints over time.

Syllabus Topic : Mobile Robot Hardware

5.3 Mobile Robot Hardware

Q. 5.3.1 Explain Mobile robot Hardware and its structure.
(Refer sections 5.3 and 5.3.1) **(8 Marks)**

- Mobile robots need to be navigating their environment, build or update maps, plan and execute actions. They should flexible to environmental changes.
- They should also be able to work together with other robots and human operators, as well as learn something new from their experience.
- It requires substantial high computing power and computing power of the right sort to perform these complex tasks in a real world i.e., a concurrent hardware and software architecture.
- This will help in design and construction of real robots.
- Robots are very fast, multi-degree of freedom devices for which the plant kinematics changes as fast as the device moves.
- This is mainly challenging for robot arm control, but is non-trivial for vehicle control too. It is necessary to sense the environment in order to determine how to act.
- The main advantage of mobile robotics is that they can potentially operate in an environment that is changeable and uncertain, that's why sensing is important.
- Since practically important environments vary, it is rarely the case that any single sensor suffices for all situations, so that sensor data-fusion is necessary. As sensor data is intrinsically noisy, and the range, reflectance, and other parameters of real sensors are limited, the control system must be able to deal with uncertain information about the environment.
- Sensors typically have high bandwidths, and there is inevitable processing latency, reducing and jeopardising the stability margin of the control.
- Practically, useful mobile robots must operate in real time.
- It is useful to differentiate a number of control layers, which in turn poses the challenge of a multi-rate, multilevel system. Typically, a control loop operates at about 25Hz. A trajectory planner needs to be able to deliver set points to the low level control, and be able to perform re-planning of trajectories in case obstacles are encountered.

5.3.1 Structure of Mobile Robot

- Any robot system or autonomous mobile robot needs constantly to process large amounts of sensory data in order to build a representation of its environment and to determine meaningful actions.
- The extent to which control architecture can support this enormous processing task in a timely manner is affected significantly by the organisation of information pathways within the architecture.
- The flow of information from sensing to action should be maximised to provide minimal delay in responding to the dynamically changing environment.
- A distributed processing architecture offers a number of advantages for coping with the significant design and implementation complexity inherent in sophisticated robot systems.
- First, it is often cheaper and more resilient than alternative uniprocessor designs.
- More significantly, multiple, possibly redundant, processors offer the opportunity to take advantage of parallelism for improved throughput and for fault tolerance. Note that we distinguish the design of a processing structure (architecture) from its realisation in hardware and/or software.
- Two principal designs have been adopted : functional and behavioural decomposition.
- Functional decomposition follows the classical top-down approach to build systems. The entire control task of a mobile robot is divided into subtasks which are then implemented by separate modules.
- These functional modules form a chain through which information flows from the robot's environment, via the sensors, through the robot and back to the environment via actuators, closing the feedback loop. Most previous mobile robots have been based on this approach.
- In contrast, behavioural decomposition is a bottom-up approach to building a system. A behaviour encapsulates the perception, explore, avoidance, planning, and task execution capabilities necessary to achieve one specific aspect of robot control.

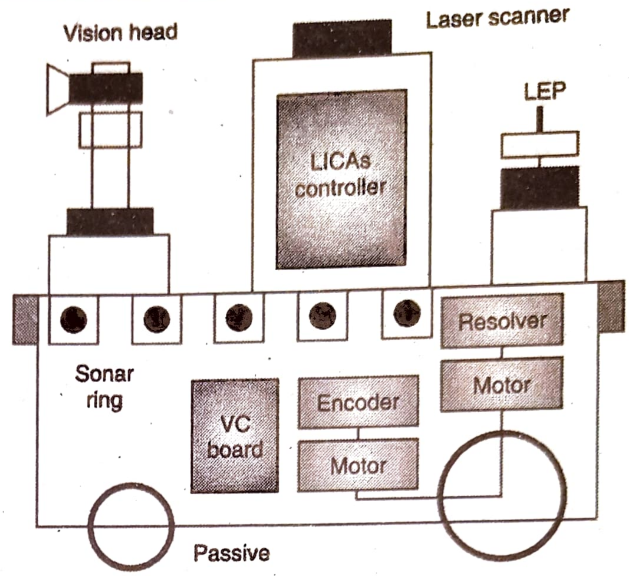


Fig. 5.3.1 : Structure of our mobile robot

5.3.2 Components of Mobile Robot

Q. 5.3.2 Explain components of Mobile Robot.
(Refer section 5.3.2) **(4 Marks)**

- A mobile robot is a combination of various hardware (physical) and software (computational) components.
- In terms of hardware components, a mobile robot can be considered as a collection of subsystems for the following terms :

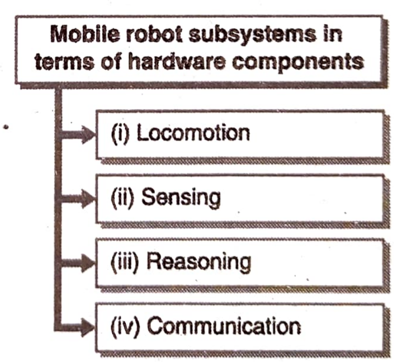


Fig. 5.3.2 : Mobile robot subsystems in terms of hardware components

➜ **(i) Locomotion**

It specifies how the robot moves through its environment.

➜ **(ii) Sensing**

It mainly shows how the robot measures properties of itself and its environment.

➜ **(iii) Reasoning**

It specifies how the robot maps the measurements into actions.

➜ **(iv) Communication**

- It specifies how the robot communicates with an outside operator.
- In terms of software components, a set of subsystems are responsible for :
  - **Planning :** It requires some sort of Planning in its various aspects.

Syllabus Topic : Non-Visual Sensors

5.4 Non-Visual Sensors

Q. 5.4.1 Write note on Non-visual Sensors.
(Refer section 5.4) **(4 Marks)**

- Sensors are nothing but the devices which are used to sense as well as measure the physical properties of the environment.
- For example, temperature, luminance, resistance to touch, weight, size, etc.
- Transduction is the most important aspect of sensors which is a process that converts one type of energy into another.
- They inform about the low-level information regarding the environment in which the robot is working.
- Robotic sensors are used to estimate a robot's condition and environment. These signals are passed to a controller to enable appropriate behavior.
- Sensors in robots are based on the functions of human sensory organs. Robots require extensive information about their environment in order to function effectively.
- Sensors provide analogs to human senses and can monitor other phenomena for which humans lack explicit sensors.
- **Simple Touch :** Sensing an object's presence or absence.
- **Complex Touch :** Sensing an object's size, shape and/or hardness.
- **Simple Force :** Measuring force along a single axis.
- **Complex Force :** Measuring force along multiple axes.
- **Simple Vision :** Detecting edges, holes and corners.
- **Complex Vision :** Recognizing objects.
- **Proximity :** Non-contact detection of an object.

Sensors can measure physical properties, such as the distance between objects, the presence of light and the frequency of sound. They can measure :

- **Object Proximity :** The presence/absence of an object, bearing, color, distance between objects.
- **Physical orientation :** The co-ordinates of object in space.
- **Heat :** The wavelength of infrared or ultra violet rays, temperature, magnitude, direction.
- **Chemicals :** The presence, identity, and concentration of chemicals or reactants.
- **Light :** The presence, color, and intensity of light.
- **Sound :** The presence, frequency, and intensity of sound.
- Motion controllers, potentiometers, tacho-generators and encoder are used as joint sensors, whereas strain-gauge based sensing is used at the end-effector location for contact force control.

Syllabus Topic : Contact Sensors

5.4.1 Contact Sensors (Bumper tactile)

Q. 5.4.2 Write note on contact Sensors.
(Refer section 5.4.1) **(4 Marks)**

- Contact sensors are considered as most common sensors in the field of robotics.
- There is need of physical contact regarding other objects to trigger.
- Transducer is used by the Contact sensors for the sensing operation.
- There are number of contact sensors such as a push button switch, limit switch or tactile bumper switch, potentiometer, strain gauge etc.
- There are two main types, **bumper** and **tactile.**
- **Bumper** type sensor are basically used to detect whether they are touching anything, the result of this information is either Yes or No. It is not possible for them to give information

about intensity of hardness of the contact or what thing they are touching.

- **Tactile** sensor are considered as little bit more complex and give information regarding how hard the sensor is touched, or the exact direction and rate of relative movement. Tactile sensors which measure the touch pressure are usually depending upon strain gauges or pressure sensitive resistances.
- The use of these sensors is mainly for obstacle avoidance for the robots. When they hit an obstacle, it triggers the robot to perform a task. The task may be reversing, turning, switching on a LED, Stopping etc.

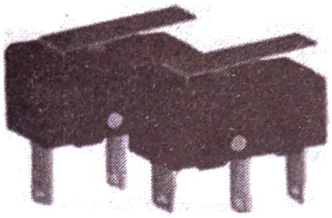


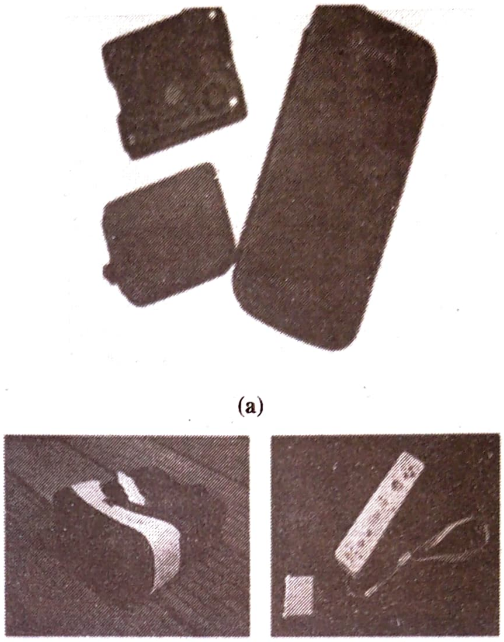
Fig. 5.4.1 : Limit switch (Contact sensor)

Syllabus Topic : Inertial Sensors

5.4.2 Inertial Sensors

Q. 5.4.3 Write note on Inertial Sensors. (Refer section 5.4.2) **(4 Marks)**

- Inertial sensors are considered as the type of external sensors which avoid making any reference with the external world.
- These sensors are basically used to measure derivatives of the robot's position variables.
- The term inertial sensor is used to denote the combination of a three-axis accelerometer and a three axis gyroscope.
- Devices containing these sensors are commonly referred to as inertial measurement units (IMUs).
- Inertial sensors are nowadays also present in most modern smart-phone, and in devices such as Wii controllers and Virtual Reality (VR) headsets, as shown in Fig. 5.4.2.
- Fig. 5.4.2 (a) - Left bottom : an Xsens MTX IMU[156], Left top : A Triviso colibri wireless IMU[148], Right : A Samsung galaxy S4 mimi smartphone.
- Fig. 5.4.2 (b) - A Samsung gear VR.
- Fig. 5.4.2 (c) - A Wii controller containing an accelerator and a motionplus expansion device containing a gyroscope



(a)

(b) (c)

Fig. 5.4.2 : Examples of devices containing inertial sensors

- A gyroscope measures the sensor's angular velocity, i.e. the rate of change of the sensor's orientation.
- An accelerometer measures the external specific force acting on the sensor.
- The specific force consists of both the sensor's acceleration and the earth's gravity.
- Nowadays, many gyroscopes and accelerometers are based on Micro Electro Mechanical System (MEMS) technology.
- MEMS components are small, light, inexpensive, have low power consumption and short start-up times.
- Their accuracy has significantly increased over the years. There is a large and ever-growing number of application areas for inertial sensors.
- Generally speaking, inertial sensors can be used to provide information about the pose of any object that they are rigidly attached to.
- It is also possible to combine multiple inertial sensors to obtain information about the pose of separate connected objects.
- Hence, inertial sensors can be used to track human motion.

- This is often referred to as motion capture. The application areas are as diverse as robotics, biomechanical analysis and motion capture for the movie and gaming industries.
- In fact, the use of inertial sensors for pose estimation is now common practice for instance robotics and human motion tracking.
- Inertial sensors are also frequently used for pose estimation of cars, boats, trains and aerial vehicles, see.

Syllabus Topic : Infrared Sensors

5.4.3 Infrared Sensors (IR Sensors)

emitter
detector

Q. 5.4.4 Write note on Infrared Sensors.
(Refer section 5.4.3) **(4 Marks)**

- IR sensors use infrared light to sense objects in front of them and gauge their distance.
- The commonly used Sharp IR sensors have two black circles which are used for this process; an emitter and a detector (see Fig. 5.4.3).

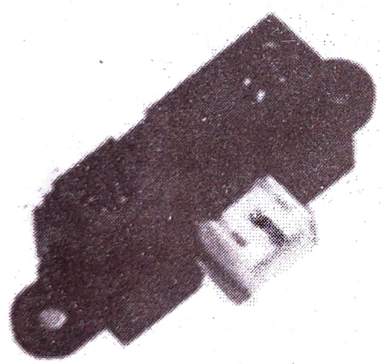


Fig. 5.4.3 : Infrared Sensors

- A pulse of infrared light is emitted from the emitter and spreads out in a large arc. If no object is detected then the IR light continues forever and no reading is recorded.
- However, if an object is nearby then the IR light will be reflected and some of it will hit the detector.
- This forms a simple triangle between the object, emitter and detector. The detector is able to detect the angle that the IR light arrived back at and thus can determine the distance to the object.
- This is remarkably accurate and although interference from sunlight is still a problem, these sensors are capable of detecting dark objects in sunlight now.

☞ How to wire them up?

- These sensors have three pins, generally with a red, black and yellow wire coming out of them.
- Red is connected used to power the sensor, black is ground and yellow is the analogue output of the sensor.
- This can be attached to one of the analogue in pins on the mbed(p15-p20) or suitable micro-controller and the distance can be read as a voltage with low voltages corresponding to close objects and high voltages corresponding to distant objects.

☞ Limitations

- These sensors are far from perfection and have quite a small range.
- They are usually most effective (though this depends on particular makes) at between 10 cm to a maximum of about 1m. However, complex scenery (many different objects) will cause a problem as the sensor will see all objects within the arc created by the IR emitter.
- It is recommended that you search for the relevant data sheet or conduct simple tests to find ideal values beyond which your robot acknowledged the obstacle.
- Sunlight or flames also present a problem as they emit a lot of IR light and thus interfere with the IR sensor providing false readings. However, these sensors are suitable for indoor use.
- Interference from other sensors can also be a problem if there are multiple robots or parallel sensors.
- As with all analogue signals, noise will exist in the readings taken from the sensor.

☞ 360 view

- For simple obstacle avoidance it is sufficient to simply see the obstacles in front of you. However, for more advanced avoidance or for searching it is advantageous to see all around your robot, or to at least have a larger view angle.
- This could be achieved using two sensors, facing away from one another, pointing left forwards and right forwards.
- This would allow a robot to identify which direction the obstacle was in and thus turn away from it in the correct direction.

Syllabus Topic : SONAR

5.5 SONAR

Q. 5.5.1 Explain : SONAR. (Refer section 5.5) (4 Marks)

- **SONAR (SOund Navigation And Ranging)** is a technique that uses sound propagation (usually underwater, as in submarine navigation) to navigate, communicate with or detect objects on or under the surface of the water, such as other vessels.
- Two types of technologies share the name "SONAR" : passive sonar is essentially listening for the sound made by vessels; active sonar is emitting pulses of sounds and listening for echoes.
- SONAR may be used as a means of acoustic location and of measurement of the echo characteristics of "targets" in the water.
- Acoustic location in air was used before the introduction of RADAR. SONAR may also be used in air for robot navigation, and SODAR (an upward looking in-air SONAR) is used for atmospheric investigations.
- The term SONAR is also used for the equipment used to generate and receive the sound. The acoustic frequencies used in SONAR systems vary from very low (infrasonic) to extremely high (ultrasonic).

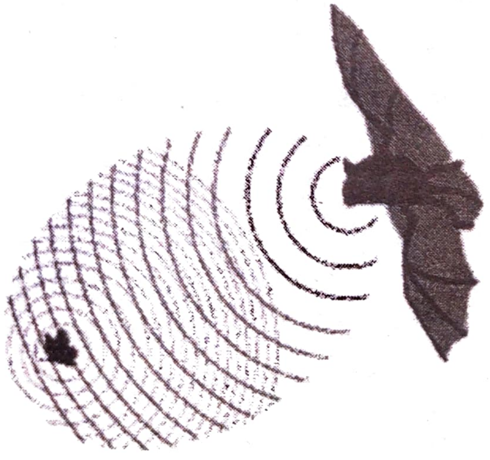


Fig. 5.5.1

How Sonar Works in Robotics

- The microcontroller instructs sonar to go. Further the sonar release a mostly inaudible (impossible to hear) sound, time passes, then detects the return echo.
- The SONAR then instantly sends a voltage signal to the microcontroller, which maintains the track of the time which passes and can compute the distance of the object(s) detected from the robot.

Power Requirements

- In general a SONAR needs ground power for signal transmit (the 'go' command), and signal receive (signals when a sound returns) lines.
- The typical SONAR module consumes roughly 100 mA in standby mode, meaning no sound pulses are being emitted.

Syllabus Topic : RADAR

5.6 RADAR

Q. 5.6.1 Explain : RADAR. (Refer section 5.6) (4 Marks)

- **RAdio Detecting And Ranging (RADAR)** is near about similar to SONAR in its principles of operation.
- In RADAR, transmission of high frequency radio waves is carried out, and reflections of these waves are observed to gain range measurements and other properties.
- RADARs are useful in mobile vehicles since they are fast and also give information about the surface property and geometry.
- **For example,** it is possible to use RADAR to discriminate between various terrain types, and this can be helpful in estimating traversability.
- RADAR can go through the surface layer of any specific object and thus it can give information regarding the subsurface structures.
- As the base of RADAR is radio instead of acoustic waves, its use is possible in environments where there is lack of an atmosphere like surface of other planets.
- Phase and frequency detection is very important for Mobile robot RADAR systems so as to measure distance to target.
- Microwave as well as the millimetre wave RADAR systems provides operational range and performance characteristics which are well suited for various types of mobile robot applications.

- Similar to SONAR systems, however RADAR systems also experience problems with secular reflections and the comparatively large footprint of the RADAR signal.
- RADAR sensors are example of external sensors. And they are used to identify range, altitude, direction or speed.

Syllabus Topic : Laser Rangefinders

5.7 Laser Rangefinders

Q. 5.7.1	Write note on Laser Rangefinders. (Refer section 5.7)	(4 Marks)

- A most important objective regarding sensing is to obtain estimates of the distance to objects in the environment. For this purpose various sensing technologies are used such as laser rangefinder.
- The methodologies on which Laser rangefinders are based are as follows :
  - **Triangulation** : The use of geometric relationships between the outgoing light beam, the incoming ray, and its position on the film plane.
  - **Time-of-flight :** The measurement of the time delay for an outgoing light ray to hit a target whose distance is being measured and returned.
  - **Phase-based** : Based on the difference between the phase of the emitted and reflected signals.
- The principle of triangulation-based laser rangefinders is similar to those which are based on regular light sources.
- However Laser sources have the advantages of being better collimated.
- Laser time-of-flight and phase-based sensing, however, exploit the time delay for signal propagation instead of geometric effects.
- High resolution and good power efficiency can be achieved by the use of a narrow collimated beam.
- It requires specific lasers since they are coherent sources which can generate very brief pulses that remain collimated over substantial distances.
- The base of sensing technology is measurement of the delay or the phase difference among the emitted laser signal and returned reflection.
- The process of measurement may be interferometric or direct but in both the cases depends upon significant signal processing.
- The maximum range of the sensor is limited by the emitted signal strength.
- The operating range of low-power systems is of a few meters, whereas the higher power systems can work over distance of a km or even more.
- This technology is similar to the one which has been used to compute the distance from the earth to the surface of the moon to astonishingly high accuracy.
- As there is divergence of laser beam with distance, the accuracy of localization of the recovered distance is less with more remote targets, even though it is not considered as an issue for interplanetary targets.

Syllabus Topic : Biological Sensing

5.8 Biological Sensing

Q. 5.8.1	Explain the term : Biological Sensing. (Refer section 5.8)	(4 Marks)

- Biology is a vast stream which provides inspiration for the most of artificial intelligence as well as robotics. Hence it is important to observe few of the myriad sensing mechanisms which are commonly found in living Creatures.
- Although sensory stimuli in animals are generally used for the purpose of diverse objectives, the behaviour is classified into two basic classes : ***tropism*** and ***taxis***.
- These are related with the stimulus-driven growth of plants and sessile organisms and the oriented movements of animals, respectively.
- The term ***topotaxis*** was developed to refer to reactions that are directed with respect to a stimulus (as opposed to undirected ***phobotactic*** responses such as random motions).
- Further it leads to a family of some more behavioural categories, such as :
  1. ***Telotaxis*** : represents a turning response which aligns an animal's direction of motion with a stimulus.
  2. ***Astrotaxis*** : represents alignment to celestial objects.

3. ***Polamtaxis*** **:** represents orientation effect which is basically provoked by polarized light.

4. ***Mnemotaxis*** **:** represents a learned direction change in response to a stimulus.

- An associated notion is that of ***kineses***. These are considered as the reactions which are more general as compared to orientation change, for example change in the speed of motion (*orthokinesis*) which are triggered by a stimulus.

Syllabus Topic : Robot System Control

5.9 Robot System Control

Q. 5.9.1 Explain in detail Robot System Control. (Refer section 5.9) **(4 Marks)**

- A control system for a completely autonomous mobile robot must perform many complex information processing tasks in real time.
- It operates in an environment where the boundary conditions (viewing the instantaneous control problem in a classical control theory formulation) are changing rapidly.
- In fact the determination of those boundary conditions is done over very noisy channels since there is no straightforward mapping between sensors (e.g. TV cameras) and the form required of the boundary conditions.
- The usual approach to building control systems for such robots is to decompose the problem into a series (roughly) of functional units.
- After analyzing the computational requirements for a mobile robot we can decide to use task-achieving behaviors as our primary decomposition of the problem.
- This is illustrated by a series of horizontal slices in Fig. 5.9.1. As with a functional decomposition, we implement each slice explicitly then tie them all together to form a robot control system.
- Our new decomposition leads to a radically different architecture for mobile robot control systems, with radically different implementation strategies plausible at the hardware level, and with a large number of advantages concerning robustness, buildability and testability.

Syllabus Topic : Horizontal Decomposition

5.9.1 Horizontal Decomposition

Q. 5.9.2 Write note on Horizontal Decomposition in Robotics. (Refer section 5.9.1) **(4 Marks)**

- It is also known as functional decomposition. In number of autonomous robot systems, this methodology is used which is a top-down classical methodology.
- This module is described by scientists Hu and Brady which makes the classic horizontal decomposition of a control system as follows :

(i) **Perception :** A module to collect data from the environment.

(ii) **Model :** A module used to construct an environmental model from the robot's perception regarding its environment.

(iii) **Plan :** A module used to build a plan of action for the robot.

(iv) **Execute :** This module helps to move the module as per the plan.

(v) **Motion controller :** Low level control is provided by this module.

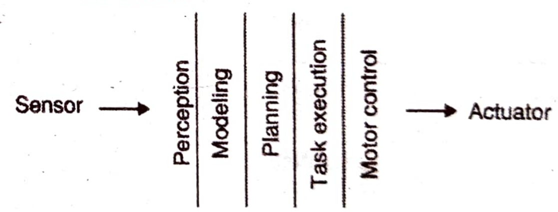


Fig. 5.9.1 : Horizontal Decomposition

- In the horizontal control system the individual modules operate in a deterministic fashion. It is important to remember that the execution of system will not start until code of all modules does not get complete.
- The base of traditional deliberative architecture is sensing followed by planning.
- It is called as sense- plan-act cycle.
- SMPA (sense-model-plan-act cycle) is the system under which internal models are developed and planner being developed.

- This vehicle was developed to navigate both on and off-road, exhibiting goal directed autonomous behaviour like road following, avoiding obstacle, cross country navigation, landmark detection etc.

5.9.1(A) Hierarchical Control

- The Hierarchical Paradigm is historically the oldest method of organizing intelligence in mainstream robotics.
- It dominated robot implementations from 1967, with the inception of the first AI robot, Shakey, up till the late 1980's when the Reactive Paradigm burst onto the scene.
- As noted in Part I, a robotic paradigm is defined by the relationship between the three primitives (SENSE, PLAN, ACT) and by the way sensory data is processed and distributed through the system.
- The Hierarchical Paradigm is sequential and orderly, as shown in Figs. 5.9.2 and 5.9.3.

Fig. 5.9.2 : S, P, A organization of Hierarchical Paradigm

ROBOT Primitives	Input	Output
SENSE	Sensor data	Sensed information
PLAN	Information(Sensed and/or cognitive)	Directives
ACT	Directives	Actuator commands

Fig. 5.9.3 : Alternative description of how the 3 primitives interact in the Hierarchical Paradigm

- First the robot senses the world and constructs a global world map. Then "eyes" closed, the robot plans all the directives needed to reach the goal.
- Finally, the robot acts to carry out the first directive. Then the robot has carried out the SENSE-PLAN-ACT sequence, it begins the cycle again: eyes open, the robot senses the consequence of its action, replans the directives (even though the directives may not have changed), and acts.

Syllabus Topic : Vertical Decomposition

5.9.2 Vertical Decomposition

Q. 5.9.3 Write note on Vertical Decomposition in Robotics. (Refer section 5.9.2) **(4 Marks)**

- As we have seen that the horizontal decomposition is based upon planning reactive control, situated agents, embedded systems, motor schema, the vertical decomposition is based on animal models of intelligence.
- The entire action regarding the robot is decomposed on the basis of behavior instead of by a deliberative reasoning process.
- The main reason of introduction of behavior-based mechanism is to handle several difficulties which mostly encountered while adapting classic planner to handle low level robot control.

☞ Frequent difficulties encountered by the classic planner

1. **Multiple Goals :** The low level robot control expected to meet several goals in parallel. The classic planner likely to achieve a single goal at a time. It is expected from controller to provide safety during the process of executing commanded motion, processing sensor input and handling communication tasks. There is time-critical nature of all these tasks and the deterministic, discrete model of processing is not considered as well suited to achieve multiple goals.
2. **Multiple Sensors :** There are real time constrains to the sensors on a robot. The retrieval of data should be fast otherwise it may be overwritten by subsequent measurements. Similarly the acquisition and identification of data must be in space-time else it will not be analyzed properly. The time constants of different sensors may be different. Some return the result within fraction of second while some take longer.
3. **Robustness :** It is necessary for the low level system to be insensitive relatively to conflicting, confounding or missing data from single or multiple robot sensors.
4. **Extensibility :** It should be easy to modify the control system to handle changes in sensor, task or locomotive configurations.

Syllabus Topic : Hybrid Control Architectures

5.10 Hybrid Control Architectures

P S - A

Q. 5.10.1 Explain Hybrid Control Architecture with suitable diagram. (Refer section 5.10) **(4 Marks)**

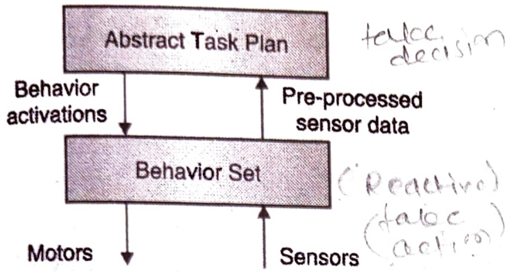


Fig. 5.10.1 : Hybrid Control Architectures

- Hybrid architectures combine reactive control with abstract task planning
- Abstract task planning layer makes deliberative decisions and plans goal directed policies
- Reactive behavior layer provides reactive actions and handles sensors and actuators.
- In this architecture initially the planning of dividing a task into subtasks is done by the robot. Then it identify suitable behaviors to perform those subtasks.
- Further as per the reactive paradigm, the execution of behaviors start.
- Such mechanism is called as PLAN, SENSE-ACT (P,S-A) in which the comma represents that the first step is of PLANNING while in second step both SENSE and ACT are implemented.
- In the context of Hybrid paradigm, sensing organization is considered as mixture of Hierarchical and Reactive styles.
- For each behavior which needs the sensor data, it is routed. This data is also available to the planner for the purpose of constructing a task-oriented global world model.
- It is responsibility of planner to keep watch on the sensing done by each behavior. When any obstacle is there to behavior, then the planner put it into a map of the world.
- The computations performed by each function depends upon it own rate; deliberative planning which is usually considered as expensive computationally updating at every five seconds.
- The execution of reactive behavior is at 1/60 second. Maximum robots run at 80 cm / second.

Advantages

Permits goal-based strategies and ensures fast reactions to unexpected changes. So reduces complexity of planning.

Disadvantage

Choice of behaviours limits range of possible tasks and the behaviour interactions have to be well modelled to be able to form plans.

Syllabus Topic : Middleware

5.11 Middleware

Q. 5.11.1 Write note on Middleware in Robotics. (Refer section 5.11) **(8 Marks)**

- Middleware is computer software that connects software components or applications.
- Generally a middleware consists of a set of services that allows multiple processes running on one or more machines to interact.
- Robotic systems are usually complex systems built on many different hardware and software components, as sensors and actuators as well as planners and control algorithms.
- In general, on each robot runs a software that is responsible for reading sensors data, extracting the needed information from them, computing the sequence of actions to accomplish a given task and controlling the actuators to execute the actions.
- Using a custom approach, there will be a single monolithic application that will handle all these tasks, making code maintenance hard and preventing every form of code reuse and sharing between different projects.
- Such a scenario, with many hardware and software components that needs to communicate and collaborate to reach a goal, is exactly where a middleware can help improving the organization, the maintainability and the efficiency of the code.

- The whole application can be structured into many little concern separated tasks, as "get a sensor reading", "extract features from some data", "drive the motors to some speed".
- Different components can exchange data using a common communication channel provided by the middleware, using interfaces that are consistent between different applications.
- In this way, it becomes really easy to share and reuse code among different projects, or change an algorithm to get some functionality as it is only necessary to keep the same interface.
- As an example, if you need to switch from a proximity sensor to another, it is possible to write a new component that share the same interface and update it without modifying the rest of the application.
- This concept can be extended to large and complex applications, in which using a middleware can clearly improve the overall code organization and reduce the programming effort.

5.11.1 Robotics Middleware Projects

- A wide variety of projects for robotics middleware exist.
- Middleware products rely on a wide range of different standards, technologies, and approaches that make their use and interoperation difficult, and some developers may prefer to integrate their system themselves.
- The robotics middleware projects are as follows :

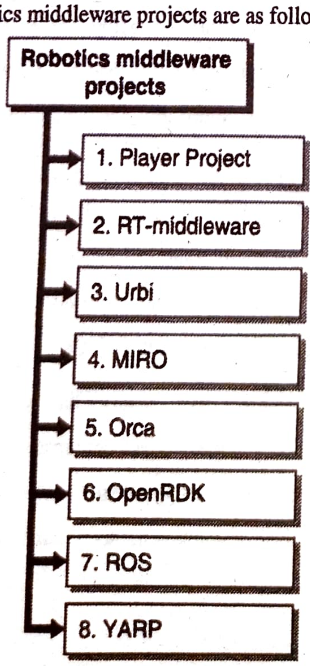


Fig. 5.11.1 : Robotics middleware projects

➜ 1. Player Project

- The Player Project (formerly the Player/Stage Project) is a project to create free software for research into robotics and sensor systems.
- Its components include the Player network server and the Stage robot platform simulators.
- Although accurate statistics are hard to obtain, Player is one of the most popular open-source robot interfaces in research and post-secondary education.
- Most of the major intelligent robotics journals and conferences regularly publish papers featuring real and simulated robot experiments using Player and Stage.

➜ 2. RT-middleware

- RT-middleware is a common platform standards for Robots based on distributed object technology.
- RT-middleware supports the construction of various networked robotic systems by the integration of various network-enabled robotic elements called RT-Components.
- The specification standard of RT-components is discussed and defined by the Object Management Group (OMG).

➜ 3. Urbi

- Urbi is an open source cross-platform software created in C++ used to develop applications for robotics and complex systems.
- It is based on the UObject distributed C++ component architecture. It also includes the urbiscript orchestration language which is a parallel and event-driven script language.
- UObject components can be plugged into urbiscript and appear as native objects that can be scripted to specify their interactions and data exchanges.
- UObjects can be linked to the urbiscript interpreter, or executed as autonomous processes in "remote" mode, either in another thread, another process, a machine on the local network, or a machine on a distant network.

➜ 4. MIRO

- Miro is a distributed object oriented framework for mobile robot control, based on CORBA (Common Object Request Broker Architecture) technology.

- The Miro core components have been developed under the aid of ACE (Adaptive Communications Environment), an object oriented multi-platform framework for OS-independent interprocess, network and real time communication.
- They use TAO (The ACE ORB) as their ORB (Object Request Broker), a CORBA implementation designed for high performance and real time applications.
- Currently supported platforms include Pioneers, the B21, some soccer robots and various robotic sensors.

5. Orca

- Orca describes its goals as :
  - o To enable software reuse by defining a set of commonly-used interfaces;
  - o To simplify software reuse by providing libraries with a high-level convenient API; and
  - o To encourage software reuse by maintaining a repository of components.
- They(Orca) also state : "To be successful, we think that a framework with such objectives must be : general, flexible and extensible; sufficiently robust, high-performance and full-featured for use in commercial applications, yet sufficiently simple for experimentation in university research environments."
- They describe their approach as :
  - o Adopts a Component-Based Software Engineering approach without applying any additional architectural constraints.
  - o Uses a commercial open-source library for communication and interface definition
  - o Provides tools to simplify component development but makes them strictly optional to maintain full access to the underlying communication engine and services.
  - o Uses cross-platform development tools.
- Orca software is released under LGPL and GPL licenses.

6. OpenRDK

OpenRDK is an open-source software framework for robotics for developing loosely coupled modules.

- It provides transparent concurrency management, inter-process (via sockets) and intra-process (via shared memory) blackboard-based communication and a linking technique that allows for input/output data ports conceptual system design.
- Modules for connecting to simulators and generic robot drivers are provided.

7. ROS

- ROS(Robot Operating System), is a collection of software frameworks for robot software development, providing operating system-like functionality on a heterogeneous computer cluster.
- ROS provides standard operating system services such as hardware abstraction, low-level device control, implementation of commonly used functionality, message-passing between processes, and package management.

8. YARP

- YARP is an open-source software package, written in C++ for interconnecting sensors, processors, and actuators in robots.

Syllabus Topic : High-Level Control

5.12 High-Level Control

Q. 5.12.1 Write note High-Level Control in Robotics.
(Refer section 5.12) **(8 Marks)**

- The implementation of high-level robot control system is on the basis of logic within the cognitive robotics technique.
- The controller is planned according to the logic of a particular event calculus which is recognized for interpretation of functions.
- The controller's fundamental model is described with the help of a cycle that performs actions like intelligence, designing, operation which require both scheduling and SDA.
- Sensor Data Assimilation (SDA) can be defined as a theorem that helps in establishing functions.
- The robot performs a task of an off-board computer with the help of High-level control which interacts with the robot through an RS232 port.

- The high-level controller is capable of starting on-board execution of low-level routines like wall tracing, angle turning etc.
- The low-level routine shows interaction between the status of the robot's sensors and the high-level controller that decides the next procedure after termination.
- The execution factors of the low-level actions are remote so the essential target is to focus on the high-level controller.
- A high-level control can be defined as a group of logical formulae describing functions and their consequences related to the robot and other agents.
- The detailing applied to symbolize functions and their consequences with the help of event calculus and the framework difficulty which is conquered by using limitations.
- The theory of the event calculus comprises functions or events along with instances.
- A specific domain is explained with the help of Initiates and Terminates procedures.
- The hierarchical planning must be performed to carry out interrupt scheduling, sensing and operating efficiently.
- The account of sensor data assimilation (SDA) is required because sensors do not convey information directly to the robot's model.
- But the sensors supply raw information indirectly to the robot's model.
- Both planning and SDA are executed with the help of single logic programming.
- The implementation of system cycle consists of characteristics which are as follows:
  - Planning and SDA are both depending on declaration of abductive theorem that establishes procedures functioning on groups of event calculus formulae. These procedures obey the rules of the logical requirements.
  - Planning and SDA are those procedures that enclose resources. They are depending on constant delay to enable the interruption of sensing, scheduling and performing.
  - Hierarchical planning provides spontaneity which assists planning in a sequential order maintaining the rapid creation of an initial executable operation.
  - The outcomes of SDA can depict differences in existing plan as a result needs rapid re-planning.
- An event calculus robot plan includes particular parts which are as follows :
  - A group of Initiates and Terminates rules that define consequences of the robotic functions which are primitive and low-level.
  - A group of Happens rule that define sources of robot sensor events.
  - A group of Initiates and Terminates rules that define consequences of the robotic functions which are high-level and complex.
  - A group of Happens rule that define functions which are high-level and complex in terms of additional primitive ones. These definitions are capable of performing tasks like progression, selection, and recursion.
  - A group of statements indicate some predicates that are abdicable.
- The planning process subsequently decomposes with the help of resolution which is adjacent to rule.
- This decomposition can defer any group as follows:
  - Additional sub-goals must be accomplished.
  - Additional sub-actions must be decomposed.
  - The plan must include executable and primitive functions.
  - The negated clipped rule which is related to protected connections in partial-order planning provides authority to preserve successive processing all over.
- The moment an entire plan is created with an executable initial operation which is not decomposed completely the robot starts its actions.
- For that moment, the SDA process is also in progress.
- In various tasks like direction-finding, the SDA process eventually creates a group of abducted **Happens rules** that define external functions that give details about the received sensor information.

- According to the sense-plan-act cycle, the event calculus can be considered as a logical programming language related to the agents.
- Consequently, event calculus programs include both declarative as well as procedural implication since it consists of sentences of logic and an execution model.
- The two robotic applications described in event calculus programs are as follows :
  1. Direction-finding and
  2. Constructing map.
- Even though not a single robot program represented at this point shows much spontaneity, the system performs creation of extremely reactive control programs.
- The key to accomplish spontaneity is to make sure that the program comprises high-level complex functions that rapidly decompose in various conditions to perform initial executable function.
- Each unpredicted event resolves impulsive re-planning that results into suitable new function to be implemented.

Syllabus Topic : Human Robot Interface

5.13 Human Robot Interface

HRI Interface

Q. 5.13.1 Explain Human robot Interface. (Refer section 5.13) **(8 Marks)**

- The maximum use of automation and especially the use of robots lead to growth in industry and also in everyday activities of an individual.
- The existence of individual robotics in our homes may result into essential civic changes in the future with the help of individual robots supporting our maturing society in the fields like health care, treatment, and therapy and also helping as performers and domestic staff.
- On the other hand, existing technology is still restricted in applications.
- Fully independent robot that is capable of executing new tasks in difficult, free, unidentified and altering environments similar to our homes is not available up till now.
- Human beings are extremely flexible and can effortlessly adapt to varying conditions, however they are extremely inaccurate and dependable as compared to robots.
- Therefore, at least in close proximity to future, it is sensible for robots and humans to work together with each other so that they can acquire benefits from the particular capabilities of each other.
- Additionally, the opportunity for robots to gain knowledge of new tasks by their continuous communication with non-skilled humans and expanding gradually towards independence is a key aspect for the improvement of individual robots in self-motivated real-world environments.
- Robot learning in the course of communication with humans needs well-organized machine learning algorithms and understandable, spontaneous human–robot communication systems.
- The machine learning algorithms are always subjected to essential research on the topics like imitation knowledge, knowledge by manifestation and social knowledge.
- Recognizing the human being as teacher and robotic as student is an association having great significance, and the communication scenario is an essential part of the structural design.
- In addition to this when human beings train a robot; it is doubtful whether they properly understand what the robot is learning during simple tasks.
- The deficiency in understanding the robot during the learning process indicates a major functioning issue when the robot learning is prepared online.
- With the help of robot learning, it is complicated for the user to forecast the robots behaviour which turns out to be conflicting as it is customized according to the learning process.
- There is always a difference among the user expectations regarding the robot and the robot's real performance which is resulted due to the lack of advice accessible throughout the learning process.
- The user can evaluate his or her prospects and the consequence once the instructions are fulfilled and requested for the first time.

- Finally, this difference may initiate a loss of confidence in the robot and exploitation of automation that decrease the entire presentation of the system.
- The feedback should be maintaining the user expectations properly, and it should be made available with the help of interface.
- The interface must provide sufficient data so that the user can recognize limitations of the learning process.
- The recognition of the interface and its feedback is considered as significant and discussion about their significance is dominant when it approaches to installing learning robot systems at the laboratory so that the non-skilled users can use them.
- They considered the impact of different interfaces on the effectiveness of robot learning.
- In the background of teaching a robot identifies a latest visual item which shows the authority of an interface performed on the basis of object that uses an intermediary object. This object displays the perception of the robot and the actual learning process.
- In the same way, during a direction-finding training task for the learning process performed by the user which observes the world through the eyes of the robot.
- In other words, the interface should explicitly show what the robot understands from its sensors and its algorithms.
- Focusing on this goal the interfaces on the basis of gesture are displayed in or voice interfaces that are poorer as they are unable to assist, the user decide the uncertainty about what the robot recognizes.
- Therefore, the maintenance of interfaces on the basis of screen is presently the most appropriate interfaces to learn the communication with a learning robot since the communication with the user can be perfectly restricted and prohibited.
- These interfaces can also exhibit interactive associations among environmental attributes and working out processes, and they can show an improved reality in the structure of virtual reality or improved reality.
- Supplemented reality interfaces which are not dependent on screen like schematic augmented reality interfaces must offer similar benefits, but the technology is not grown-up or flexible as much as necessary to be measured to employ and is costly.
- In addition, new problems are generated by online robot learning in terms of managing allocation and adapting interface.
- The queries which take place are as follows:
  1. The decision for start, stop, or restart of the learning process.
  2. The application of the automation achieved from learning and
  3. The reflection of interface that exhibits latest robot capabilities resulting from learning process.
- The user includes an opportunity to select when to use the performance of the robot and regenerate the learning process.
- The interface among robot and human beings structures the way in which user operates on robot and its learning processes.
- Additionally, it offers the appropriate data about the existing state of the robot, the learning process, and the nearby environment.
- Therefore, a suitably planned interface can assist to overcome the perceptive and probability issues happening due to learning facilities of the robot.
- The most necessary conditions needed to solve a complex problem are as follows:
  - The manner in which human–robot interface must be designed to maintain robot learning.
  - The data must be offered in such a way that the information and the communication choices which are existing can manipulate to a great extent as per the perception of the user.
  - The concentration is more on examining the authority of various types of feedback on the system for checking the performance of robot as well as user existing in an environment where circumstances can alter over the time.

- o The assumption is that performance of the system can be enhanced if users include a superior knowledge of the status of robot learning.
- o The result of adding samples about the performance related to the robot learned on the basis of given notifications regarded changes which are observed by users that utilize additional data and waiting for the required learned performance related to the robot and that eventually enhance performance.

5.13.1 Human Robot Interaction (HRI) interaction

Q. 5.13.2 Explain Human robot Interaction. (Refer section 5.13.1) (8 Marks)

- **Human Robot Interaction** is the study of interactions between humans and robots.
- It is often referred as HRI by researchers. Human–robot interaction is a multidisciplinary field with contributions from human-computer interaction, artificial intelligence, robotics, natural language understanding, design, and social sciences.
- Human robot interaction has been a topic of both science fiction and academic speculation even before any robots existed.
- The origin of HRI as a discrete problem was stated by 20th century author **Isaac Asimov** in **1941**, in his novel I, Robot. He states the three Laws of Robotics as,
  1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
  2. A robot must obey any orders given to it by human beings, except where such orders would conflict with the First Law.
  3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.
- These three laws of robotics determine the idea of safe interaction.
- The closer the human and the robot get and the more intricate the relationship becomes, the more the risk of a human being injured rises.
- Nowadays in advanced societies, manufacturers employing robots solve this issue by not letting humans and robots share the workspace at any time.
- This is achieved by defining safe zones using lidar sensors or physical cages.
- Thus the presence of humans is completely forbidden in the robot workspace while it is working.
- With the advances of artificial intelligence, the autonomous robots could eventually have more proactive behaviors, planning their motion in complex unknown environments.
- These new capabilities keep safety as the primary issue and efficiency as secondary.
- To allow this new generation of robot, research is being conducted on human detection, motion planning, scene reconstruction, intelligent behavior through task planning and compliant behavior using force control (impedance or admittance control schemes).
- The goal of HRI research is to define models of humans' expectations regarding robot interaction to guide robot design and algorithmic development that would allow more natural and effective interaction between humans and robots.
- Research ranges from how humans work with remote, tele-operated unmanned vehicles to peer-to-peer collaboration with anthropomorphic robots.
- Many in the field of HRI study how humans collaborate and interact and use those studies to motivate how robots should interact with humans.

5.13.2 The Goal of Friendly Human Robot Interactions

- Robots are artificial agents with capacities of perception and action in the physical world often referred by researchers as workspace.
- Their use has been generalized in factories but nowadays they tend to be found in the most technologically advanced societies in such critical domains as search and rescue, military battle, mine and bomb detection, scientific exploration, law enforcement, entertainment and hospital care.

- These new domains of applications imply a closer interaction with the user. The concept of closeness is to be taken in its full meaning, robots and humans share the workspace but also share goals in terms of task achievement.
- This close interaction needs new theoretical models, on one hand for the robotics scientists who work to improve the robots utility and on the other hand to evaluate the risks and benefits of this new "friend" for our modern society.
- With the advance in AI, the research is focusing on one part towards the safest physical interaction but also on a socially correct interaction, dependent on cultural criteria.
- The goal is to build an intuitive, and easy communication with the robot through speech, gestures, and facial expressions.
- Dautenhahn refers to friendly Human–robot interaction as "Robotiquette" defining it as the "social rules for robot behaviour (a 'robotiquette') that is comfortable and acceptable to humans".
- The robot has to adapt itself to our way of expressing desires and orders and not the contrary. But every day environments such as homes have much more complex social rules than those implied by factories or even military environments.
- Thus, the robot needs perceiving and understanding capacities to build dynamic models of its surroundings.
- It needs to categorize objects, recognize and locate humans and further their emotions.
- The need for dynamic capacities pushes forward every sub-field of robotics.
- Furthermore, by understanding and perceiving social cues, robots can enable collaborative scenarios with humans. For example, with the rapid rise of personal fabrication machines such as desktop 3d printers, laser cutters, etc., entering our homes, scenarios may arise where robots can collaboratively share control, co-ordinate and achieve tasks together.
- Industrial robots have already been integrated into industrial assembly lines and are collaboratively working with humans.
- The social impact of such robots have been studied and has indicated that workers still treat robots and social entities, rely on social cues to understand and work together.
- On the other end of HRI research the cognitive modelling of the "relationship" between human and the robots benefits the psychologists and robotic researchers the user study are often of interests on both sides.
- This research endeavours part of human society. For effective human - humanoid robot interaction numerous communication skills and related features should be implemented in the design of such artificial agents/systems.

5.13.3 Methods for Perceiving Humans

- Most methods intend to build a 3D model through vision of the environment.
- The proprioception sensors permit the robot to have information over its own state. This information is relative to a reference.
- Methods for perceiving humans in the environment are based on sensor information. Research on sensing components and software led by Microsoft provide useful results for extracting the human kinematics.
- An example of older technique is to use colour information for example the fact that for light skinned people the hands are lighter than the clothes worn. In any case a human modelled a priori can then be fitted to the sensor data.
- The robot builds or has (depending on the level of autonomy the robot has) a 3D mapping of its surroundings to which is assigned the humans locations.
- A speech recognition system is used to interpret human desires or commands. By combining the information inferred by proprioception, sensor and speech the human position and state (standing, seated).

5.13.4 Methods for Motion Planning

- Motion planning in dynamic environment is a challenge that is for the moment only achieved for 3 to 10 degrees of freedomrobots.
- Humanoid robots or even 2 armed robots that can have up to 40 degrees of freedom are unsuited for dynamic environments with today's technology.
- However lower-dimensional robots can use potential field method to compute trajectories avoiding collisions with human.

5.13.5 Cognitive Models and Theory of Mind

- Humans exhibit negative social and emotional responses as well as decreased trust toward some robots that closely, but imperfectly, resemble humans; this phenomenon has been termed the "Uncanny Valley."
- However recent research in telepresence robots has established that mimicking human body postures and expressive gestures has made the robots likeable and engaging in a remote setting.
- Further, the presence of a human operator was felt more strongly when tested with an android or humanoid telepresence robot than with normal video communication through a monitor.
- While there is a growing body of research about users perceptions and emotions towards robots, we are still far from a complete understanding.
- Only additional experiments will determine a more precise model.
- Based on past research there are some indications about current user sentiment and behavior around robots:
  - During initial interactions, people are more uncertain, anticipate less social presence, and have fewer positive feelings when thinking about interacting with robots. This finding has been called the human-to-human interaction script.
  - It has been observed that when the robot performs a proactive behaviour and does not respect a "safety distance" (by penetrating the user space) the user sometimes expresses fear. This fear response is person-dependent.
  - It has also been shown that when a robot has no particular use, negative feelings are often expressed. The robot is perceived as useless and its presence becomes annoying.
  - People have also been shown to attribute personality characteristics to the robot that were not implemented in software.

5.13.6 Methods for Human Robot Co-ordination

- A large body of work in the field of human-robot interaction has looked at how humans and robots may better collaborate.
- The primary social cue for humans while collaborating is the shared perception of an activity, to this end researchers have investigated anticipatory robot control through various methods including: monitoring the behaviors of human partners using eye tracking, making inferences about human task intent, and proactive action on the part of the robot.
- The studies revealed that the anticipatory control helped users perform tasks faster than with reactive control alone.
- A common approach to program social cues into robots is to first study human-human behaviors and then transfers the learning.
- For example, co-ordination mechanisms in human-robot collaboration are based on work in neuroscience which examined how to enable joint action in human-human configuration by studying perception and action in a social context rather than in isolation.
- These studies have revealed that maintaining a shared representation of the task is crucial for accomplishing tasks in groups.
- For example, scientists have examined the task of driving together by separating responsibilities of acceleration and braking i.e., one person is responsible for accelerating and the other for braking; the study revealed that pairs reached the same level of performance as individuals only when they received feedback about the timing of each other's actions.
- Similarly, researchers have studied the aspect of human-human handovers with household scenarios like passing dining plates in order to enable an adaptive control of the same in human-robot handovers.
- Most recently, researchers have studied a system that automatically distributes assembly tasks among co-located workers to improve co-ordination.

5.13.7 Applications of Human Robot Interaction (HRI)

Q. 5.13.3 Enlist applications of HRI.
(Refer section 5.13.7) **(4 Marks)**

- Robots have already been deployed to environments such as the Collapse of the World Trade Center.
- Other applications areas include :
  - Entertainment
  - Education
  - Field robotics
  - Home and companion robotics
  - Hospitality
  - Rehabilitation and Elder Care
  - Robot Assisted Therapy (RAT)