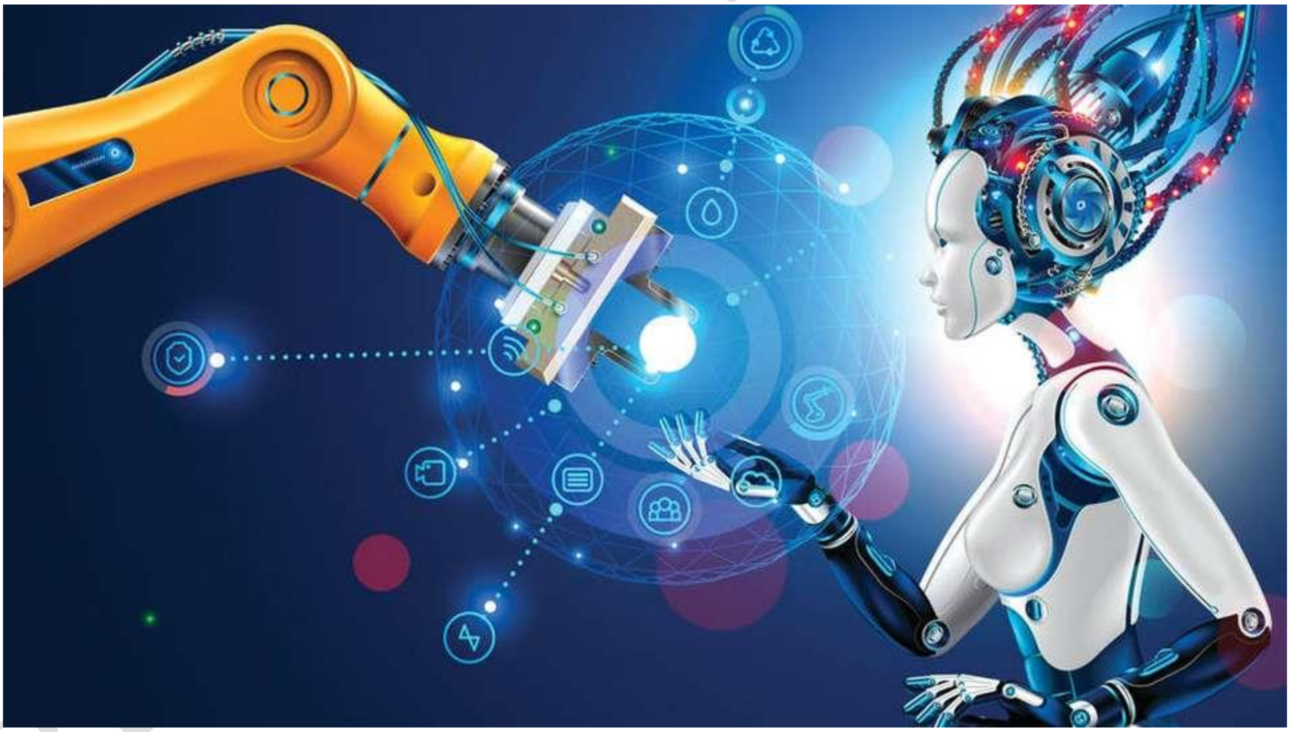
BHADRAK ENGINEERING SCHOOL & TECHNOLOGY (BEST), ASURALI, BHADRAK

Artificial Intelligence & Robotics (Th: 04-c)

(As per the 2020-21 syllabus of the SCTE&VT, Bhubaneswar, Odisha)



Sixth Semester

E & TC Engg.

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ARTIFICIAL INTELIGENCE & ROBOTICS
CHAPTER-WISE DISTRIBUTION OF PERIODS & MARKS

SL. NO.	Chapter/ Unit No.	Topics	Periods as per Syllabus	MARKS
1	**01**	ARTIFICIAL INTELLIGENCE	10	20
2	**02**	INTRODUCTION TO ROBOTICS	08	15
3	**03**	COORDINATE FRAMES,MAPPING,AND TRANSFORMS	08	15
4	**04**	ROBORYT KINEMATICS AND DYNAMICS	10	20
5	**05**	SENSORS AND VISION SYSTEM	10	10
6	**06**	ROBOT CONTROL & ROBOT ACTUATION SYSTEMS	08	10
7	**07**	CONTROL HARDWARE AND INTERFACING	06	10
	TOTAL		**60**	**100**

CHAPTER NO.- 01
ARTIFICIAL INTELLIGENCE

Learning Objectives:

1.1-Definition of AI, Scope of AI -Games, theorem proving, natural language processing, Vision and speech processing, robotics, expert systems
1.2- AI techniques- search knowledge, abstraction.
1.3- Problem solving - State space search; Production systems, search space control: depth-first, breadth-first search, heuristic search, Hill climbing, best-first search, branch and bound.
1.4- Knowledge Representation- Predicate Logic: Unification, modus pones,resolution.
1.5- Structured Knowledge Representation: Semantic Nets: slots, exceptions and default frames, conceptual dependency, scripts.
1.6-Concept of learning, learning automation, genetic algorithm, Learning by inductions, neural nets

1.1- Definition of AI, Scope of AI-games, theorem proving, natural language processing, vision and speech processing, robotics, expert systems.

Definition of AI

- **A**rtificial Intelligence (AI) is a branch of *Science* which deals with helping machines find solutions to complex problems in a more human-like fashion.
- This generally involves borrowing characteristics from human intelligence, and applying them as algorithms in a computer friendly way.
- A more or less flexible or efficient approach can be taken depending on the requirements established, which influences how artificial the intelligent behavior appears.

Scope of AI-games

Game Playing

- We can buy machines that can play master level chess for a few hundred dollars.
- There is some AI in them, but they play well against people mainly through brute force computation--looking at hundreds of thousands of positions.
- To beat a world champion by brute force and known reliable heuristics requires being able to look at 200 million positions per second.

Speech Recognition

- In the 1990s, computer speech recognition reached a practical level for limited purposes.
- Thus United Airlines has replaced its keyboard tree for flight information by a system using speech recognition of flight numbers and city names.

Understanding Natural Language

- The computer has to be provided with an understanding of the domain the text is about, and this is presently possible only for very limited domains.

Computer Vision

- The world is composed of three-dimensional objects, but the inputs to the human eye and computers' TV cameras are two dimensional.
- Some useful programs can work slowly in two dimensions, but full computer vision requires partial three-dimensional information that is not just a set of two-dimensional views.

First-order theorem proving-

- .One of the first fruitful areas was that of program verification whereby first-order theorem provers were applied to the problem of verifying the correctness of computer programs in languages such as Pascal, Ada, etc.
- First-order theorem proving is one of the most mature subfields of automated theorem proving.
- It is still semi-decidable, and a number of sound and complete calculi have been developed, enabling fully automated systems.
- More expressive logics, such as Higher-order logics, allow the convenient expression of a wider range of problems than first order logic, but theorem proving for these logics is less well developed.

Natural language processing-

- Natural language processing (NLP) is the ability of a computer program to understand human language as it is spoken and written -- referred to as natural language. It is a component of artificial intelligence (AI).
- NLP has existed for more than 50 years and has roots in the field of linguistics.
- It has a variety of real-world applications in a number of fields, including medical research, search engines and business intelligence.

Working of natural language processing (NLP)-

- NLP enables computers to understand natural language as humans do.
- Whether the language is spoken or written, natural language processing uses artificial intelligence to take real-world input, process it, and make sense of it in a way a computer can understand.
- Just as humans have different sensors -- such as ears to hear and eyes to see -- computers have programs to read and microphones to collect audio.
- And just as humans have a brain to process that input, computers have a program to process their respective inputs.
- At some point in processing, the input is converted to code that the computer can understand.
- There are two main phases to natural language processing: data pre-processing and algorithm development.

Vision and Speech processing

- In traditional speech recognition frameworks, many practical complexities need to be deal with in the case of traditional speech recognition systems.
- The traditional algorithms used to perform speech recognition have limited capabilities and can identify a limited number of words only.
- These algorithms are not capable of adapting as languages change over time. Finally, the accuracy rate of traditional algorithms is poor, making the speech recognition system unreliable.
- With the advent of AI and machine learning (ML) models, the capability of algorithms improved exponentially.
- ML models can process a much larger dataset with more accuracy as compared to traditional models.

Robotics

- Robotics is an interdisciplinary field that integrates computer science and engineering.
- Robotics involves design, construction, operation, and use of robots.
- The goal of robotics is to design machinesthat can help and assist humans.
- Robotics integrates fields of mechanical engineering, electrical engineering, information engineering, mechatronics, electronics, bioengineering, computer engineering, control engineering, software engineering, among others.

Expert Systems

- A “knowledge engineer" interviews experts in a certain domain and tries to embody their knowledge in a computer program for carrying out some task.
- How well this works depends on whether the intellectual mechanisms required for the task are within the present state of AI.
- When this turned out not to be so, there were many disappointing results. One of the first expert systems was MYCIN in 1974, which diagnosed bacterial infections of the blood and suggested treatments.

1.2-AI Techniques- Search Knowledge, Abstraction.

Search Knowledge

- Knowledge Representation in AI describes the representation of knowledge.
- Knowledge Representation and Reasoning (KR, KRR) represents information from the real world for a computer to understand and then utilize this knowledge to solve complex real-life problems like communicating with human beings in natural language.
- Knowledge representation in AI is not just aboutstoring data in a database, it allows a machine to learn from that knowledge and behave intelligently like a human being.
- The different kinds of knowledge that need to be represented in AI include

1. Objects
2. Events
3. Performance
4. Facts
5. Meta-Knowledge
6. Knowledge-base

Abstraction of AI

- In software engineering and computer science, abstraction is a technique for arranging complexity of computer systems.
- It works by establishing a level of complexity on which a person interacts with the system, suppressing the more complex details below the current level.
- The programmer works with an idealized interface and can add additional levels of functionality that would otherwise be too complex to handle. For an example, a programmer writing code that involves numerical operations may not be interested in the way numbers are represented in the underlying hardware.

1.3-Problem Solving-State space search, production systems, Search space control-depth-first, breadth first search, heuristic search. Hill climbing, best-first search, branch and bound.

Problem Solving Techniques

- Artificial Intelligence is beneficial for solving complex problems due to its efficient methods of solving.
- Following aresome of the standard problem-solving techniques used in AI:

Heuristics

- The heuristic method helps comprehend a problem and devises a solution based purely on experiments and trial and error methods.

However, these heuristics do not often provide the best optimal solution to a specific problem. Instead, these un-doubted offer efficient solutions to attain immediate goals.

- Therefore, the developers utilize these when classic methods do not provide an efficient solution for the problem. Since heuristics only provide time- efficient solutions and compromise the accuracy, these are combined with optimization algorithms to improve efficiency.

Searching Algorithms

- Searching is one of the primary methods of solving any problem in AI.
- Rational agents or problem-solving agentsuse these searching algorithms to find optimal solutions.
- Types of Searching Algorithms
  There are following two main types of searching algorithms:
  Informed Search
  Uninformed Search

State space search

- State space search is a process used in the field of computer science, including artificial intelligence (AI), in which successive configurations or states of an instance are considered, with the intention of finding a goal state with a desired property.
- State space search often differs from traditional computer science search methods because the state space is implicit: the typical state space graph is much too large to generate and store in memory.
- A solution to combinational search instance may consist of the goal state itself, or of a path from some initial state to the goal state.

Production System of AI

- Production system is a computer programed typically used to provide some form of AI, which consists primary link of a set of rules about behavior but it also includes the mechanism necessary tofollow those rules as the system responds to states of the word.
- The measure components of production system in AI is Global database.

Search space control:-

Depth First Search (DFS) Algorithm

- Depth first search (DFS) algorithm starts with the initial node of the graph G, and then goes to deeper and deeper until we find the goal node or the node which has no children.
- The data structure which is being used in DFS is stack. The process is similar to BFS algorithm. In DFS, theedges that leads to an unvisited node are called discovery edges while the edges that leads to an already visited node are called block edges.

Algorithm

Step 1: SET STATUS = 1 (ready state) for each node in G

Step 2: Push the starting node A on the stack and set its STATUS = 2 (waiting state)

Step 3: Repeat Steps 4 and 5 until STACK is empty

Step 4: Pop the top node N. Process it and set its STATUS = 3 (processed state)

Step 5: Push on the stack all the neighbors of N that are in the ready state (whose STATUS = 1) and settheir

STATUS = 2 (waiting state)[END OF LOOP]

Step 6: EXIT

Breadth First Search (BFS) Algorithm

- Breadth first search is a graph traversal algorithm that starts traversing the graph from root node and exploresall the neighboring nodes.
- Then, it selects the nearest node and explore all the unexplored nodes.
- The algorithm follows the same process for each of the nearest node until it finds the goal.
- The algorithm starts with examining the node A and all ofits neighbors.
- In the next step, the neighbors of the nearest node of A are explored and process continues inthe further steps.

- The algorithm explores all neighbors of all the nodes and ensures that each node is visited exactly once and no node is visited twice.
- ***Algorithm***

  Step 1: SET STATUS = 1 (ready state)for each node in G

  Step 2: Enqueue the starting node A

  and set its STATUS = 2(waiting state)

  Step 3: Repeat Steps 4 and 5 untilQUEUE is empty

  Step 4: Dequeue a node N. Process itand set its STATUS = 3

  (processed state).

  Step 5: Enqueue all the neighbors ofN that are in the ready state

  (whose STATUS = 1) and settheir STATUS = 2

  (waiting state) [END OF LOOP]

  Step 6: EXIT

Heuristic search-

- A heuristic search method does not always guarantee to find an optimal or the best solution, but may instead find a good or acceptable solution within a reasonable amount of time and memory space.
- Several commonly used heuristic search methods include hill climbing methods, the best-first search

Hill climbing

- Hill Climbing is a heuristic search used for mathematical optimization problems in the field of ArtificialIntelligence.
- It tries to find a sufficiently good solution to the problem. This solution may not be the global optimal maximum.

Features of Hill Climbing

1. Variant of generate and test algorithm: It is a variant of generate and test algorithm. The generate andtest algorithm is as follows:

i. Generate possible solutions.

ii. Test to see if this is the expected solution.

iii. If the solution has been found quit else go to step 1.

Hence we call Hill climbing as a variant of generate and test algorithm as it takes the feedback from thetest procedure. Then this feedback is utilized by the generator in deciding the next move in search space.

2. Uses the Greedy approach : At any point in state space, the search moves in that direction only which optimizes the cost of function with the hope of finding the optimal solution at the end.

Best first search

- Best first search is a traversal technique that decides which node is to be visited next by checking whichnode is the most promising one and then check it. For this it uses an evaluation function to decide the traversal.
- This best first search technique of tree traversal comes under the category of heuristic search or informedsearch technique.
- The cost of nodes is stored in a priority queue. This makes implementation of best-first search is same asthat of breadth First search. We will use the priority queue just like we use a queue for BFS.

Branch and bound

- Branch and bound is an algorithm design paradigm which is generally used for solving combinatorial optimization problems.
- These problems are typically exponential in terms of time complexity and may require exploring all possible permutations in worst case.
- The Branch and Bound Algorithm technique solves these problems relatively quickly

1.4 Knowledge Representation-Predicate logic, unification, Modus pones, resolution

Knowledge Representation

- Knowledge Representation in AI describes the representation of knowledge. Basically, it is a study of how the beliefs, intentions, and judgments of an intelligent agent can be expressed suitably for automated reasoning. One of the primary purposes of Knowledge Representation includes modeling intelligent behavior for an agent.
- The different kinds of knowledge that need to be represented in AI include:

- Objects
- Events
- Performance
- Facts
- Meta-Knowledge
- Knowledge-base

Predicate Logic

- Predicate Logic deals with predicates, which are propositions, consist of variables.
- A predicate is an expression of one or more variables determined on some specific domain. A predicate with variables can be made a proposition by either authorizing a value to the variable or by quantifying the variable.
- The following are some examples of predicates.

Consider E(x, y) denote "x = y"

Consider X(a, b, c) denote "a + b + c = 0"

Consider M(x, y) denote "x is married to y."

Quantifier:

- The variable of predicates is quantified by quantifiers.
- There are two types of quantifier in predicate logic are Existential Quantifier and Universal Quantifier.Existential Quantifier.

Unification

- Unification is a process of making two different logical atomic expressions identical by finding asubstitution. Unification depends on the substitution process.
- It takes two literals as input and makes them identical using substitution.
- Let Ψ_1 and Ψ_2 be two atomic sentences and σ be a unifier such that, $\boldsymbol{\Psi_1}$⊠ = $\boldsymbol{\Psi_2}$⊠, then it can beexpressed as UNIFY (Ψ_1, Ψ_2).
- Example: Find the MGU for Unify{King(x), King(John)}

Conditions for Unification:

Following are some basic conditions for unification:

- Predicate symbol must be same, atoms or expression with different predicate symbol can never beunified.
- Number of Arguments in both expressions must be identical.
- Unification will fail if there are two similar variables present in the same expression.

Modus ponens

- In propositional logic, modus ponens (/ˈmoʊdəs ˈpoʊnɛnz/; MP), also known as modus ponendo ponens (Latin for "mode that by affirming affirms")
- Implication elimination or affirming the antecedent, is a deductive argument form and rule of inference.
- It can be summarized as "P implies Q. P is true. Therefore Q must also be true."
- Modus ponens is closely related to another valid form of argument, modus tollens. Both have apparently similar but invalid forms such as affirming the consequent, denying the antecedent, and evidence of absence. Constructive dilemma is the disjunctive version of modus ponens.
- Hypothetical syllogism is closely related to modus ponens and sometimes thought of as "double modus ponens."

Resolution

- Resolution is a theorem proving technique that proceeds by building refutation proofs, i.e., proofs by contradictions. It was invented by a Mathematician John Alan Robinson in the year 1965.
- Resolution is used, if there are various statements are given, and we need to prove a conclusion of thosestatements.
- Unification is a key concept in proofs by resolutions.
- Resolution is a single inference rule which can efficiently operate on the conjunctive normal form or clausal form.

Steps for Resolution:

- Conversion of facts into first-order logic.
- Convert FOL statements into CNF
- Negate the statement which needs to prove (proof by contradiction)
- Draw resolution graph (unification).

1.5-Structured knowledge representation: Semantic nets: slots Exceptions and defaults frames, conceptual dependency, and scripts.

Structured Knowledge Representation

- Representation and Mapping - Mapping is the process that maps facts to representations and vice versa.
- Properties of Good Knowledge Representation

1. Represential Adequacy: Ability to represent allknowledge needed in the domain
2. Inferential Adequacy: Ability to manipulate knowledge to derive new structures inferred from old
3. Inferential Efficiency: Ability to perform inference in the most efficient directions 4. Acquisitional Efficiency: Ability to acquire new information easily.

Semantic network

- A semantic network, or frame network is a knowledge base that represents semantic relations between concepts in a network.
- This is often used as a form of knowledge representation.
- It is a directed or undirected graph consisting of vertices, which represent concepts, and edges, which represent semantic relations between concepts, mapping or connecting semantic fields. for example, a graph database or a concept map.

Slots

- A frame has associated with it a set of own slots, and each own slot of a frame has associated with it a setof entities called slot values.
- Formally, a slot is a binary relation, and each value V of an own slot S of a frame F represents the assertion that the relation S holds for the entity represented by F and the entity represented by V (i.e., (S F V)).

Exceptions and default frames

Frames

- Frames are an artificial intelligence data structure used to divide knowledge into substructures by representing "stereotyped situations".
- They were proposed by Marvin Minsky in his 1974 article "
- A Frame work for Representing Knowledge". Frames are the primary data structure used in artificial intelligence frame language; they are stored as ontologies of sets.
- Frames are also an extensive part of knowledge representation and reasoning schemes.

Frame Structure

- The frame contains information on how to use the frame, what to expect next, and what to do when these expectations are not met.
- Some information in the frame is generally unchanged while other information, stored in "terminals", usually change.
- Terminals can be considered as variables. Top level frames carry information, that is always true about the problem in hand, however, terminals do not have to be true.

Conceptual dependency

- Conceptual dependency theory is a model of natural language understanding used in artificial intelligence systems.
- Roger Schank at Stanford University introduced the model in 1969, in the early days of artificial intelligence.
- This model was extensively used by Schank's students at Yale University such as Robert Wilensky, Wendy Lehnert, and Janet Kolodner.
- The model uses the following basic representational tokens: real world objects, each with some attributes. real world actions, each with attributes times locations
- A set of conceptual transitions then act on this representation, e.g. an ATRANS is used to represent a transfer such as "give" or "take" while a PTRANS is used to act on locations such as "move" or "go". AnMTRANS represents mental acts such as "tell", etc.

Script

- A script is a structured representation describing a stereotyped sequence of events in a particular context.
- Scripts are used in natural language understanding systems to organize a knowledge base in terms of the situations that the system should understand.
- Scripts use a frame-like structure to represent the commonly occurring experience like going to the movies eating in a restaurant, shopping in a supermarket.

1.6-Concept of learning, learning automation, Genetic Algorithm Concept of learning.

Concept of learning

- Learning is one of the fundamental building blocks of artificial intelligence (AI) solutions.
- From a conceptual stand point, learning is a process that improves the knowledge of an AI program

by making observations about its environment.

- To understand the different types of AI learning models, we can use two of the main elements of human learning processes: knowledge and feedback.
- From the knowledge perspective, learning models can be classified based on the representation of input and output data points.
- In terms of the feedback, AI learning models can be classified based on the interactions with the outside environment and user.

Learning Automation

- Artificial intelligence (AI) is sometimes confused with automation, and the terms are often used interchangeably
- Robotic Process Automation (RPA) or marketing automation software is great for simple activities and repetitive tasks that follow instructions or work flows set by individuals.
- The trick with robotic process automation or marketing automation is for humans to anticipate every permutation so the machine is programmed to behave the right way every time.
- AI refers to how computer systems can use huge amounts of data to imitate human intelligence and reasoning, allowing the system to learn, predict and recommend what to do next.
- Capabilities enabled by AI include natural language processing (NLP), computer vision, and facial recognition.
- Most AI that uses machine learning today works in an assistive fashion, providing next best action recommendations to humans who then decide whether to trust them or not and then manually make adjustments.

Genetic Algorithms

- Genetic algorithms (GA) work by simulating the logic of Darwinian selection, where only the best are selected for replication.
- Over many generations, natural populations evolve according to the principles of natural selection and stated by Charles Darwin in The Origin of Species.
- Genetic algorithms are able to address complicated problems with many variables and a large number of possible outcomes by simulating the evolutionary process of “survival of the fittest” to reach a defined goal.
- They operate by generating many random answers to a problem, eliminating the worst and cross-pollinating better answers.
- In computing terms, a genetic algorithm implements the model of computation by having arrays of bits or characters (binary string) to represent the chromosomes.
- Each string represents a potential solution. The genetic algorithm then manipulates the most promising chromosomes searching for improved solutions.
- A genetic algorithm operates through a cycle of three stages:

1. Build and maintain a population of solutions to a problem
2. Choose the better solutions for recombination with each other
3. Use their offspring to replace poorer solutions.

Learning by induction

- Inductive learning also called Concept Learning is a way in which AI systems try to use a generalized rule to carry out observations.
- The goal of inductive learning is to learn the function for new data when the output and the examples of the function are input into the AI system.Example
- Induction starts with the specifics and then draws the general conclusion based on the specific facts. Examples of Induction: I have seen four students at this school leave trash on the floor. The students in this school are disrespectful.

Neural nets

- Neural nets are a means of doing machine learning, in which a computer learns to perform some task by analyzing training examples Most of today's neural nets are organized into layers of nodes, and they're “feed-forward,” meaning that data moves through them in only one direction.

- A neural network (NN), in the case of artificial neurons called artificial neural network (ANN) or simulated neural network (SNN), is an interconnected group of natural or artificial neurons
- In more practical terms neural networks are non-linear statistical data modeling or decision making tools.
- They can be used to model complex relationships between inputs and outputs or to find patterns in data.
- An artificial neural network involves a network of simple processing elements (artificial neurons) which can exhibit complex global behavior, determined by the connections between the processing elements and element parameters.

Applications

- Neural networks can be used in different fields. The tasks to which artificial neural networks are applied tend to fall within the following broad categories:
- Data processing, including filtering, clustering, blind signal separation and compression.
- Application areas of ANNs include nonlinear system identification and control (vehicle control, process control), game-playing and decision making (backgammon, chess, racing), pattern recognition (radar systems, face identification, object recognition).

POSSIBLE SHORT TYPE QUESTIONS WITH ANSWER

Q 1- Write definition of AI. (S-22,24)

Artificial intelligence (AI) is the ability of a computer or a robot controlled by a computer to do tasks thatare usually done by humans because they require human intelligence and discernment.

Q 2-Write different scope of AI.

- AI in Science and Research. AI is making lots of progress in the scientific sector. ...
- AI in Cyber Security. Cybersecurity is another field that's benefitting from AI. ...
- AI in Data Analysis. Data analysis can benefit largely from AI and ML. ...
- AI in Transport. ...
- AI in Home. ...
- AI in Healthcare.

Q 3- Define robotics.

Robotics, design, construction, and use of machines (robots) to perform tasks done traditionally byhuman beings Robots are widely used in such industries as automobile manufacture to perform simple repetitive tasks, and in industries where work must be performed in environments hazardous to humans.

Q 4 write different technique of AI.(S-22)

1. Machine Learning
2. NLP (Natural Language Processing)
3. Automation and Robotics
4. Machine Vision

Q 5-Define DFS.

Depth-first search (DFS) is an algorithm for traversing or searching tree or graph data structures. The algorithm starts at the root node (selecting some arbitrary node as the root node in the case of a graph)and explores as far as possible along each branch before backtracking.

Q 6- Define BFS.

Breadth-first search (BFS) is an algorithm for traversing or searching tree or graph data structures. It starts at the tree root (or some arbitrary node of a graph, sometimes referred to as a 'search key'[1]), and explores all of the neighbor nodes at the present depth prior to moving on to the nodes at the next depth level.

Q 7-Define heuristic search.

A Heuristic is a technique to solve a problem faster than classic methods, or to find an approximate solution when classic methods cannot. This is a kind of a shortcut as we often trade one of optimality, completeness, accuracy, or precision for speed.

Q 8-Define Best first search.

A search is the most commonly known form of best-first search. It uses heuristic function h(n), and costto reach the node n from the start state g(n). It has combined features of UCS and greedy best-first search, by which it solves the problem efficiently.

Q 9-Define Hill climbing technique.(S-23)

Hill Climbing Algorithm in Artificial Intelligence. Hill climbing algorithm is a local search algorithm which continuously moves in the direction of increasing elevation/value to find the peakof the mountain or best solution to the problemHill Climbing is mostly used when a good heuristic is available.

Q 10-Define predicate logic.

In logic and philosophy, predicate logic is a system of mathematical logic. It uses predicates to express the state of certain things, which are "incomplete propositions" with a placeholder for objects or subjectsthat must be inserted in order to obtain a valid proposition.

Q 11-Define semantic nets.

A semantic network is used when one has knowledge that is best understood as a set of concepts that are related to one another. Most semantic networks are cognitively based. They also consist of arcsand nodes which can be organized into a taxonomic hierarchy.

Q 12- Define slots.(S-23)

A slot is a narrow opening in a machine or container, for example, a hole that you put coins in to make a machine work. He dropped a coin into the slot and dialed. Synonyms: opening, hole, groove, vent More Synonyms of slot. 2. transitive verb/intransitive verb.

Q 13-Define default frames.

Vision draws a line between the first natural join (columns with the same name, data type and length)shared by the tables you cannot display these columns as fields on the form, because they are duplicates of the same columns in the Master table.

Q14-Define genetic algorithm.

A genetic algorithm (GA) is a method for solving both constrained and unconstrained optimization problems based on a natural selection process that mimics biological evolution.

Q 15-Define Game Thory in AI.(S-22)

It is a branch of Mathematics used to model the strategic interaction between different players in a context with predefined rules and outcomes. It can be applied in different ambit of AI. (S-22)

POSSIBLE TYPE LONG QUESTIONS

1- Explain scope of AI in details seaech strategies in AI. (S-22)
2- Explain about theorem proving technique.
3- Explain DFS and BFS briefly and differianciate between them.(S-22, 24)
4- Explain the hill climbing technique and best first search technique.
5- Explain knowledge representation in AI.
6- Explain about predicate logic with algorithm.(S-23)
7- Give a brief explanation of Pick and Place work cycle. (S-24)
8- What is Heuristic Search ? Classify and write the algorithm of Hill Climbing.(S-24)

CHAPTER NO. - 02
INTRODUCTION TO ROBOTICS

<u>Learning Objectives:</u>

2.1Types and components of a robot, Classification of robots, Closed-loop and open- loop control systems.

2.2 Kinematics systems; Definition of mechanisms and manipulators examples. Social issues and safety.

2.3-Robot Anatomy- Links -Joints and joints Notation Scheme -Degrees of Freedom (DOF) Required DOF in a Manipulator-Arm Configuration -Wrist Configuration-The End- Effector.

2.4-Sensors and Vision

2.1 Types and components of a robot, Classification of robots, Closed-loop and open- loop control systems

Types and components of a robot:

Manipulator:

- Just like the human arm, the robot consists of what is called a manipulator having several joints andlinks.

End effector:

- The base of the manipulator is fixed to base support and at its other free end, the End effector is attached. The End effector is expected to perform tasks normally performed by the palm and finger arrangements of the human arm.

The Locomotion Device:

- In the case of Human Beings, the power for the movement of the arm, the palm and fingers is provided bymuscles. For the robot the power for the movement (locomotion) is provided by the motors.
- The motors used for providing locomotion in robots are of three types depending on the source of energy: Electric, Hydraulic or Pneumatic.

The Controller:

- The digital computer (both the hardware and the software) acts as a controller to the robot.
- The controller functions in a manner analogous to the human brain.
- With the help of this controller, the robot is able to carry out the assigned tasks.
- The controller directs and controls the movement of the Manipulator and the End effector. In other words, the controller controls the robot.

The Sensors:

- Without the data supplied by the sense organs, the brain would be incapable of intelligence.
- In other words, the controller (the computer) of the robot cannot do any meaningful task, if the robot is not with acomponent analogous to the sense organs of the human body.
- Sensors are nothing but measuring instruments which measures quantities such as position, velocity, force, torque, proximity, temperature, etc.

Classification of robot:

- The robot is a computer programmable machine that can carry out complex actions automatically. It canbe guided and controlled either by an external control device or by the controller embedded within the machine.
- The classification of robots can be done on various criteria such as their power source, size of the robot, type of drive system used etc.

Classification of robots based on the power source

- On the basis of the power source, the robots can be classified into 5 major divisions namely electrical,hydraulic, pneumatic, nuclear, and green.

Electrical power source

- Robots operating with the electrical power source can further be sub divided as AC or DC systems.
- Direct current systems usually provide greater torque but they often require more maintenance for the motors.
- DC systems are common for the hobby robotics world as those systems are usually mobile, battery- powered robots.
- AC powered robots are common in industries and these often use Servo motors. Stepper motors are also used for these systems.

Hydraulic Power Source

- Hydraulic power generates a large amount of force and it is used for heavy loads in robotics.
- The system uses some other form of energy for generating hydraulic pressure.
- The robot uses this hydraulic force for performing its tasks.
- Hydraulic robots have some drawbacks such as-as a hydraulic leak, fire hazard, increased noise, increased maintenance and the cost of oil.

Pneumatic Power Source

- Pneumatic robots are powered by compressed air or compressed inert gases.
- These are used for highspeed and high load carrying capabilities.
- These systems are very fast and the industries use them as a ready supply of cheap pneumatic pressure. However, the biggest problem with these robots is the difficulty in maintaining their position. This is due to the fact that gas is compressible, and stopping it mid stroke leads to drifting.

Nuclear Power Source

- Nuclear-powered robots used their own nuclear reactor that is smaller than the nuclear reactors of nuclearpower plants or submarines.
- Nuclear powered robots are used by space agencies such as NASA for deep space exploration.
- Nuclear powered robots run for years and decades without the need for human interaction which makesthem perfect fit for the space missions.

Green Power Source

- Green Power source refers to a wide variety of power sources that have the commonality of easy replacement without any negative ecological impact.
- The potential green power sources for powering the robots include solar power, wind power, organicsources, natural heat sources etc.

Closed loop control system

- The behavior of the system can be determined with the help of a differential equation is known as the control system.
- So it controls different devices as well as systems with the help of control loops.
- Control systems are classified into two types like open loop and closed loop.

Open Loop Control System

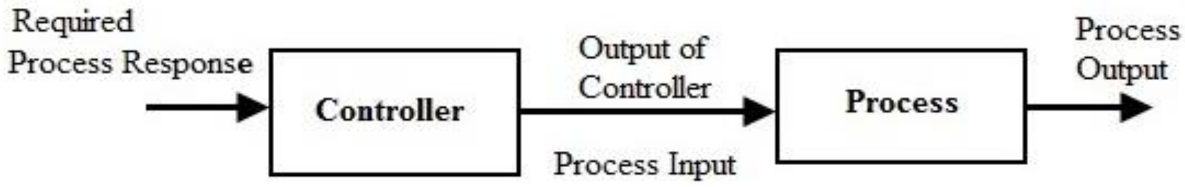
- In this kind of control system, the output doesn't change the action of the control system otherwise; the working of the system which depends on time is also called the open-loop control system.
- It doesn't haveany feedback. It is very simple, needs low maintenance, quick operation, and cost-effective.
- The accuracy of this system is low and less dependable.
- The example of the open-loop type is shown below.

Advantages

- The open-loop control system is easy, needs less protection; operation of this system is fast & inexpensive.

Disadvantages

- It is reliable and has less accuracy.

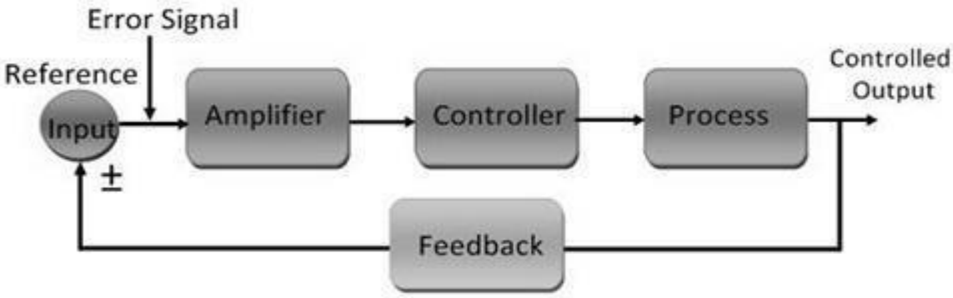


Example

- The clothes dryer is one of the examples of the open-loop control system.
- In this, the control action can be done physically through the operator.
- Based on the clothing's wetness, the operator will fix the timer to 30 minutes. So after that, the timer will discontinue even after the machine clothes are wet.
- The dryer in the machine will stop functioning even if the preferred output is not attained.
- This displays that the control system doesn't feedback.
- In this system, the controller of the system is the timer.

Closed-Loop Control System

- The closed-loop control system can be defined as the output of the system that depends on the input ofthe system.
- This control system has one or more feedback loops among its input & output.



- The main advantages of the closed-loop control system are accurate, expensive, reliable, and requireshigh maintenance.

Example

- The best example of the closed-loop control system is AC or air conditioner.
- The AC controls the temperature by evaluating it with the nearby temperature.
- The evaluation of temperature can be done through the thermostat.
- Once the air conditioner gives the error signal is the main difference between the room and the surrounding temperature. So the thermostat will control the compressor.
- These systems are accurate, expensive, reliable, and requires high maintenance.

2.2-Kinematics systems; Definition of mechanisms and manipulators, social issues safety

Kinematics systems-

- Robot kinematics studies the relationship between the dimensions and connectivity of kinematic chains and the position, velocity and acceleration of each of the links in the robotic system.
- The relationship between mass and inertia properties, motion, and the associated forces and torques is studied as part of robot dynamics.

Forward kinematics

- Forward kinematics specifies the joint parameters and computes the configuration of the chain.
- For serialmanipulators this is achieved by direct substitution of the joint parameters into the forward kinematics equations for the serial chain..

Inverse kinematics

Robot Jacobian

- The time derivative of the kinematics equations yields the Jacobian of the robot, which relates the joint rates to the linear and angular velocity of the end-effector.
- The principle of virtual work shows that the Jacobian also provides a relationship between joint torques and the resultant force and torque applied bythe end-effector.

Velocity kinematics

- The robot Jacobian results in a set of linear equations that relate the joint rates to the six-vector formed from the angular and linear velocity of the end-effector, known as a twist.
- Specifying the joint rates yields the end-effector twist directly.
- The inverse velocity problem seeks the joint rates that provide a specified end-effector twist. This is solved by inverting the Jacobian matrix.

Definition of mechanism and manipulator Mechanism

- An assembly of moving parts performing a complete functional motion, often being part of a largemachine; linkage.
- The structure or arrangement of parts of a machine or similar device, or of anything analogous.

Manipulator

- In robotics, a manipulator is a device used to manipulate materials without direct physical contact by the operator.
- The applications were originally for dealing with radioactive or biohazardous materials, using robotic arms,
- It is an arm-like mechanism that consists of a series of segments, usually sliding or jointed called cross- slides, which grasp and move objects with a number of degrees of freedom.

Social Issue and safety

Legislation

- Human societies are regulated by bodies of legislation.
- While remaining within the academic realm, AI and ML developments have stayed fairly oblivious to legal concerns, but the moment these technologies start occupying the social space at large, their impact on people is likely to hit a few legal walls.

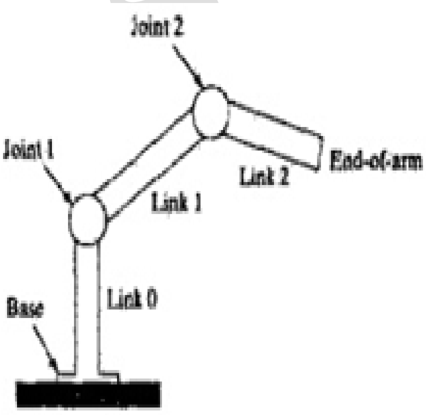
Privacy and Anonymity

- Technological advances and the widespread adoption of networked computing and telecommunication systems are flooding our societies with data.
- The physical society bonds are being swiftly amplified by our use of virtual social networks.

2.3-Robot Anatomy- Links -Joints and joints Notation Scheme -Degrees of Freedom (DOF) Required DOF in a Manipulator-Arm Configuration -Wrist Configuration-The End- Effector.

Robert Anatomy-

The anatomy of robot is also known as structure of robot.



- The Anatomy of Industrial Robots deals with the assembling of outer components of a robot such as wrist, arm, and body.
- Before jumping into Robot Configurations, here are some of the key facts about robot anatomy.

Links or End Effectors:

- A hand of a robot is considered as end effectors. The grippers and tools are the two significant types of end effectors. The grippers are used to pick and place an object, while the tools areused to carry out operations like spray painting, spot welding, etc. on a work piece.

Robot Joints:

- The joints in an industrial robot are helpful to perform sliding and rotating movements ofa component.

Manipulator:

- The manipulators in a robot are developed by the integration of links and joints. In the body and arm, it is applied for moving the tools in the work volume. It is also used in the wrist to adjustthe tools.

Kinematics:

- It concerns with the assembling of robot links and joints. It is also used to illustrate therobot motions.

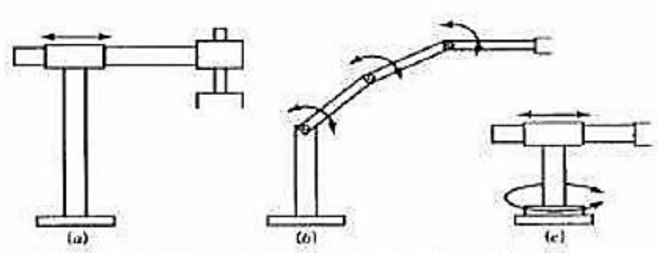
Joint Notation Scheme

- A robot joint is a mechanism that permits relative movement between parts of a robot arm. The joints of a robot are designed to enable the robot to move its end-effector along a path from one position to another as desired.
- The basic movements required for a desired motion of most industrial robots are:

1. Rotational movement: This enables the robot to place its arm in any direction on a horizontal plane.
2. Radial movement: This enables the robot to move its end-effector radially to reach distant points.
3. Vertical movement: This enables the robot to take its end-effector to different heights.
4. These degrees of freedom, independently or in combination with others, define the complete motion of the end-effectors.

- Prismatic joints are also known as sliding as well as linear joints. They are called prismatic because the cross section of the joint is considered as a generalized prism. They permit links to move in a linear relationship.
- Revolute joints permit only angular motion between links. Their variations include:
  Rotational joint (R)
  Twisting joint (T)
  Revolving joint (V)
- In a prismatic joint, also known as a sliding or linear joint (L), the links are generally parallel to one another. In some cases, adjoining links are perpendicular but one link slides at the end of the other link.
- A rotational joint (R) is identified by its motion, rotation about an axis perpendicular to the adjoining links. Here, the lengths of adjoining links do not change but the relative position of the links with respect to one another changes as the rotation takes place.
- A twisting joint (T) is also a rotational joint, where the rotation takes place about an axis that is parallel to both adjoining links.
- A revolving joint (V) is another rotational joint, where the rotation takes place about an axis that is parallel to one of the adjoining links. Usually, the links are aligned perpendicular to one another at this kind of joint. The rotation involves revolution of one link about another.

The Joint Notation:



Robot configurations: (a) LL Robot, (b) RRR robot, (c) TL robot

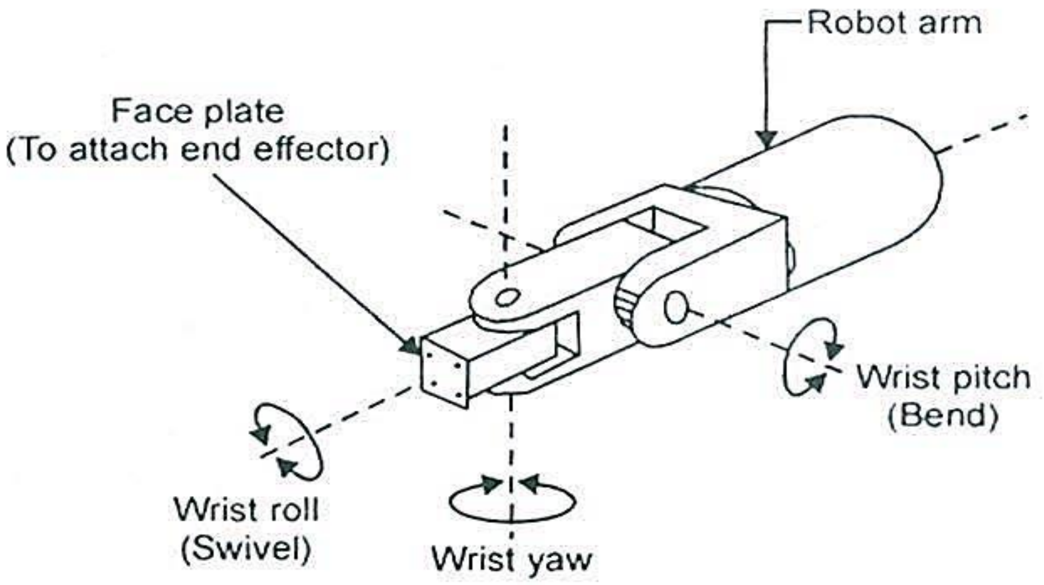
Degree of freedoms (DOF) Required DOF in a Manipulator-

- ➢ In physics, the degrees of freedom (DOF) of a mechanical system is the number of independent parameters that define its configuration or state.
- ➢ It is important in the analysis of systems of bodies in mechanical engineering, structural engineering, aerospace engineering, robotics, and other fields.
- ➢ The position of a single rail car (engine) moving along a track has one degree of freedom because the position of the car is defined by the distance along the track.

Six degrees of freedom (6 DOF)

- Moving up and down (elevating/heaving);
- Moving left and right (strafing/swaying);
- Moving forward and backward (walking/surging);
- Swivels left and right (yawing);
- Tilts forward and backward (pitching);
- Pivots side to side (rolling

Wrist configuration-



Roll-

- ➢ This is also called wrist swivel; this involves rotation of the wrist mechanism about the arm axis.

Pitch-

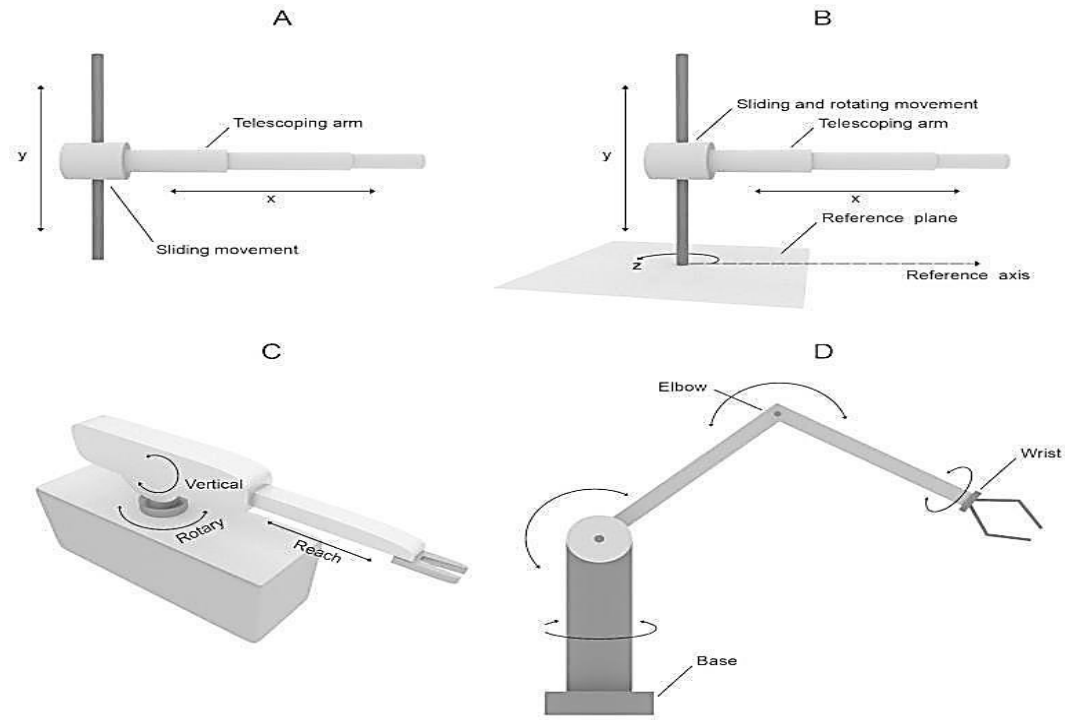
- ➢ It involves up & down rotation of the wrist. This is also called as wrist bend.

Yaw-

- ➢ It involves right or left rotation of the wrist.

Robot Arm Configurations-

- A robotic arm is a type of mechanical arm, usually programmable, with similar functions to a human arm.
- The links of such a manipulator are connected by joints allowing either rotational motion or translation displacement.
- The joints in these machines can be given names like “shoulder”, “elbow”, and “wrist”.
- A robot arm can be categorized according to its geometry. Identify and briefly discuss the fourt types of robot arm configurations illustrated in the figure.



A-Cartesian Configuration
- The arm movement of a robot using the Cartesian configuration can be described by three intersecting perpendicular straight lines, referred to as the X, Y, and Z axes.
- One advantage of robots with a Cartesian configuration is that their totally linear movement allows for simpler controls.
- They also have a high degree of mechanical rigidity, accuracy, and repeatability

B-Cylindrical Configuration
- A cylindrical configuration consists of two orthogonal slides, placed at a 90° angle, mounted on a rotary axis.
- A cylindrical configuration generally results in a larger work envelope than a Cartesian configuration.
- These robots are ideally suited for pick-and-place operations.
- Typical applications for cylindrical configurations include the following: machine loading and unloading, investment casting

C-Spherical (Polar) Configuration
- The spherical configuration, sometimes referred to as the polar configuration, resembles the action of the turret on a military tank. T
- he spherical configuration generally provides a larger work envelope than the Cartesian or cylindrical configurations.
- The design is simple and provides good weight lifting capabilities.

D-Revolute (Articulated) Configuration
- The revolute configuration, or jointed-arm, is the most common.
- These robots are often referred to as anthropomorphic because their movements closely resemble those of the human body.
- It also offers a more flexible reach than the other configurations, making it ideally suited to welding and spray paintingoperations.

The End effector-
- In robotics, an end effector is a device or tool that's connected to the end of a robot arm where the

hand would be.

- The end effector is the part of the robot that interacts with the environment.
- The structure of anend effector and the nature of the programming and hardware that drives it depend on the task the robot will be performing.
- If a robot needs to pick something up, a type of robot hand called a gripper is the most functional end effector.
- If a robot needs to be able to tighten screws,however, then the robot must be fitted with an end effector that can spin.

End effectors used in manufacturing include:

- anti-collision sensors
- brushes
- cameras
- cutting tools
- drills
- grippers
- magnets
- sanders
- screw drivers
- spray guns
- vacuum cups

2.4-Sensor and Vision

- Vision sensors use images captured by a camera to determine presence, orientation, and accuracy of parts.
- These sensors differ from image inspection "systems" in that the camera, light, and controller arecontained in a single unit, which makes the unit's construction and operation simple.
- There are differences between these sensors and other general-purpose sensors.
- For example, multi-point inspections can be done with a single sensor.

POSSIBLE SHORT TYPE QUESTIONS WITH ANSWER

1-Define open loop and closed loop control system.

Ans: Closed loop control system

- The behavior of the system can be determined with the help of a differential equation is known as the control system.
- So it controls different devices as well as systems with the help of control loops.
- Control systems are classified into two types like open loop and closed loop.

Open Loop Control System

- In this kind of control system, the output doesn't change the action of the control system otherwise; the working of the system which depends on time is also called the open-loop control system.

2-Write two types of Robert and define it.

Ans: 1. Industrial Robots

This kind of robot mainly deploying in industries for manufacturing. There are different kinds of industrial robots available.

2. Collaborative Robots

These are one of the popular sub-categories of industrial robots. Cobots are designed to work with people not to replace people.

3-Define Manipulator.(S-23)

Ans: Manipulator:

- The manipulators in a robot are developed by the integration of links and joints. In the body and arm, it is applied for moving the tools in the work volume. It is also used in the wrist to adjustthe tools.

4-Define Velocity Kinematics.

Ans: Velocity kinematics

- The robot Jacobian results in a set of linear equations that relate the joint rates to the six-vector formed from the angular and linear velocity of the end-effector, known as a twist.
- Specifying the joint rates yields the end-effector twist directly.

5-What is Robot Anatomy? (S-22)

Ans: Robot Anatomy deals with the study of different joints and link and other. A Robotic joints provides relative motion between two links of the Robot. Each joint or axis provides a certain degree of freedom of motion. The Anatomy of Robot is also known as Structure of Robot.

6-What is Work Envelope? (S-22)

Ans- It is its range of movement. It is the shape created when a manipulator reaches forward, backward, up and down. These distances are determined by the length of a robot’s arm and the design of its axes.

POSSIBLE LONG TYPE QUESTIONS

1-Define Classification of Robert based on the Power source.

2-Explain Robert Anatomy and DOF required in a Manipulator.(S-23)

3-Define End-effector and Explain End-effector used in manufacturing Industries.

4-Show the various joints used in Industrial Serial Manipulator and explain.(S-22,24)

5-Classify optical encoders and explain the working of various optical encoders.(S-24)

6- Explain different applications of Robot. (S-22)

CHAPTER-3
Coordinate frames, mapping and transforms

Learning objectives

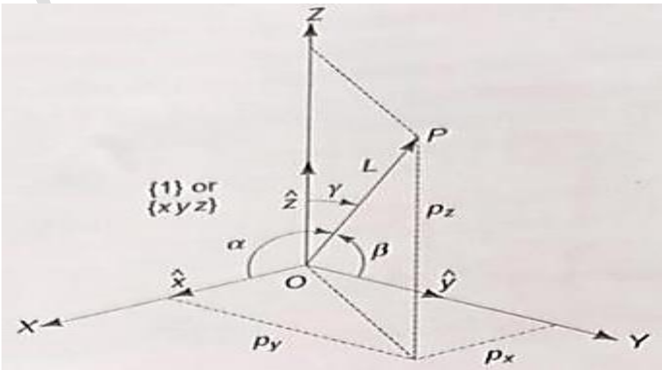
3.1-Coordinate frames, mapping, and transforms. Coordinate Frames –Mapping between Rotated Frames -Mapping between Translated Frames Mapping between Rotated and Translated Frames.

3.2Fundamental Rotation, Principal Axe Rotation, Fixed Angel Representation Euler Angle Representations, Equivalent Angle Axis Representation.

3.1 Coordinate frames, mapping, and transforms. Coordinate Frames-Mapping between Rotated Frames -Mapping between Translated Frames Mapping between Rotated and Translated Frames.

Coordinate frames –

- In a 3-D space, a c0ordinate frame is set of three orthogonal right-handed axes, Y,Z called principal axes. Such a frame shown in figure with the origin of the principal axes at o along with the unit vector { x, y, z } along t5he axes. This frameis labelled as {x y z} or by a number as {1} using a numbering scheme.
- A point P in a 3-d space can be defend with respect to this coordinate frame by vector OP (a directed line from origin O to point P pointing towards p).
- In vector notation Second frame is rotated with respect to the first, the origin of both the frame issame. In robotics, this is referred as changing the orientation
- The second frame is moved away from the first the axes of both frames remain parallel respectively. This is the translation of the origin of the second frame from the first frame in space.
- Second frame is rotating with respect to the first and moved away from it thatis the second frame is translated and it is orientation is also changed.
- This situation are modelled and it is important to note that mapping changes the description of the point and not the point itself.



{Position and orientation of a point *P* in a coordinate frame}

where p_x, p_y, p_z are the components of the vector $\overrightarrow{OP}$ along the three coordinate axes or the projections of the vector $\overrightarrow{OP}$ on the axes X, Y, Z, respectively. A frame-space notation is introduced as ${}^{P}\boldsymbol{P}$ to refer to the point P (or vector $\overrightarrow{OP}$) with respect to frame {1} with its components in the frame as $p_x p^1 p_y$, and $^1p_2$, that is,

$$^1P = {}^1p_x\hat{x} + {}^1p_y\hat{y} + {}^1p_z\hat{z}$$

- Observe that the leading superscript refers to the coordinate frame number (frame {1} in this case) and $[\boldsymbol{A}]^T$ indicates the transpose of matrix $\boldsymbol{A}$. In addition, the direction of the position vector $\overrightarrow{OP}$ can be expressed by the direction cosines:

$$\cos\alpha = \frac{^1p_x}{L}, \cos\beta = \frac{^1p_y}{L}, \cos\gamma = \frac{^1p_z}{L}$$
$$L = |\overrightarrow{\boldsymbol{P}}| = |\overrightarrow{OP}| = \sqrt{(^1p_x)^2 + \left(^1p_y\right)^2 + (^1p_z)^2}$$

- where α, β, and γ are, respectively, the right-handed angles measured from the coordinate axes to the vector $\overrightarrow{\boldsymbol{OP}}$, which has a length L.

Mapping

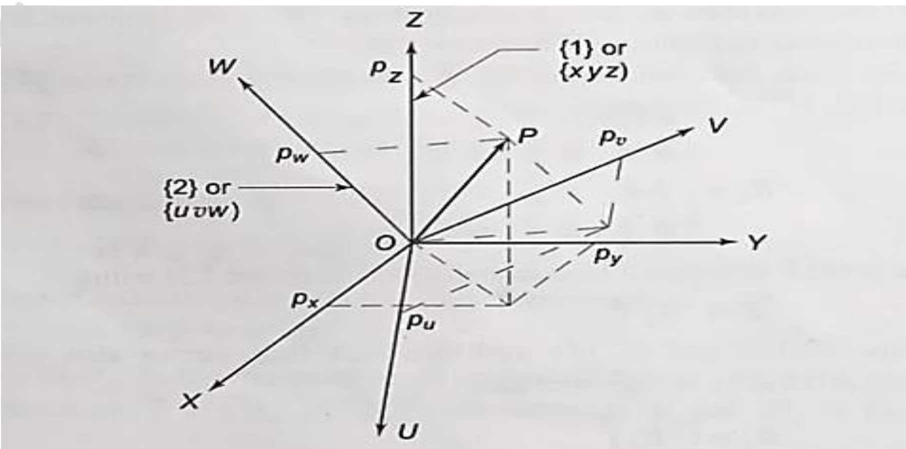
- Mappings refer to changing the description of a point (or vector) in space from one frame to another frame. The second frame has three possibilities in relation to the first frame.

Coordinate frames –Mapping between rotated frame.

(a) Second frame is rotated with respect to the first; the origin of both the frames is same. In robotics, this is referred as changing the orientation.
(b) Second frame is moved away from the first, the axes of both frames remain parallel, respectively. This is a translation of the origin of the second frame from the first frame in space.
(c) Second frame is rotated with respect to the first and moved away from it, that is, the second frame is translated and its orientation is also changed. These situations are modelled in the following sections. It is important to note that mapping changes the description of the point and not the point itself.
Mapping between Rotated Frames
Consider two frames, frame {1} with axes X, Y, Z, and frame {2} with axes U, V, W with a common origin, as shown in Fig. 2.2. A point P in space can be described by the two frames and can be expressed as vectors $^1\boldsymbol{P}$ and $^2\boldsymbol{P}$,

$$^1\boldsymbol{P} = {}^1p_x\hat{\boldsymbol{x}} + {}^1p_y\hat{\boldsymbol{y}} + {}^1p_z\hat{z}$$
$$^2\boldsymbol{P} = {}^2p_u\hat{u} + {}^2p_v\hat{v} + {}^2p_w\hat{w}$$

- where ^2p_u, ^2p_v, ^2p_w are projections of point P on frame {2} or $\{uvw\}$ (the U, V, W coordinates). Because the point P is same, its two descriptions given by Eqs. and are related.



- Now, let the problem be posed as, "The description of point P in frame {2} is known and its description in frame {1} is to be found (or vice-versa)." This is accomplished by projecting the vector ${}^2P$ on to the coordinates of frame {1}. Projections of ${}^2\boldsymbol{P}$ on frame {1} are obtained by taking the dot product of ${}^2\boldsymbol{P}$ with the unit vectors of frame {1}. Thus, substituting for ${}^2P$ from Eq. give,

$$
\begin{aligned}
{}^1p_x &= \hat{x}\cdot{}^2\boldsymbol{P} = \hat{\boldsymbol{x}}\cdot{}^2p_u\hat{u} + \hat{\boldsymbol{x}}\cdot{}^2p_v\hat{v} + \hat{\boldsymbol{x}}\cdot{}^2p_w w \\
{}^1p_y &= \hat{y}\cdot{}^2\boldsymbol{P} = \hat{\boldsymbol{y}}\cdot{}^2p_u\hat{u} + \hat{\boldsymbol{y}}\cdot{}^2p_v\hat{v} + \hat{y}\cdot{}^2p_w\hat{w} \\
{}^1p_z &= \hat{z}\cdot{}^2\boldsymbol{P} = \hat{z}\cdot{}^2p_u\hat{u} + \hat{z}\cdot{}^2p_v\hat{v} + \hat{z}\cdot{}^2p_w\hat{w}
\end{aligned}
$$

- This can be written in matrix form as

$$
\begin{bmatrix} {}^1p_x \\ {}^1p_y \\ {}^1p_z \end{bmatrix} = \begin{bmatrix} \hat{x}\cdot\hat{u} & \hat{x}\cdot\hat{v} & \hat{x}\cdot\hat{w} \\ \hat{y}\cdot\hat{u} & \hat{y}\cdot\hat{v} & \hat{y}\cdot\hat{w} \\ \hat{z}\cdot\hat{u} & \hat{z}\cdot\hat{v} & \hat{z}\cdot\hat{w} \end{bmatrix} \begin{bmatrix} 2 \\ {}^2p_x \\ {}^2p_y \\ {}^2p_z \end{bmatrix}
$$

- In compressed vector-matrix notation Eq. (2.8) is written as

$$ {}^1P = {}^1R_2\,{}^2P $$

where

$$
{}^1R_2 = \begin{bmatrix} \hat{x}\cdot\hat{u} & \hat{x}\cdot\hat{v} & \hat{x}\cdot\hat{w} \\ \hat{y}\cdot\hat{u} & \hat{y}\cdot\hat{v} & \hat{y}\cdot\hat{w} \\ \hat{z}\cdot\hat{u} & \hat{z}\cdot\hat{v} & \hat{z}\cdot\hat{w} \end{bmatrix}
$$

- Because frames {1} and {2} have the same origin, they can only be rotated with respect to each other, therefore, $\boldsymbol{R}$ is called a rotation matrix or rotational transformation matrix. It contains only the dot products of unit vectors of the two frames and is independent of the point P.
- Thus, rotation matrix ${}^1R_2$ can be used for transformation of the coordinates of any point P in frame {2} (which has been rotated with respect to frame {1}) to frame {1}.
- On similar lines, the rotation matrix ${}^2R_1$, which expresses frame {1} as seen from frame {2}, is established as
- Hence, a point P in frame {1} is transformed
  Hence, a point P in frame {1} is transformed to frame {2} using

$$ {}^2P = {}^2R_1\,{}^1P $$

- The fact that vector dot product is commutative, it is easily recognized that

$$ {}^2R_1 = [\,{}^1R_2]^T $$

- ${}^2\boldsymbol{P}$ is expressed as

$$ {}^2P = [\,{}^1R_2]^{-1}\,{}^1P = {}^2R_1\,{}^1P = [\,{}^1R_2]^T\,{}^1P $$

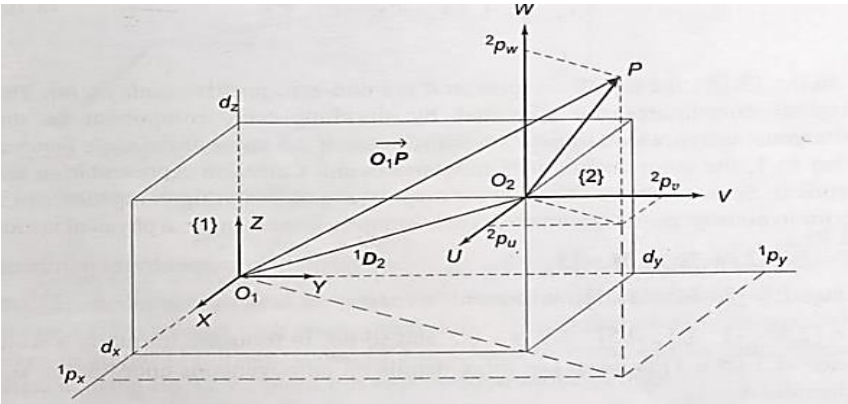
- Therefore, it is concluded that

$$ {}^2R_1 = [\,{}^1R_2]^{-1} = [\,{}^1R_2]^T $$

or, in general, for any rotational transformation matrix R.

Mapping between translated frame

Consider two frames, frame {1} and frame {2}, with origins O_1 and O_2 such that the axes of frame {1} are parallel to axes of frame {2}, as shown in Fig. 2.3. A point P in space can be expressed as vectors $\overrightarrow{\boldsymbol{O}_1\boldsymbol{P}}$ and $\overrightarrow{\boldsymbol{O}_2\boldsymbol{P}}$ with respect to the frames {1} and {2}, respectively.



- The two vectors are related as

$$\overrightarrow{\boldsymbol{O_1P}} = \overrightarrow{\boldsymbol{O_2P}} + \overrightarrow{\boldsymbol{O_1O_2}}$$

or in the notation introduced earlier Eq. becomes,

$$^1P = {}^2P + {}^1D_2$$

- where $^1D_2 = \overrightarrow{O_1O_2}$ is the translation of origin of frame {2} with respect to frame {1}. Because $^2P = [\,^2p_u\,^2p_v\,^2p_w]^T$, substituting ^2P and $^1D_2$ in Eq. (2.17) gives

$$^1\boldsymbol{P} = (\,^2p_u + d_x)\hat{x} + \left(\,^2p_v + d_y\right)\hat{y} + (\,^2p_w + d_z)\hat{z}$$

- As $^1P = {}^1p_x\hat{x} + {}^1p_y\hat{y} + {}^1p_z\hat{z}$, this gives
- $^1p_x = {}^2p_u + d_x$; $^1p_y = {}^2p_v + d_y$; $^1p_z = {}^2p_z + d_z$
Translation is qualitatively different from rotation in one important respect. In rotation, the origin of two coordinate frames is same. This invariance of the origin

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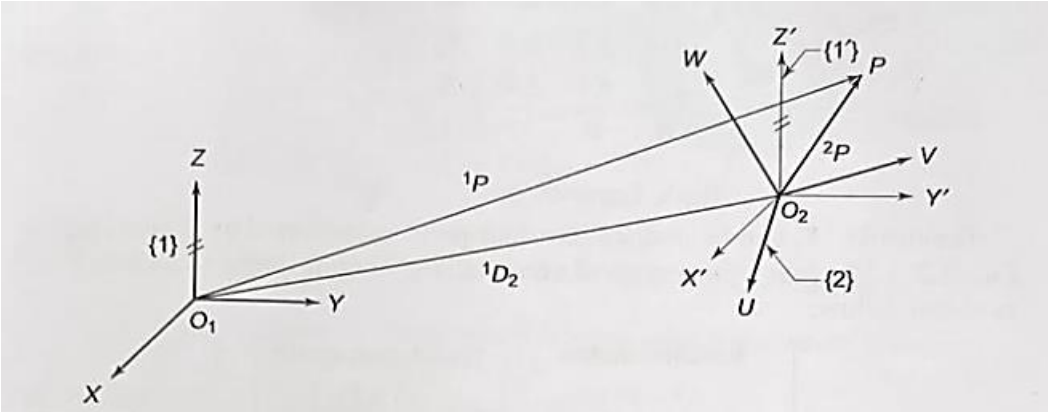
$$^1\boldsymbol{P} = (\,^2p_u + d_x)\hat{x} + \left(\,^2p_v + d_y\right)\hat{y} + (\,^2p_w + d_z)\hat{z}$$

- As $^1P = {}^1p_x\hat{x} + {}^1p_y\hat{y} + {}^1p_z\hat{z}$, this gives

$$^1p_x = {}^2p_u + d_x;\ ^1p_y = {}^2p_v + d_y;\ ^1p_z = {}^2p_z + d_z$$

- Translation is qualitatively different from rotation in one important respect. In rotation, the origin of two coordinate frames is same. This invariance of the origin.

Mapping between rotated and translated frame



$\overrightarrow{\boldsymbol{O_1P}} = \overrightarrow{\boldsymbol{O_2P}} + \overrightarrow{\boldsymbol{O_1O_2}}$

Vector $\overrightarrow{\boldsymbol{O_2P}}$ in frame {2} is ${}^{2}\boldsymbol{P}$; therefore, it must be transformed to frame {1}. First, consider an intermediate frame $\{1'\}$ with its origin coincident with O_2. The frame $\{1'\}$ is rotated with respect to frame {2} such that its axes are parallel to axes of frame {1}. Thus, frame $\{1'\}$ is related to frame {2} by pure rotation. Hence, using Eq. (2.9), point P is expressed in frame $\{1'\}$ as

${}'\boldsymbol{P} = {}^{1'}\boldsymbol{R}_2\,{}^{2}\boldsymbol{P}$ $\{1'\}$ is aligned with frame {1}, ${}^{1}\boldsymbol{R}_2 = {}^{1}\boldsymbol{R}_2$. Hence

- Because frame $\{1'\}$ is aligned with frame {1}, ${}^{1}\boldsymbol{R}_2 = {}^{1}\boldsymbol{R}_2$. Hence $\overrightarrow{\boldsymbol{O_2P}} = {}^{1}\boldsymbol{P} = {}^{1}\boldsymbol{R}_2\,{}^{2}\boldsymbol{P}$ $d_x d_y d_z)$ in frame {1}

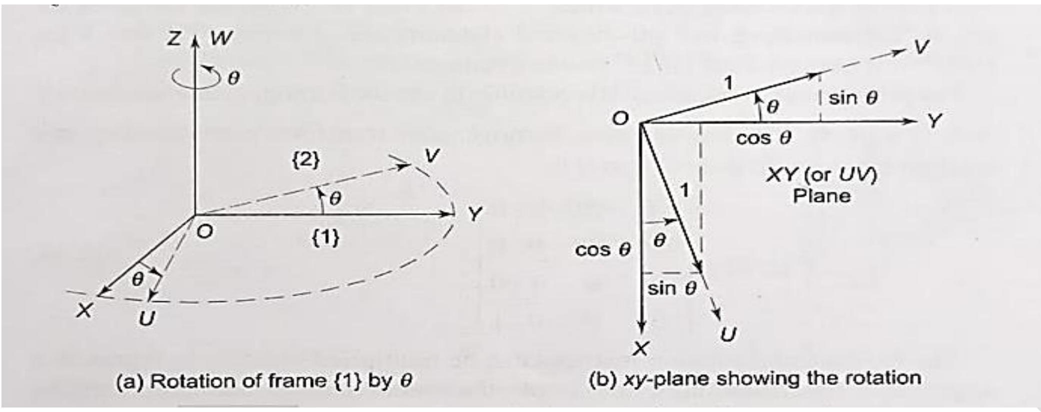
- Using the homogeneous coordinates, from (2.10) and (2.20), the two can be combined into a single 4×4 terms on the right-hand side of matrix, which is then written as ${}^{1}\boldsymbol{P} = {}^{1}\boldsymbol{T}_2\,{}^{2}\boldsymbol{P}$

- Here, ${}^{1}\boldsymbol{P}$ and ${}^{2}\boldsymbol{P}$ are 4×1 vectors as in Eq. (2.19) with a scale factor of 1 and $\boldsymbol{T}$ is 4×4 matrix referred to as the homogeneous transformation matrix (or homogeneous transform). It describes both the position and orientation of frame {2} with respect to frame {1} or any frame with respect to any other frame. The components of ${}^{1}\boldsymbol{T}_2$ matrix are as under

3.2-Fundamental Rotation, Principal Axe Rotation, Fixed Angel Representation Euler Angle Representations, Equivalent Angle Axis Representation.

Fundamental rotation-

- To determine the orientation of frame {2}, which is rotated about one of the three principal axes of frame {1}, consider, for example, the rotation of frame {2} with respect to frame {1} by angle θ about the z-axis of frame {1}, as shown in a $3 - D$ .The corresponding rotation matrix ${}^{1}R_2$, known as the fundamental rotation matrix, is denoted by the symbol $\boldsymbol{R}_z(\theta)$ or $\boldsymbol{R}(z, \theta)$ or $\boldsymbol{R}_{z,\theta}$.



(a) Rotation of frame {1} by θ (b) xy-plane showing the rotation

Or

$$R_z(\theta) = \begin{bmatrix} C\theta & -S\theta & 0 \\ S\theta & C\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

where $S\theta = \sin\theta$ and $C\theta = \cos\theta$.

- The fundamental rotation matrix for a rotation of angle θ about z-axis of the frame. Similarly, fundamental rotation matrices for rotation about x-axis and y-axis can be obtained and these are:

$$R_x(\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & C\theta & -S\theta \\ 0 & S\theta & C\theta \end{bmatrix}$$

$$\text{and } R_y(\theta) = \begin{bmatrix} C\theta & 0 & S\theta \\ 0 & 1 & 0 \\ -S\theta & 0 & C\theta \end{bmatrix}$$

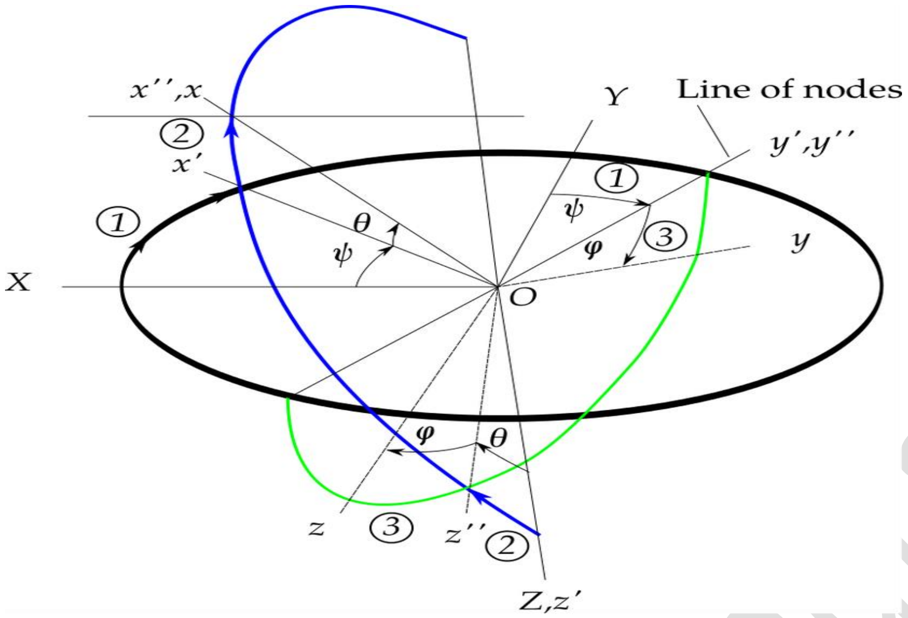
- The rotation matrices $\boldsymbol{R}_x, \boldsymbol{R}_y$, and $\boldsymbol{R}_z$ exhibit a pattern and using this pattern these matrices can be easily written. The rotation matrix for rotation about k^{th} principal axis $R_k(\theta)$ can be obtained as follows: The elements of i th row and i^{th} column for $i = 1,2$, or 3 for $k = x, y$, or z respectively, of 3×3 matrix $\boldsymbol{R}_k(\theta)$ are zero except the element (i, i), which is 1.

- The other two diagonal elements are $\cos\theta$. The remaining two off-diagonal elements are $\pm\sin\theta$, with $-\sin\theta$ for $(i+1)^{\text{th}}$ row and $\sin\theta$ for $(i+2)^{\text{th}}$ row in cyclic order.

- For principal axes rotations, it is possible to use the homogeneous transform T with $D = [0 \quad 0 \quad 0]^T$. For example, homogeneous transform corresponding to a rotation by an angle θ about z-axis is

$$T(z, \theta) = \begin{bmatrix} C\theta & -S\theta & 0 & 0 \\ S\theta & C\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Principal Axe Rotation-



- Let the fixed frame {1}(frame $\{xyz\}$) and moving frame {2} (frame $\{uvw\}$) be initially coincident. Consider the sequence of rotations about the three axes of fixed frame.
  (i) First, moving frame {2} is rotated by an angle θ_1 about x-axis to frame $\{2'\}$. This rotation is described by the rotation matrix $R_x(\theta_1)$.
  (ii) Next, the frame $\{2'\}$ is rotated by an angle θ_2 about y-axis to give frame $\{2''\}$.

- This rotation is described by the rotation matrix $R_y(\theta_2)$.
  (iii) Finally, it is rotated by an angle θ_3 about z-axis to frame {2} as in Fig. 2.14(c). This rotation is described by the rotation matrix $R_z(\theta_3)$.

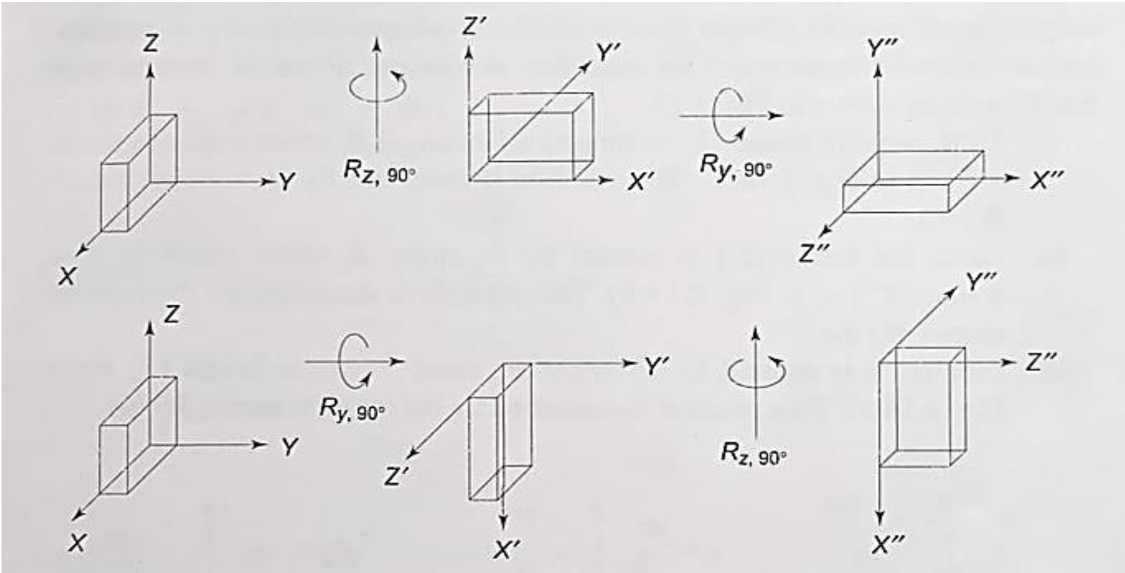
Fixed angel representation

Where $C_i = C\theta_i = \cos\theta_i$ and $S_i = S\theta_i = \sin\theta_i$.

- It is important to note the sequence of multiplication of R matrices. A different sequence may not give the same result and obviously will not correspond to same orientation of the rotated frame. This is because the matrix product is not commutative. In view of this, it can be concluded that two rotations in general do not result in same orientation and the resultant rotation matrix depends on the order of rotations.

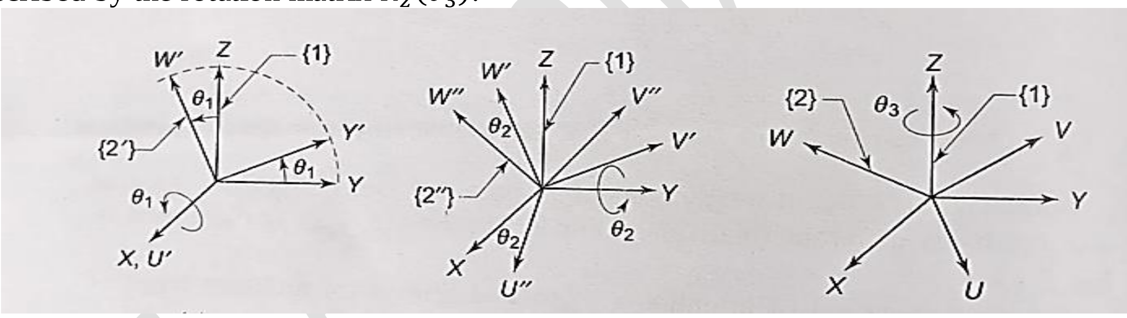
- Another significant variable is how the rotations are performed. There are two alternatives:
  (i) to perform successive rotations about the principal axes of the fixed frame.
  (ii) to perform successive rotations about the current principal axes of a moving frame.
  The successive rotations in either case, in general, do not produce identical results.

- The effect of two successive rotations of 90° to an object about the principal axes of the fixed frame. It is observed that the final orientation of the object is different when same two rotations are made but the order of rotations is changed.



- Let the fixed frame {1}(frame $\{xyz\}$) and moving frame {2} (frame $\{uvw\}$) be initially coincident. Consider the sequence of rotations about the three axes of fixed frame.
  (i) First, moving frame {2} is rotated by an angle θ_1 about x-axis to frame $\{2'\}$. This rotation is described by the rotation matrix $R_x(\theta_1)$.
  (ii) Next, the frame $\{2'\}$ is rotated by an angle θ_2 about y-axis to give frame $\{2''\}$.

- This rotation is described by the rotation matrix $R_y(\theta_2)$.
  (iii) Finally, it is rotated by an angle θ_3 about z-axis to frame {2} as in Fig. 2.14(c). This rotation is described by the rotation matrix $R_z(\theta_3)$.



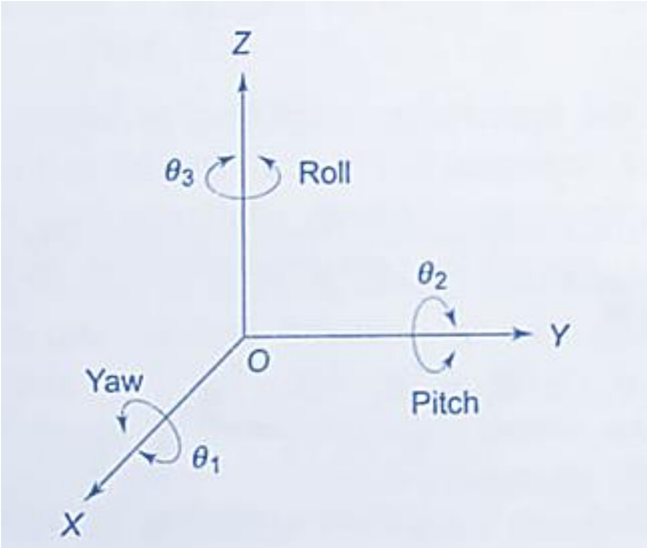
- The final frame orientation is obtained by composition of rotations with respect to the fixed frame and the overall rotation matrix ${}^1R_2$ is computed by premultiplication of the matrices of elementary rotations, that is,

$$\boldsymbol{R}_{xyz}(\theta_3\theta_2\theta_1) = {}^1\boldsymbol{R}_2 = \boldsymbol{R}_z(\theta_3)\boldsymbol{R}_y(\theta_2)\boldsymbol{R}_x(\theta_1) \text{(Rotation ordering right to left)}$$

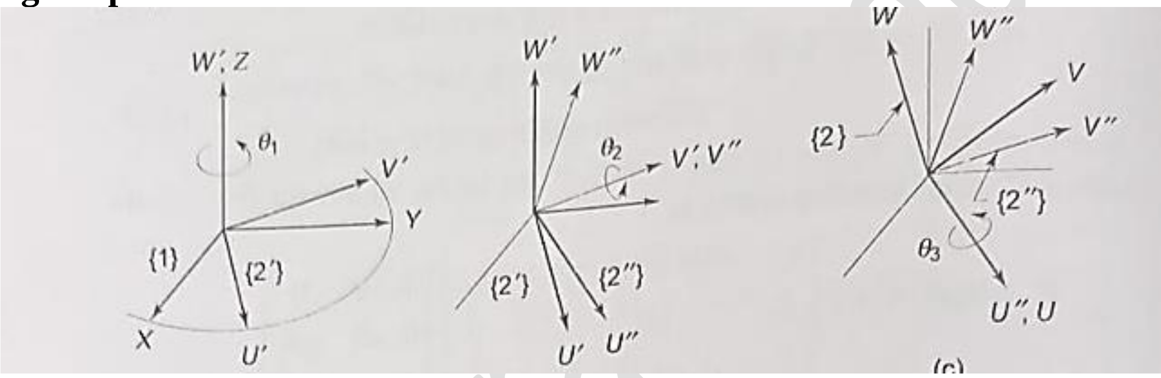
$$\boldsymbol{R}_{xyz}(\theta_3\theta_2\theta_1) = \begin{bmatrix} C_3 & -S_3 & 0 \\ S_3 & C_3 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C_2 & 0 & S_2 \\ 0 & 1 & 0 \\ -S_2 & 0 & C_2 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & C_1 & -S_1 \\ 0 & S_1 & C_1 \end{bmatrix}$$

$$\text{or } \boldsymbol{R}_{xyz}(\theta_3\theta_2\theta_1) = \begin{bmatrix} C_2C_3 & S_1S_2C_3 - C_1S_3 & C_1S_2C_3 + S_1S_3 \\ C_2S_3 & S_1S_2S_3 + C_1C_3 & C_1S_2S_3 - S_1C_3 \\ -S_2 & S_1C_2 & C_1C_2 \end{bmatrix}$$

- The final frame orientation for any set of rotations performed about the axes of the fixed frame (e.g. ZYX, ZXZ etc.) can be obtained by multiplying the rotation matrices in a consistent order as indicated in Eq. (2.59). In fixed angle representation, order of rotations XYZ or ZYX are equivalent, that is, $R_{xyz}(\theta_1\theta_2\theta_3) = R_{zyx}(\theta_1\theta_2\theta_3)$.



Euler angel representation-



(i) To begin with, frame $\{2\}$ is rotated by an angle θ_1 about its w-axis coincident with z-axis of frame $\{1\}$. The rotated frame is now $\{2'\}$ and the rotation is described by the rotation matrix $R_w(\theta_1)$.
(ii) Next, moving frame $\{2'\}$ is rotated by an angle θ_2 about v'-axis, the rotated v-axis to frame $\{2''\}$. This rotation is described by the rotation matrix $R_{v'}(\theta_2)$.
(iii) Finally, frame $\{2''\}$ is rotated by an angle θ_3 about its u''-axis, the rotated u-axis to give frame $\{2\}$. This rotation is described by the rotation $\boldsymbol{R}_{u''}(\theta_3)$.
This convention for specifying orientation is called WVU-Euler angle representation, viewing each of these rotations as descriptions of frames relative to each other, the equivalent rotation matrix is computed by post multiplication of the matrices of the elementary rotations as

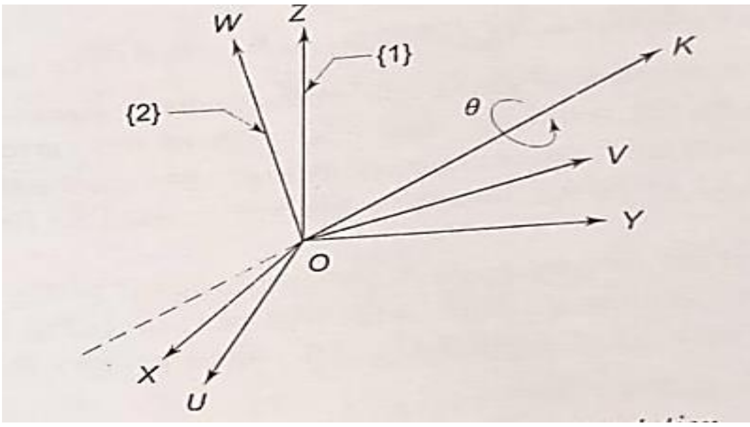
The rotations are performed ordering left to right)
The rotations are performed atout the current axes of the moving frame

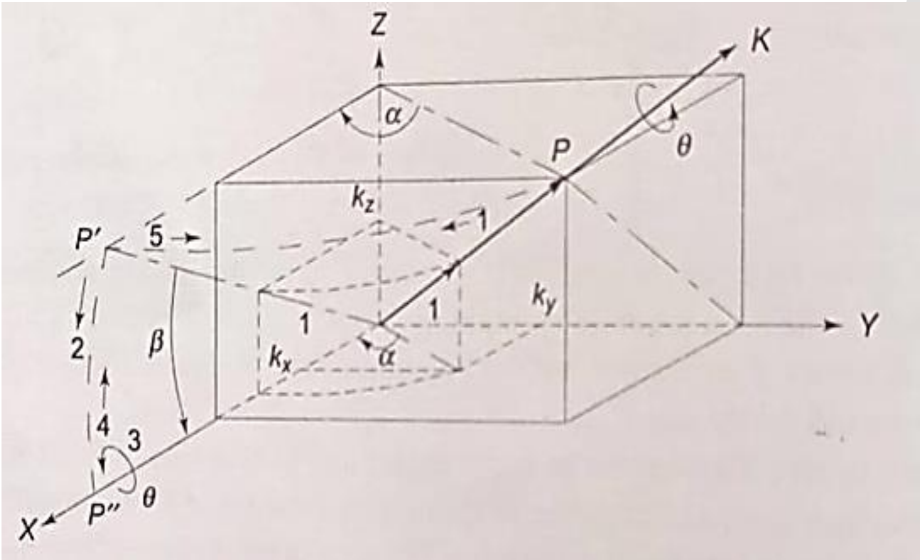
$$R_{\text{wou}}(\theta_1\theta_2\theta_3) = \begin{bmatrix} C_1 & -S_1 & 0 \\ S_1 & C_1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C_2 & 0 & S_2 \\ 0 & 1 & 0 \\ -S_2 & 0 & C_2 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & C_3 & -S_3 \\ 0 & S_3 & C_3 \end{bmatrix}$$

$\{uvw$

$$R_{wou}(\theta_1\theta_2\theta_3) = \begin{bmatrix} C_2C_3 & S_1S_2C_3 - C_1S_3 & C_1S_2C_3 + S_1S_3 \\ C_2S_3 & S_1S_2S_3 + C_1C_3 & C_1S_2S_3 - S_1C_3 \\ -S_2 & S_1C_2 & C_1C_2 \end{bmatrix}$$

Equivalents angel axis representation-





- First, rotate the vector $\boldsymbol{P}$ (along with axis k and frame $\{2\}$ of Fig. 2.17) by an angle $-\alpha$ about z-axis such that this rotation causes the axis k to lie in xz-plane of frame $\{1\}$. This rotation, marked as " 1" in Fig. 2.18 and is written as

$$^1R_2 = R_z(-\alpha)$$

- Next, vector $\boldsymbol{P}$ (along with rotated axis k) is rotated about y-axis by an angle β so that axis k aligns with x-axis, rotation " 2 ". At the end of this rotation,

$$^1R_2 = R_y(\beta)R_z(-\alpha)$$

- Now a rotation " 3 " of angle θ about the rotated axis k, which is rotation about x-axis, is made

POSSIBLE SHORT TYPE QUESTIONS WITH ANSWER

Q1- Define coordinate frames.

A coordinate frame in two-dimensional space is a set of two vectorshaving unit length and that make a right angle with one another.

The vectors are called the x-vector and the y-vector. (It is often just a matter of convenience which is x and which is y, as long as you don'tswitch in the middle of a problem.)

Q 2- Define mapping.

Mapping refers to changing the description of a point or vector in spacefrom one frame to another frame. The 2nd frame has three posibilities inrelation to the 1st frame. It is important to note that mapping changes the description of the point not the point itself.

Q3- Differentiate between Spatial and Redundant Manipulator. (S-24)

Spatial Manipulator- 1- It possesses less degree of freedom.

2- Atleast one of the links of the mechanism possesses a general spatial motion.

Redundant Manipulator- 1- It possesses more degree of freedom.

2- It is exploited to achieve more dextrons robotic motion.

Q 4- Define Euler angel representation.

The **Euler angles** are three angles introduced by Leonhard Euler to describe the orientation of a rigidbody with respect to a fixed coordinate system

They can also represent the orientation of a mobile frame of reference in physics or the orientation of a general basis in 3-dimensional linear algebra. Alternative forms were later introduced by Peter GuthrieTait and George H. Bryan intended for use in aeronautics and engineering.

Q 5-What is principial axe rotation.

A principal axis of rotation (or principal direction) is an eigenvector of the mass moment of inertia tensor (introduced in the previous section) defined relative to some point (typically the centerof mass). The corresponding eigenvalues are called the principal moments of inertia.

POSSIBLE LONG TYPE QUESTIONS

Q1-The coordinates of point P with respect to a moving coordinate frame are given as P=[0.5 0.8 1.3 1]^{T}.

Q2-What are the coordinates of P with respect to coordinate frame, if the moving frame is rotated by 90^0 about z axis of the fixed frame.(S-23)

Q3-Determine the rotation matrix for a rotation of 45^0 of y axis, followed byarotation 120^0 of z axis and final rotation of 90^0 about x axis.

Q4-Discuss about the Mapping between Rotated and Traslated Frame. (S-22,24)

Q5-Explain the Kinematic modelling of the Manipulator.(S-24)

CHAPTER NO.- 04:
ROBOT KINAMATICS AND DYNAMICS

Learning Objectives-

4.1- Kinematic Modelling: Mechanical Structure and Notations, Description of Links and Joints

4.2- Coordinate transformation, DH parameters, Jacobian, Singularity and Statics

4.3-Dynamic Modelling: Equations of motion: Euler-Lagrange formulation

4.4-The Inverse Kinematics-Manipulation Workspace - Solvability of Inverse Kinematic Model

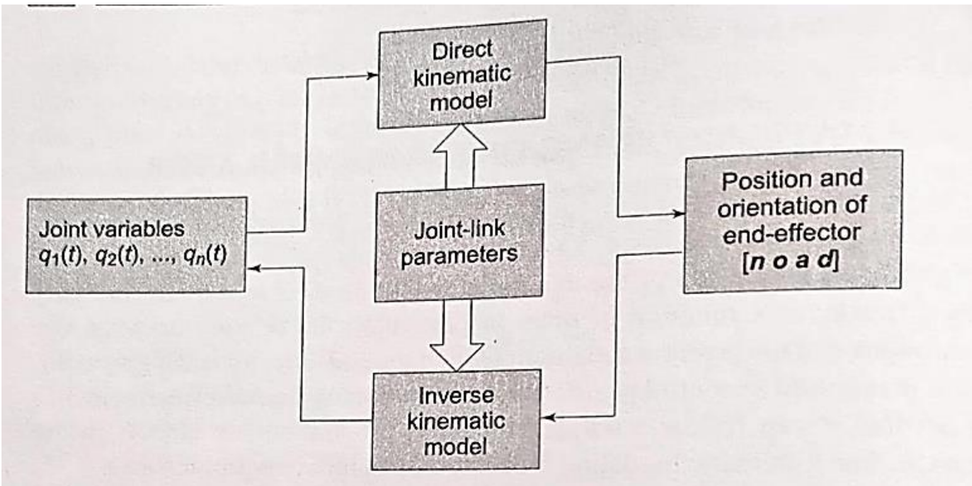
4.1. Kinematic Modelling: Mechanical Structure and Notations Description of Links and Joints

Kinematic modeling-

With the definition of fixed and variable kinematic parameters for each link, kinematic models can be defined. This model is the analytical description of the spatial geometry of motion of the manipulator with respect to a fixed (inertial) reference frame, as a function of time. In particular, the relation between the joint-variables and the position and orientation of the end-effector is the kinematic model. It is required to control position and orientation of the end-effector, in 3-D space, so that it can follow a defined trajectory or manipulate objects in the workspace. The kinematic modelling problem is split into two problems as:

1 Given the set of joint-link parameters, the problem of finding the position and orientation of the end-effector with respect to a known (immobile or inertial) reference frame for an n-DOF manipulator is the first problem. This is referred to as direct (or forward) kinematic model or direct kinematics. This model gives the position and orientation of the endeffector as a function of the joint variables and other joint-link constant parameters.

2 For a given position and orientation of the end-effector (of the n-DOF manipulator), with respect to an immobile or inertial reference frame, it is required to find a set of joint variables that would bring the end-effector in the specified position and orientation.
This is the second problem and is referred to as the inverse kinematic model or inverse kinematics.

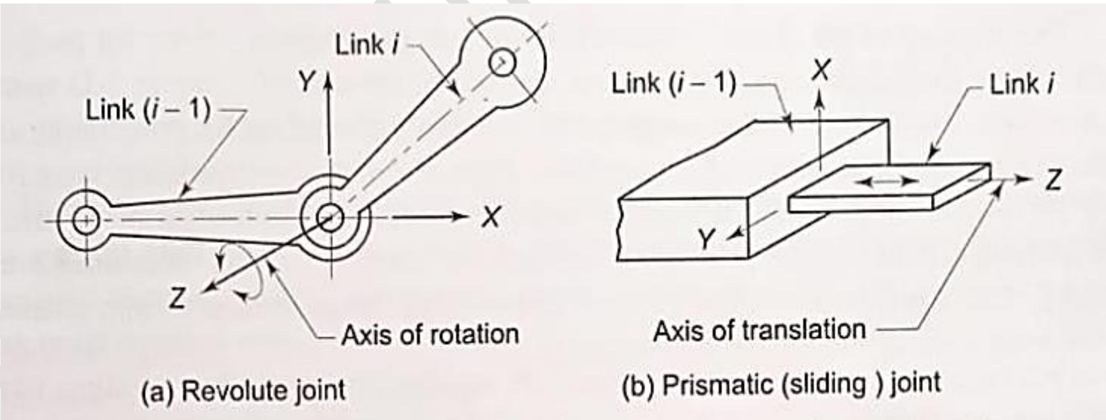


Mechanical structure and notation

- The anatomy of the manipulator was discussed in Chapter 1. A manipulator consists of a chain of rigid bodies, called links, connected to each other by joints, which allow linear or revolute motion between connected links each of which exhibits just one degree of freedom (DOF).

- Joints with more than one DOF are not common. A joint with m degrees of freedom can be modeled as m joints with one degree of freedom each connected with $(m-1)$ links of zero length. Most industrial robotic manipulators are open serial kinematic chains, that is, each link is connected to two other links, at the most, without the formation of closed loops. In open chain robots, all joints are motorized (active). Some robots may have closed kinematic chains such as parallelogram linkages and require different considerations to model them.

- The number of degrees of freedom a manipulator possesses is the number of independent parameters required to completely specify its position and orientation in space. Because each joint has only one degree of freedom, the degrees of freedom of a manipulator are equal to number of joints.

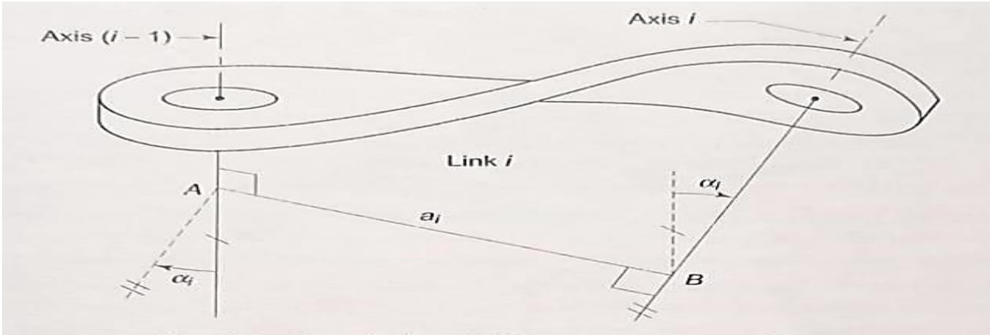


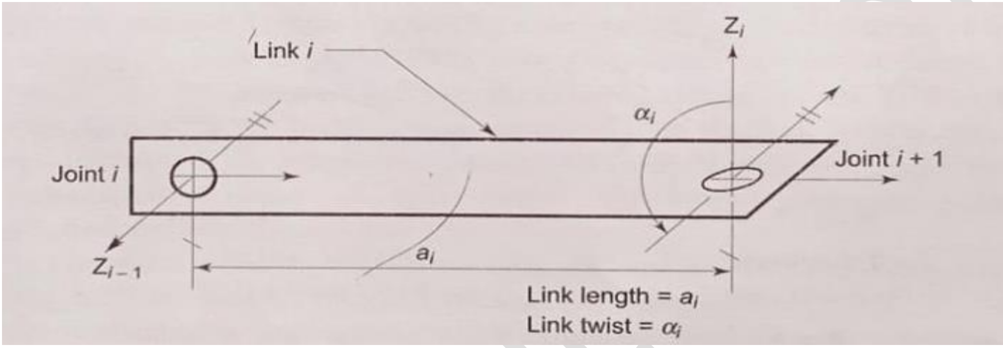
Description of links and joints

- The n-DOF robotic manipulator is modelled as a chain of rigid links interconnected by revolute and/or prismatic joints. To describe the position and orientation of a link in space, a coordinate frame is attached to each link, namely, frame $\{i\}$ to link i. The position and orientation of frame $\{i\}$, relative to previous frame $\{i-1\}$, can be described by a homogeneous transformation matrix as discussed in the previous chapter.

- In this section, the parameters required to completely specify the position and orientation of links and joints of a manipulator are discussed. Every link of the manipulator is connected to two other links with joints at either end, with the exception of the base and the end-effector, the first and the last link (recall that immobile base is link 0), which have only one joint.

➢ From a geometric viewpoint, the link defines the relative position and orientation of joint axes at its two ends. For the two axes $(i-1)$ and i, there exist a mutual perpendicular, which gives the shortest distance between the two axes. This shortest distance along the common normal is defined as the link length and





4.2. Translation and Rotation Representation, Coordinate transformation DH parameters, Jacobian, Singularity and Statics

Translation and rotation Representation-

➢ Suppose a rotation by θ is performed, followed by a translation by. x_t, y_t . This can be used to place the robot in any desired position and orientation. Note that translations and rotations do not commute! If the operations are applied

successively, each $(x, y) \in \mathcal{A}$ is transformed to

$$\begin{pmatrix} x\cos\theta - y\sin\theta + x_t \\ x\sin\theta + y\cos\theta + y_t \end{pmatrix}.$$

The following matrix multiplication yields the same result for the first two vectorcomponents:

$$\begin{pmatrix} \cos\theta & -\sin\theta & x_t \\ \sin\theta & \cos\theta & y_t \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ 1 \end{pmatrix} = \begin{pmatrix} x\cos\theta - y\sin\theta + x_t \\ x\sin\theta + y\cos\theta + y_t \\ 1 \end{pmatrix}.$$

This implies that the 3 X 3 matrix,

$$T = \begin{pmatrix} \cos\theta & -\sin\theta & x_t \\ \sin\theta & \cos\theta & y_t \\ 0 & 0 & 1 \end{pmatrix},$$

Represents a rotation followed by a translation. The matrix T will be referred to asa *homogeneous transformation matrix*. It is important to remember

that T represents a rotation *followed by* a translation (not the other way around).Each primitive can be transformed using the inverse of T, resulting in a transformed solid model of the robot. The transformed robot is denoted by $\mathcal{A}(x_t, y_t, \theta)$
, and in this case there are three degrees of freedom. The homogeneous transformation matrix is a convenient representation of the combined transformations; therefore, it is frequently used in robotics, mechanics, computer graphics, and elsewhere. It is called homogeneous because over $\mathbb{R}^3$ it isjust a linear transformation without any translation.

Co-ordinate and Transformation DH parameters-

In almost all fields of science and engineering, it is essential to identify and manipulate mathematical representations of physical, real-world quantities. Robotics is no exception. Intelligent robots build a "mental model" of themselves and the world as they perceive their environments, and they modify those models when interpreting the past and predicting the future. In an abstract sense, these models are simply a collection of numbers and labels, with no explicit meaning to the robot. It is the job of a robot engineer to correctly associate numbers with meaning, and correspondingly, meanings with numbers. (If this sounds like mumbo jumbo at the moment, some concrete examples will be offered soon enough!)

Vectors and coordinates

- Vectors extend concepts that are familiar to us from working with real numbers RR to other spaces of interest. They also succinctly represent collections of real numbers that have a common meaning like position or direction, or readings from a signal taken at a given time. Theymake mathematical expressions more compact, which helps us wrap our heads around more difficult concepts.

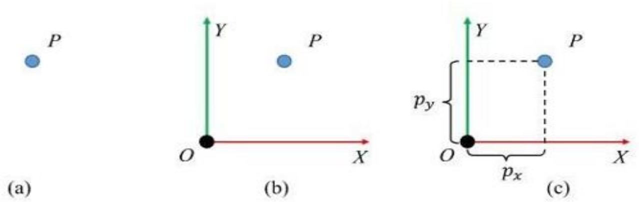
2D coordinate frames

- In the "layman's definition", an n-dimensional vector $\mathbf{x}$ is a tuple of real numbers $\mathbf{x} = (x_1, \dots, x_n) \in \mathbb{R}^n$. For now, we will work in $\mathbb{R}^2$. We will use boldface notation only temporarily to help distinguish between vectors and real numbers. In the future, the boldface will typically be dropped.

- A 2D position P is represented by a 2-element vector $\mathbf{p} = (p_x, p_y)$ that gives its coordinates relative to axis directions X and Y, offset from a position O where the axes cross, called the origin (Fig. 1). We will also represent vectors in column vector form:

$$\mathbf{p} = \begin{bmatrix} p_x \\ p_y \end{bmatrix}$$

- for use in matrix-vector products. Both parenthetical and column vector notations are equivalent and interchangeable.

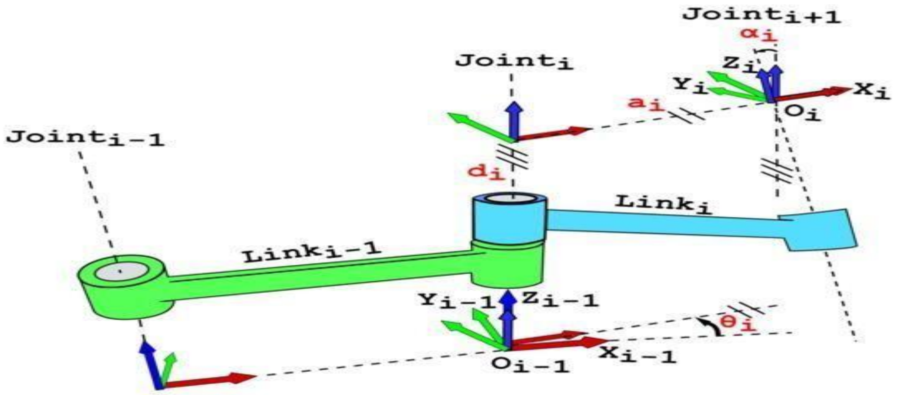


DH parameters

- In mechanical engineering, the **Denavit–Hartenberg parameters** (also called **DH parameters**) are the four parameters associated with a particular convention for attaching reference frames tothe links of aspatial kinematic chain, or robot manipulator.

- ➢ Jacques Denavit and Richard Hartenberg introduced this convention in 1955 in order to standardize the coordinate frames for spatial linkages

Four parameters-



The following four transformation parameters are known as D-H parameters :

- d: offiset along previous z to the common normal
- θ : angle about previous z, trom old x to new x
- r: Iength of the common normal (aka a, but if using this notation, do not contuse with α). Assuming a revoutute joint, this is the radius about previous z.
- α : angle about common normal, from old z axis to new z axis
  There is some choice in frame layout as to whether the previous x axis or the next x points along the common normal. The latter system allows branching chains more efficiently, as mutiple friames can all point away from their common ancestor, but in the altemative layout the ancestor can only point toward one successor. Thus, the commonly used notation places each down-chain x axis collinear with the common normal, yielding the transformation calculations shown below.
  We can note constraints on the relationships between the axes:
- the x_n-axis is perpendicular to both the z_{n-1} and z_n axes
- the x_n-axis intersects both z_{n-1} and z_n axes
- the origin of joint n is at the intersection of x_n and z_n
- y_n completes a right-handed reference firame based on x_n and z_n

Jacobian singularity-

- ➢ The manipulator Jacobian J, a function of the configuration $\boldsymbol{q}$, may become rankdeficient or singular at certain configuration in Cartesian space. In such cases, the inverse Jacobian does not exist and Eq. (5.66) is not valid. Those manipulator configurations at which J becomes noninvertible are termed as Jacobian singularities and the configuration is itself called singular.

- ➢ At a singular configuration, the Jacobian matrix $\boldsymbol{J}$ is not full rank; hence, its column vectors are linearly dependent. This means that there exists at least one direction in which the end-effector cannot be moved irrespective of values chosen for joint velocities $\dot{q}_1$ to $\dot{q}_n$.

- ➢ The study of manipulator singularities is of great significance for the following reasons:
  (a) It is not possible to give an arbitrary motion to end-effector; that is, singularities represent configurations at which structural mobility of the manipulator is reduced.
  (b) At a singularity, no solution may exist for the inverse Jacobian problem.
  (c) In the neighbourhood of a singularity, small velocities in the Cartesian space require very high velocities in the joint space. This causes problems when the manipulator is required to track a trajectory that passes close to the singularity.
  At a singular configuration, the manipulator loses one or more degrees of freedom. The singular configurations are classified into two categories based on the location of end-effector in the workspace

Jacobian static-

- The relationship between the joint torque and the end point force vector is derived using the principle of virtual work. This is use to determine the joint torques necessary to exert a givenend effecter force and movement.

$$\delta W = \tau^T \delta q - \mathcal{F}^T \delta p$$

- where δp is the $n \times 1$ vector of infinitesimal end-effector displacements $(\delta x_e, \delta \phi_e)$ caused by the endpoint force $\mathcal{F}$. In the above, it is assumed that the joints of the mechanism are frictionless and the joint torques are the net torques that balance the endpoint force $\mathcal{F}$.

- From above Eq. , the Jacobian J relates infinitesimal joint displacement δq to infinitesimal end-effector displacement δp as:

$$\delta \boldsymbol{p} = J(\boldsymbol{q})\delta \boldsymbol{q}$$

- Substituting this into above eqn and rearranging gives,

$$\delta W = (\tau - J(q)^T \mathcal{F})^T \delta q$$

- According to the principle of virtual work the manipulator mechanism is in static equilibrium, if and only if, the net virtual work is zero for arbitrary virtual displacements, that is,

$$\delta W = 0$$

- Substituting it, leads to the result

$$\tau = J(\boldsymbol{q})^T \mathcal{F}$$

- This Equation states that the transpose of the Jacobian matrix transforms the end-effector torque to the corresponding joint torques.

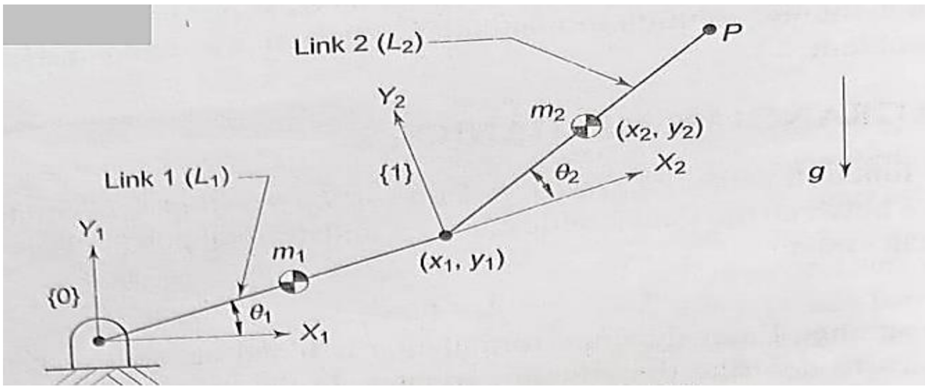
4.3. Dynamic Modelling: Equations of motion: Euler-Lagrange formulation

Equation of motion

Dynamic modeling-

Two degree of freedom manipulator

- The dynamic of a simple manipulator is worked out to illustrate the language euler formulationand to clarify the problem involve in the dynamic modeling two DOF manipulator with bothrotary joints as shown in the figure. for the manipulator, coordinate frames {0} and {1} joint variable theta 1 and theta 2, link length L1 and L2 and mass of link m1 and m2 respectively. The liner angular velocity are v1,v2,theta 1and theta2



- The LaGrange requires kinetic and potential energies of the manipulator. The inetic energy of a rigid body (a link), can be expressed as:

$$\mathcal{K} = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$$

- where v is the linear velocity, ω is the angular velocity, m is the mass, and I is the moment of inertia of the rigid body at its centre of mass.

  Thus, the kinetic energy for the link 1 with the linear velocity $v_1 = \frac{1}{2}L_1\dot{\theta}_1$, angular velocity $\omega_1 = \dot{\theta}_1$, moment of inertia $I_1 = \frac{1}{12}m_1L_1^2$, and mâss m_1 is $\mathcal{K}_1 = \frac{1}{2}m_1v_1^2 + \frac{1}{2}I_1\omega_1^2 = \frac{1}{8}m_1L_1^2\dot{\theta}_1^2 + \frac{1}{24}m_1L_1^2\dot{\theta}_1^2 = \frac{1}{6}m_1L_1^2\dot{\theta}_1^2$

  and its potential energy is

$$P_1 = \frac{1}{2}m_1gL_1\sin\theta_1$$

where g is the magnitude of acceleration due to gravity in the negative y-axis direction.

Equations of motion-

Definition

- The equations of motion of a physical system describe its *motion* as a function of *time* and optional *control inputs*. Intheir general form, they are written:

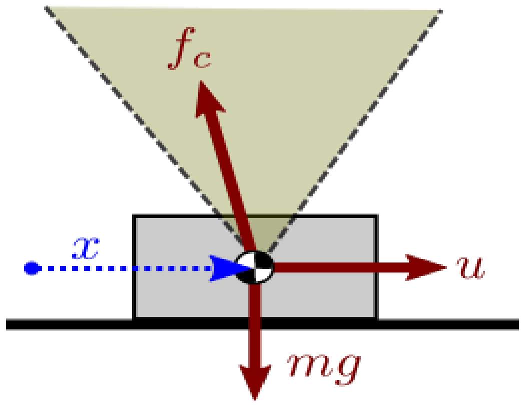
F(q(t), q˙(t),q¨(t),u(t),t)=0,F(q(t),q˙(t),q¨(t),u(t),t)=0,

where

- t is the time variable,
- q is the vector of generalized coordinates, for instancethe vector of joint-angles for a manipulator,
- q˙ is the first time-derivative (velocity) of q,
- q¨ is the second time-derivative (acceleration) of q,
- u is the vector of control inputs.

- These equations provide a mapping between the control space, the commands that we send to actuators, and the state space ofrobot motions

- Imagine a rigid block sliding on a table, which we can see as a 1-DOF (one degree of freedom) system with coordinate xx. The operator applies a horizontal force uu that pushes the block forward.



- If the force is high enough to overcome friction, applying Newton's second law of motion (and Coulomb's model of sliding friction)

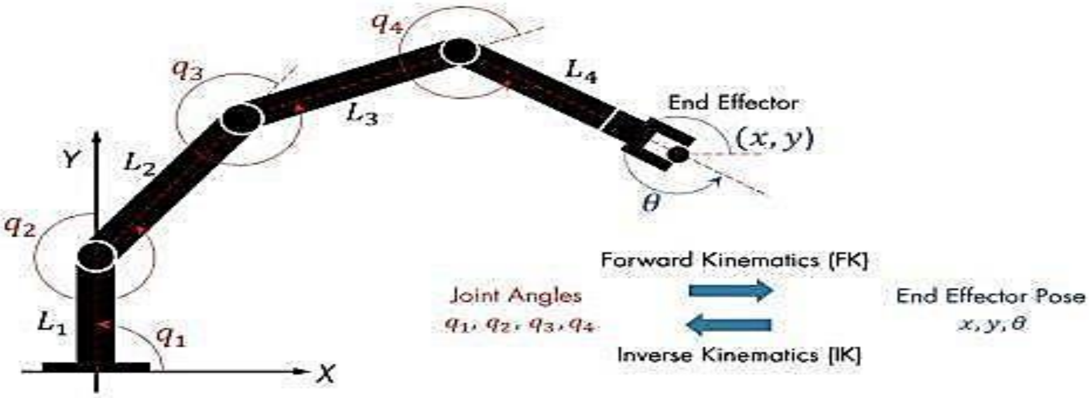
Euler La-Grange formulation Equation of motion-

- The Euler LaGrange formulation is a systematic procedure for obtaining the dynamic model of ann-DOF manipulator. The n-DOF open kinematic chain serial link manipulator has n joint position or displacement variable q= [q1…. Qn]^T .
- The LE formulation establishes the relation between the joint positions, velocities, acceleration and the generalized torque applied to the manipulator.
- The generalized torque are the non- conservative torques contributed by joints, jointfriction forces, and induced joint torque. The induced joint torque are the torques at the joints due to contact or interaction of the end effector with the environment.

4.4 The Inverse Kinematics- Manipulation Workspace- Solvability Of Inverse Kinematic Model

Inverse kinematics-Manipulation workspace

- Kinematics is the study of motion without considering the cause of the motion, such as forces and torques. Inverse kinematics is the use of kinematic equations to determine the motion of a robot to reach a desired position.
- For example, to perform automated pinpricking, a robotic arm used in a manufacturing line needs precise motion from an initial position to a desired position between bins and manufacturing machines.
- The grasping end of a robot arm is designated as theend-effector. The robot configuration is a list of joint positions that are within the position limitsof the robot model and do not violate any constraints the robot has.
- Given the desired robot’s end-effector positions, inverse kinematics (IK) can determine an appropriate joint configuration for which the end-effectors move to the target pose



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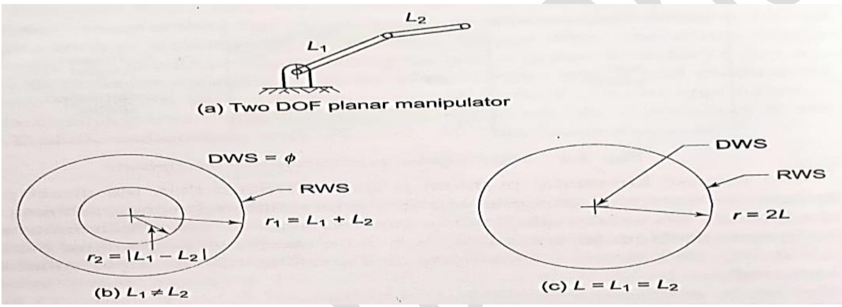
{Configuring the joint positions of a robot using forward or inverse kinematics.}

- Once the robot's joint angles are calculated using the inverse kinematics, a motion profile canbe generated using the Jacobian matrix to move the end-effector from the initial to the target pose. The Jacobian matrix helps define a relationship between the robot's joint parameters andthe end-effector velocities.
- In contrast to forward kinematics (FK), robots with multiple revolute joints generally have multiple solutions to inverse kinematics, and various methods have been proposed according tothe purpose. In general, they are classified into two methods, one that is analytically obtained (i.e., analytic solution) and the other that uses numerical calculation.

Manipulation Workspace

- The work space of manipulator is define is the volume of space in which the manipulator is able to locate its end effect. The workspace gets specified by the existence or nonexistence of solution to the inverse problem.
- The region that can be reached by the origin of the end effector frame with at least one orientation is called the reachable workspace (RWS).
- If a point in workspace can be reached only one orientation, the end effector is very poor and it is not possibleto do my practical work satisfactorily with just one fixed orientation.



- The space where the end effector can reach every point from all orientation is called dexterous workspace (DWS). It is obvious that the dexterous workspace is either smaller or same as the reachable workspace.

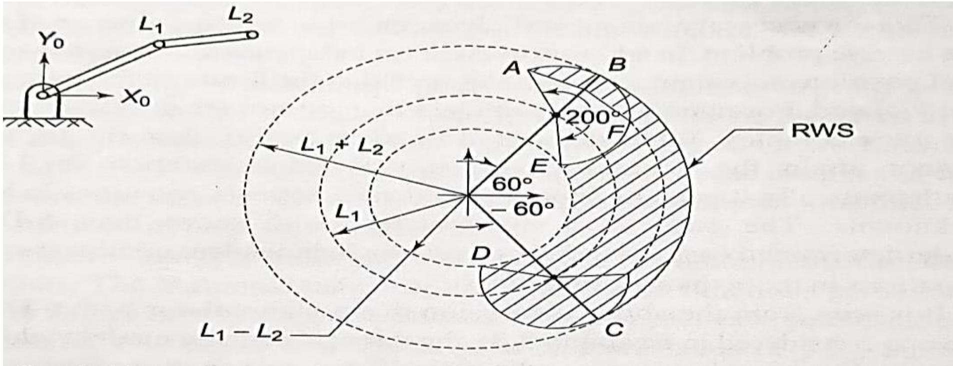
Solvability of inverse kinematic model

- Inverse kinematic is complex because the solluction is to be found for nonlinear simultaneous equation, involving transcendental functions.
- The number of simultaneous equation is also generally more than the number of unknown, making some of the equations mutually dependent. This condition lead to the possibility of multiple solution. The existence of solution ,multiple solution and method of solution.

POSSIBLE SHORT TYPE QUESTIONS WITH ANSWERS

Q1 Define kinematic model.

ANS: A **kinematic model** is a mathematical description of the robot: its functional dimensions andDoF. It describes the robot's workspace, its positional capabilities and constraints. Most often used for describing robot **kinematics**, which is also the case in this method, is the modified Denavit–Hartenberg (MDH)



Reachable workspace of a two-link planar manipulator with joint limits

notation.

Q 2 Define link and joints.

ANS: A mechanical linkage is an assembly of bodies connected to manage forces and movement. The movement of a body, or **link**, is studied using geometry so the **link** is considered to be rigid. The connections between **links** are modeled as providing ideal movement, pure rotation or sliding forexample, and are called **joints**.

Q 3 Define translation and rotation.

ANS: A **rotation** is the turning of a figure or object around a fixed point. And a **translation** is a scenario where every point in a figure is moved the exact same distance and in the same exact direction, without being rotated, reflected, or resized.

Q 4 State DH parameter.

ANS: In mechanical engineering, the Denavit–Hartenberg **parameters** (also called **DH parameters**) arethe four **parameters** associated with a particular convention for attachingreference frames to the links of a spatial kinematic chain, or robot manipulator.

The **four parameters** a_i,α_i,d_i, and θ_i are generally given the names link length, link twist, linkoffset, and joint angle, respectively.

Q 5 Define Jacobian singularity.

ANS: A **singularity** occurs when the joint velocity in joint space becomes infinite to maintain Cartesian. velocity. It shows us where the continuity in joint space breaks down as related to Cartesian space. A. **singularity** occurs whenever the determinant of the **Jacobian** is 0

Q 6 What is dynamic modelling.(S-23)

ANS: Dynamic Modeling represents the temporal aspects of a system, capturing the control elements through which the behavior of objects can be understood over time ....It is necessary to **model** only those objects with a definite lifecycle or those which exhibit significantbehavior.

Q 7 State Euler-lagrange formulation.

ANS: In the calculus of variations and classical mechanics, the Euler-Lagrange equations[1] is a systemof second-order ordinary differential equations whose solutions are stationary points of the

given action functional. The equations were discovered in the 1750s by Swiss mathematicianLeonhard Euler and Italian mathematician Joseph-Louis Lagrange.

Because a differentiable functional is stationary at its local extrema, the Euler–Lagrange equation is useful for solving optimization problems in which, given some functional, one seeks the function minimizing or maximizing it. This is analogous to Fermat's theorem in calculus, stating that at any point where a differentiable function attains a local extremum its derivative is zero.

Q 8 What is inverse Kinematics?

ANS: In computer animation and robotics, **inverse kinematics** is the mathematical process of calculating the variable joint parameters needed to place the end of a kinematic chain, such as a robot manipulator or animation character's skeleton, in a given position and orientation relative to the start of the chain. Given joint parameters, the position and orientation of the chain's end, e.g. the hand of the character or robot, can typically be calculated directly using multiple applications of trigonometric formulas, a process known as forward kinematics. However, the reverse operation is, in general, much more challenging.

Q 8 What is End effector connected to the Manipulator? (S-22)

ANS: 1. End Effector is a device or tools connected to the end of the robot arm where the hand would be.

2. It is the part of the Robot that interact with the environment.

3. It can accommodate only certain tasks without changes to its end effector by programming.

POSSIBLE LONG TYPE QUESTIONS

1-State and explain different kinematic model2-Describe different types of link and joints.

2-State and explain steps used in Trajectory Planning. (S-22)

3-State and explain DH parameters.

4- Sketch the approximate reachable workspace and the dextrous workspace of the two-DOF planar manipulator.(S-23)

5- Discuss the various types of End Effectors. (S-24)

CHAPTER NO.- 05
SENSORS AND VISION SYSTEM

Learning objectives-

5.1- Sensor: Contact and Proximity, Position, Velocity, Force, Tactile etc.

5.2-Introduction to Cameras, Camera calibration, Geometry of Image formation, Euclidean/Similarity/Affine Projective transformations

5.3-Visison application in Robotics

5.4-Kinds of sensors used in robotics: Optic Sensors -Pneumatic Sensors -Force /Torque Sensors

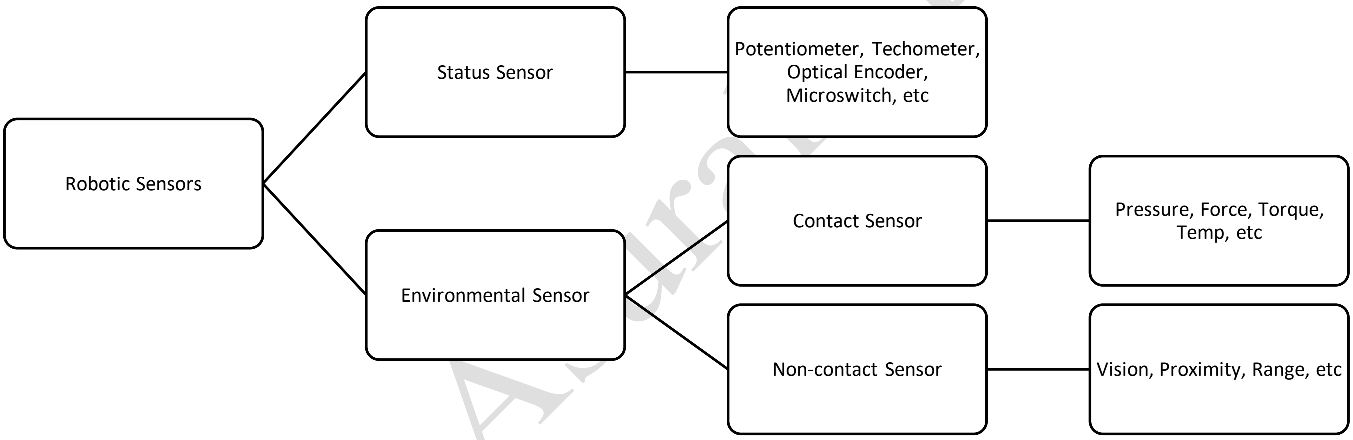
5.5-Optical Encoders

5.1- Sensor: Contact and Proximity, Position, Velocity, Force, Tactile etc.

Sensor-

Classification of robotic Sensor

Robotic sensors can be classified in number of broad groups in view of their applicability and used in robotics like property sensors, functional sensors, acoustic sensors, optic sensors and so on.



Contact and Proximity sensor-

- A proximity sensor in robotics can detect a nearby object without requiring physical touch.
- The transmitter sends electromagnetic radiation to the sensor next to it, and the receiver receives and analyzes the interruption feedback signal.
- As a result, the amount of light received in the area can be utilized to determine whether or not neighboring objects are present.
- There are many different types of proximity sensors, but only a few are commonly employed in robots.
- Infrared (IR) transceiver: Once an obstacle is detected, an IR LED sends an IR beam of light that mirrors the light received by an IR recipient.
- Ultrasound Sensor: These sensors produce high-frequency sound waves, and the recorded echo indicates that an object has been disrupted. Ultrasound sensors could be used to measure distances as well.

Positioning sensor-

- Positioning sensors in robotics are used to estimate the robot’s positioning.
- A GPS (Global Positioning) System is the most common positioning sensor.

- Satellites orbiting our planet send out signals, which are picked up and processed by a robot receiver. The two most common navigation sensors include;

GPS

- The Global Positioning System (GPS) is the most widely used positioning sensor. Satellites orbiting our planet send out signals, which are picked up and processed by a robot's receiver.
- These GPS systems are incredibly useful for robots in the outdoors, but they are ineffective indoors.

Digital Magnetic Compass

- Similar to a portable magnetic compass, the Digital Magnetic Compass uses the earth's magnetic field to produce directional measurements, guiding your robot in the appropriate direction to reach its target.
- These sensors are less expensive than GPS modules, however if you need both positional feedback and navigation, a compass should be used in conjunction with a GPS module.

Tactile sensor-

- A tactile sensor is a device that determines whether or not an object is in contact.
- A tactile sensor enables the robot to "touch and feel" commonplace objects like stair rails and lighting that dim or brighten by pressing the base.
- These sensors are used to monitor applications and interact with the environment in a gentle manner. It is divided into two categories: Touch and Force Sensors.

Force Sensors-

- Force sensors in robotics are used to calculate the forces involved in a robot's various functions, such as machine loading and unloading, material management, and so on.
- This sensor will also improve the assembling process for trouble shooting.
- A force torque sensor gives the robotic arms the feel of completing an assembly task; internal state sensors are used for measuring the end effector.

Velocity sensors-

- Velocity Sensor: A velocity or speed sensor measures consecutive position measurements at known intervals and computes the time rate of change in the position values.
- Velocity Sensors: 1) Tachometers 2) LSV 3) Piezoelectric Sensors 4) Accelerometer Sensor

5.2-Introduction to Cameras, Camera calibration, Geometry of Image formation, Euclidean/Similarity/Affine Projective transformations.

Introduction to Cameras –

- A camera is an optical instrument that records images that can be stored directly, transmitted to another location, or both.
- These imagesmay be still photographs or moving images such as videos or movies.
- The term camera comes from the word camera obscure (Latin for "dark chamber"), an early mechanism for projecting images.
- The modern camera evolved from the camera obscure & functioning of the camera is very similar to the functioning of the human eye.
  History
- The history of the camera can be traced much further back thanthe introduction of photography.
- Cameras evolved from the camera obscure, and continued to change through many generations of photographic technology, including Daguerre types, callow types, dry plates, film, and digital cameras.
- **History:** Camera Obscure Photographic cameras were a development ofthe camera obscure, a device dating back to the ancient Chinese.

Geometric camera calibration

- Geometric camera calibration, also referred to as camera re sectioning, estimates the parameters of a

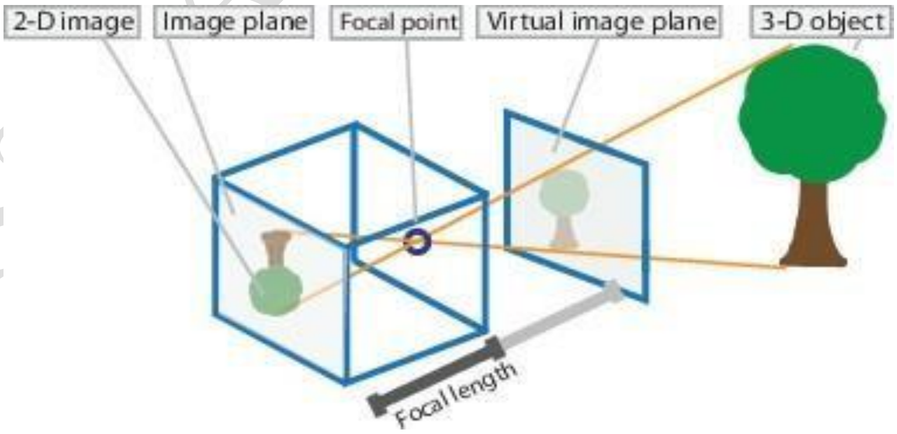
lens and image sensor of an image or video camera.
- We can use these parameters to correct for lens distortion, measure the size of an object in world units, or determinethe location of the camera in the scene.
- These tasks are used in applications such as machine vision to detect and measure objects.
- They are also used in robotics, for navigation systems, and 3-D scene reconstruction

Camera Models

- The Computer Vision Toolbox contains calibration algorithms for the pinhole camera modeland the fisheye camera model.
- The pinhole calibration algorithm is based on the model proposed by Jean-Yves Bouguet.
- The model includes, the pinhole camera model and lens distortion.
- The pinhole cameramodel does not account for lens distortion because an ideal pinhole camera does not have a lens.
- To accurately represent a real camera, the full camera model used by the algorithm includes the radial and tangential lens distortion.

Pinhole Camera Model

- A pinhole camera is a simple camera without a lens and with a single small aperture. Lightrays pass through the aperture and project an inverted image on the opposite side of the camera.
- Think of the virtual image plane as being in front of the camera and containing the upright image of the scene.



Camera Calibration Parameters-

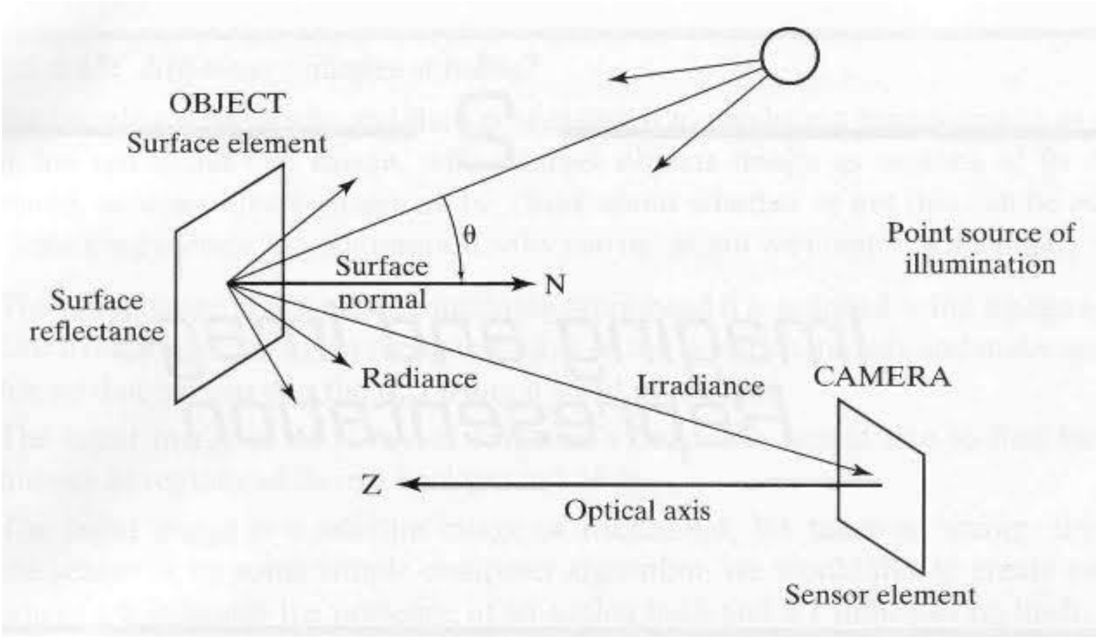
- The calibration algorithm calculates the camera matrix using the extrinsic and intrinsic parameters.
- The extrinsic parameters represent a rigid transformation from 3-D world coordinate system to the 3-D camera's coordinate system.
- The intrinsic parameters represent projective transformation from the 3-D camera's coordinates into the 2-D image coordinates.

Geometry of image formation-

The two parts of the image formation process

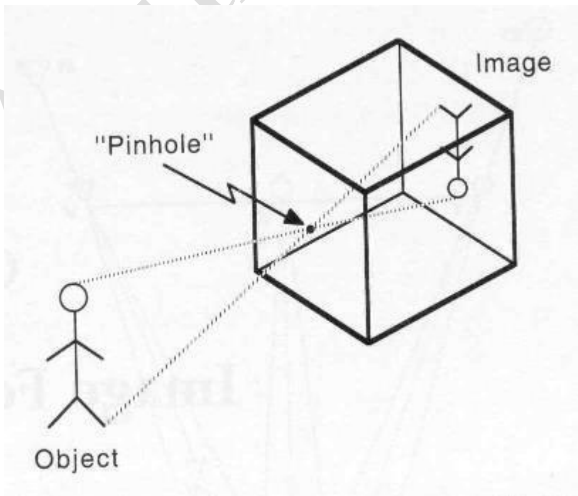
- The geometry of image formation which determines where in the imageplane the projection of a

point in the scene will be located.
- The physics of light which determines the brightness of a point in the image function of illumination and surface properties.
- The scene is illuminated by a single source.
The scene reflects radiation towards the camera.The camera senses it via chemicals on film.



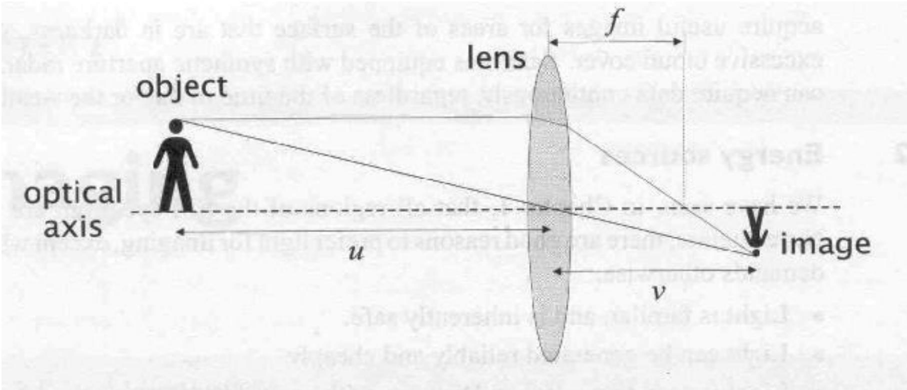
Camera Geometry

- The simplest device to form an image of a 3D scene on a 2D surface is the"pinhole “camera.
- Rays of light pass through a "pinhole" and form an inverted image of theobject on the image plane.



Camera Optics

- In practice, the aperture must be larger to admit more light.
- Lens are placed in the aperture to focus the bundle of rays from eachscene point onto the corresponding point in the image plane.



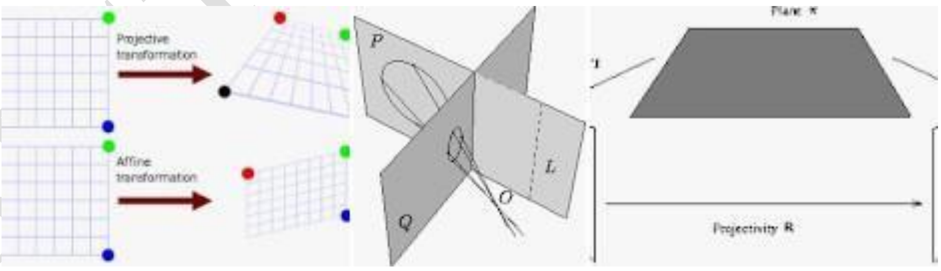
Euclidean/similarity/affine

- Euclidean geometry is a mathematical system attributed to Alexandrian Greek mathematician Euclid, which he described in his textbook on geometry: the Elements.
- Euclid's method consists in assuming a small set of intuitively appealing axioms, and deducing many other propositions (theorems) from these.
- Although many of Euclid's results had been stated by earlier mathematicians, Euclid was the first to show how these propositions could fit into a comprehensive deductive and logical system.
- The Elements begins with plane geometry, still taught in secondary school (high school) as the first axiomatic system and the first examples of mathematical proofs.
- It goes on to thesolid geometry of three dimensions. Much of the Elements states results of what are now called algebra and number theory, explained in geometrical language.

Affine transformation

- In Euclidean geometry, an affine transformation, or an affinity (from the Latin, affine, "connected with"), is a geometric transformation that preserves lines and parallelism (but notnecessarily distances and angles).
- More generally, an affine transformation is an auto morphism of an affine space (Euclidean spaces are specific affine spaces), that is, a function which maps an affine space onto itself while preserving both the dimension of any affine subspaces (meaning that it sends points to points, lines to lines, planes to planes, and so on) and the ratios of the lengths of line segments.
- Consequently, setsof parallel affine subspaces remain parallel after an affine transformation.
- An affine transformation does not necessarily preserve angles between lines or distances between points, though it does preserve ratios of distances between points lying on a straight line.

Projective Transformation



- A transformation that maps lines to lines (but does not necessarily preserve parallelism) is a projective transformation.
- Any plane projective transformation can be expressed by an invertible 3×3 matrix in homogeneous coordinates; conversely, any invertible 3×3 matrix defines a projectivetransformation of the plane.

5.3-Visison application in Robotics

Visison-

- Inspection tasks can be carried out by integrating machine vision and robots. Machine visions used to make checks for visual factors such as surface finish, dimensions, potential errors in labeling, and the presence of holes and other elements.

- Machine vision can carry out these tasks faster and with fewer errors than humans can, meaning that production becomes faster and more profitable as a result.

Application in Robotics-

Identification

- Machine vision can be incorporated in robotics, giving them the skills of object detection to allow for identification and the classification of numerous objects simultaneously.
- Machine vision looks for the“variable” part of the object, the bit that is different and sets it apart, in order to successfully identify it.
- This can help robots in ware houses to find the right item quickly, this speeds up production, and can also make retail processes more efficient.

Navigation

- Machine vision is used to enhance and correct data coming in through other sources in order to move robots safely and autonomously in a dynamic environment.
- Other measures of incoming data, such asaccelerometers and encoders, can relay small errors that add up over time.

Quality Control

- Through the capabilities of inspection and identification, machine vision can be reliably used in quality control applications.
- The machine vision techniques of inspection and identification are combined in order to assess whether products meet various quality control checks. This has the impact of making production more efficient and cost-effective.

Assembling

- Research has shown that machine vision can be integrated with robotic systems to create pick and place capabilities.
- Together, the system can accurately pick the correct assembly parts from the storage station and put them in the right assembly spaces and on the appropriate parts where they need to be fixed. This givesthe possibility of automated assembly lines with the use of robots with machine vision.

5.4-Kinds of sensors used in robotics: Optic Sensors -Pneumatic Sensors -Force /Torque Sensors

Kinds of sensors used in robotics-

Types of Robot Sensors

- Light sensors. A Light sensor is used to detect light and create a voltagedifference.
- Sound Sensor.
- Temperature Sensor.
- Contact Sensor.
- Proximity Sensor.
- Distance Sensor.
- Pressure Sensors.
- Tilt Sensors.

Optics sensors

- A optic sensor is a sensor that uses optical fiber either as the sensing element ("intrinsic sensors"), or as a means of relaying signals from a remote sensor to the electronics that process the signals ("extrinsic sensors"). Fibers have many uses in remote sensing.
- Depending on the application, fiber may be used because of its small size, or because no electrical power is needed at the remote location, or because many sensors can be multiplexed along the length of a fiber by using light wavelength shift for each sensor, or by sensing the time delay as light passes

along the fiber through each sensor.
- Time delay can be determined using a device such as an optical time-domain reflectometer and wavelength shift can becalculated using an instrument implementing optical frequency domain reflectometry.

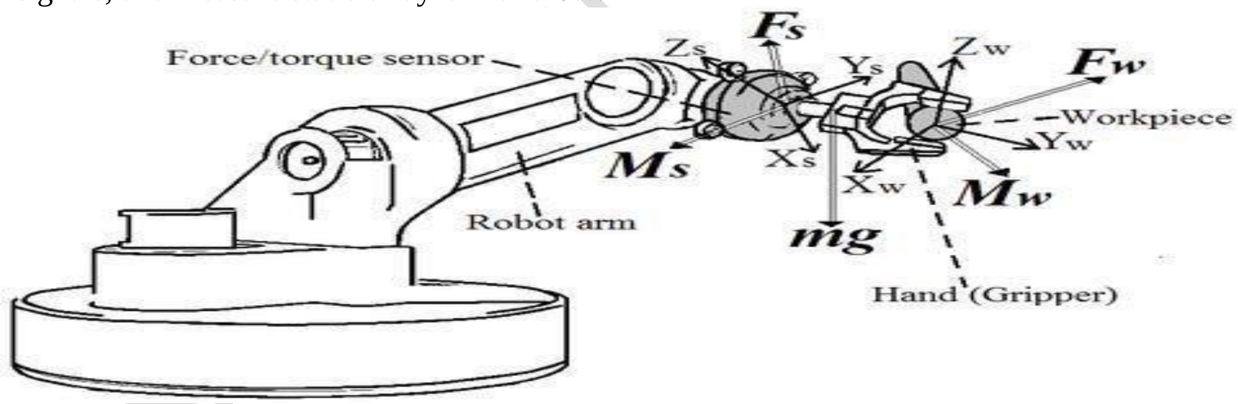
Pneumatic Sensor

- Sensors are used to provide position feedback to control systems in automated machinery and equipment.
- Pneumatic cylinders use sensors to detect the linear position of the piston for applications where position feedback is crucial.
- The most common type of sensor used for pneumatic cylinders are magnetic proximity sensors, which detect the magnetic field of a magnet integrated in the cylinder piston.
- The sensor is mounted onto the pneumatic cylinder's body and will indicate "ON" or "OFF" based on proximity to the magnet.
- Depending on the application, various different magnetic proximity sensor technologies can be used to maximizeperformance, space, and reliability

Force/Torque sensor

- A force torque (FT) sensor is an electronic device that is designed to monitor, detect, record and regulate linear and rotational forces exerted upon it.

- In other words, the FT sensor in a robotic ormechanical system can be compared to the micro-receptors in skin that equip animals with the sense of "touch."
- As a contact sensor, it is specifically designed to interact with physical objects in its environment.In order to mitigate interference from sound waves and debris, this sensor is designed to operate in a variety of climates and external conditions.
- Depending on the model and intended function, a force torque sensor is able to senddigital or analog signals, and measure static or dynamic forces.

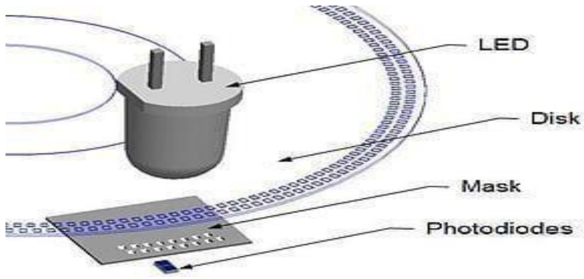


- The most popular type of force torque sensor is the six-axis sensor.
- This particular FT sensor is capable of measuring forces in every direction.
- A six-axis FT sensor generally utilizes strain gauge technology; when pressure is applied, the resistance within the gauge increases or decreases proportionally to the force it receives.

5.5-Optical Encoders

Optical encoders

- An optical encoder is a type of rotary encoder that uses a sensor to identify position change aslight passes through a patterned encoder wheel or disk.



- There are four components in an optical shaft encoder:
  A light source (an LED light)
  A sensor
  A moveable disk
  A fixed mask
- The LED shines through one side of the optical shaft encoder.
- The encoder wheel or disk has a series of tracks on it, similar to the concentric grooves in an LP.
- The mask has a corresponding track for every track on the disk of the optical encoder, and small perforations, called windows, are cut along the tracks in the mask.
- As the disk moves, different windows in the mask are covered or open, showing the movement and position of the optical shaft encoder.
- Each arc in therotation indicates a different position and has a different pattern of open/closed windows. The sensor behind the mask identifies the optical encoders' current pattern.

POSSIBLE SHORT TYPE QUESTIONS WITH ANSWER

Q1-Define contact and proximity sensor.

- A proximity sensor is a non-contact sensor that detects the presence of an object (often referred to as the"target") when the target enters the sensor's field Proximity sensors are used in phones, recycling plants, self-driving cars, anti-aircraft systems, and assembly lines.

Q 2 Define Tactile sensor.

- Tactile sensors are data acquisition devices, or transducers, that are designed to sense adversity of properties via direct physical contact (Nicholls and Lee, 1989).
- Tactile sensor designs are based around a range of different technologies some of which are directly inspired byresearch on biological touch.

Q 3 What is camera calibration?

- Geometric camera calibration, also referred to as camera resectioning, estimates the parameters of a lens and image sensor of an image or video camera.
- We can use these parameters to correct for lens distortion, measure the size of an object in world units, or determine the locationof the camera in the scene.

Q 4 Define Euclidean.

- Wiktionary. Euclidean(Adjective) Adhering to the principles of traditional geometry, in which parallel lines are equidistant. Etymology: Named after Euclid, who established the principles of plane geometry.

Q 5 What is Affine?

- An affine function is a function composed of a linear function + a constant and its graphic a straight line.The general equation for an affine function in 1D is: y = Ax + c.
- An affine function demonstrates an affine transformation which is equivalent to a linear transformation followed bya translation.

Q 6 State vision application in robotics

Machine Vision Applications

- Final inspection of sub-assemblies.
- Engine part inspection.
- Label inspection on products.

- Checking medical devices for defects.

Q 7 Statedifferent sensor used in robotics. (S-24)

List of Sensors

- Vision and Imaging Sensors.
- Temperature Sensors.
- Radiation Sensors.
- Proximity Sensors.
- Pressure Sensors.
- Position Sensors.
- Photoelectric Sensors.
- Particle Sensors.

Q 8 Define force/torque sensor.

- A force torque (FT) sensor is an electronic device that is designed to monitor, detect, record and regulate linear and rotational forces exerted upon it.
- In other words, the FT sensor in a robotic or mechanical systemcan be compared to the micro-receptors in skin that equip animals with the sense of "touch.

Q 9 Define Acoustic sensor. (S-22,24)

- It is sensor that passively detect and utilizes the presence of sound in order to activate a device.
- It is used in automotive applications like torque and pressure, sensor, medical applications and commercial application.

Q 10 Define Human Sensing. (S-24)

- It encompasses a range of technologies for detecting the presence of a human body in an area of space, typically without the international participation of the detected person.
- Common applications are search and Reuse, Serviellance etc.
- Q 9 Define Acoustic sensor. (S-22,24)

POSSIBLE LONG TYPE QUESTIONS

Q 1-State and explain different types of contact and proximity sensor.
Q-2-State andexplain principle of different sensors. (S-22)
Q-3-State and explain acoustic sensor in robotics.
Q-4-Explain about optical encoder.(S-23)
Q-5-Expalin about projective transformation of sensor of robotics.
Q-6- Write down the function of the following Sensors- i) Status Sensor, ii)Environment Sensor, iii)Safety Sensor, iv)Quality Control Sensor, v)Work cell control Sensor.(S-24)
Q-7- What is Sensor ? Explain Repeatability and accuracy in Robotics with neat sketch.(S-24)

CHAPTER NO.-06
ROBOT CONTROL AND ROBOT ACTUATION SYSTEMS

Learning Objectives:

6.1-Basics of control: Transfer functions, Control laws: P, PD, PID
6.2-non-linear and advanced control
6.3-Actuators-Electric, hydraulic and Pneumatic; transmission: Gear, Timing belt and Bearings
6.4-Parameters for selection of actuators

6.1-Basics of control: Transfer functions, Control laws: P, PD, PID

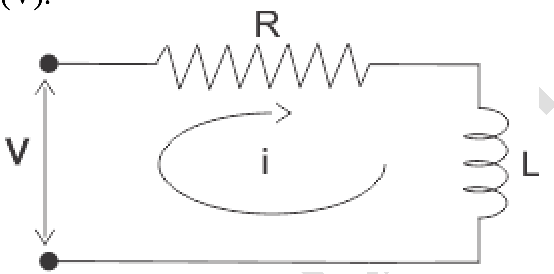
Basics of control: Transfer functions-

- The transfer function of a control system is defined as the ratio of the Laplace transform of the output variable to Laplace transform of the inputvariable assuming all initial conditions to be zero.

$$G(s) = \frac{C(s)}{R(s)}$$

Concept of Transfer Function

- The transfer function is generally expressed in Laplace Transform and it isnothing but the relation between input and output of a system.
- Let us consider a system consists of a series connected resistance (R) and inductance (L) across a voltage source (V).



- In this circuit, the current 'i' is the response due to applied voltage (V) ascause. Hence the voltage and current of the circuit can be considered as input and output of the system respectively.
- From the circuit, we get,

$$V = Ri + L\,di/dt$$

- Now applying Laplace Transform, we get,

$$V(s) = RI(s) + L[sI(s) - i(0^+)]$$

[Initially inductor behaves as open, hence $i(0^+)$]

$$V(s) = I(s)[R + Ls$$

$$\frac{I(s)}{v(s)} = \frac{1}{R + Ls} = \frac{1/L}{s + R/L}$$

- The transfer function of the system, G(s) = I(s)/V(s), the ratio of output to input.

Control law-P, PD, PID-

Proportional Controllers

- All controllers have a specific use case to which they are best suited.
- We cannot just insert any type of controller at any system and expect a goodresult – there are certain conditions that must be fulfilled.
- For a proportional controller, there are two conditions and these are written below:
- The deviation should not be large; i.e. there should not be a largedeviation between the input and output.

The deviation should not be sudden.

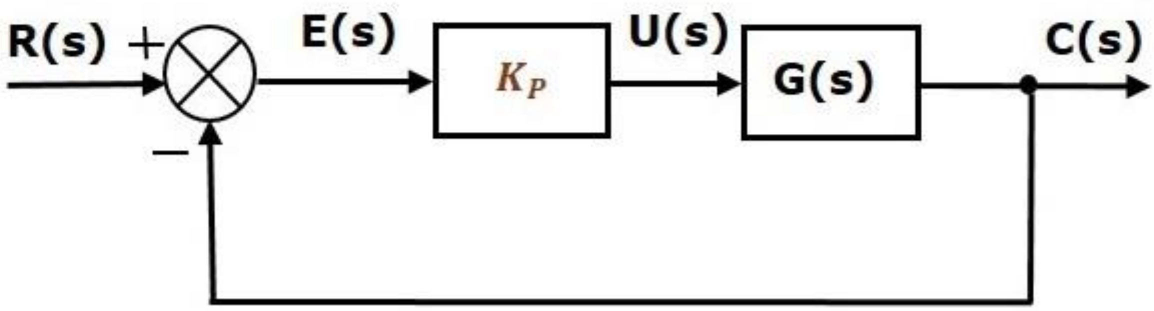
- Now we are in a condition to discuss proportional controllers, as the namesuggests in a proportional controller the output (also called the actuating signal) is directly proportional to the error signal.
- As we know in proportional controller output is directly proportional to the error signal, writing this mathematically we have.

  $A(t)\ \alpha\ \ e(t)$
- Removing the sign of proportionality, we have,

  $(t) = Kp \times e(t)$
- Where Kp is proportional constant also known as controller gain.
- It is recommended that Kp should be kept greater than unity. If the value of Kp is greater than unity, then it will amplify the error signal and thus the amplified error signal can be detected easily.

Control System with Proportional Controller (P)

- 'K' is called a proportional controller (also called error amplifier).Characteristics equation of this control system can be written as:



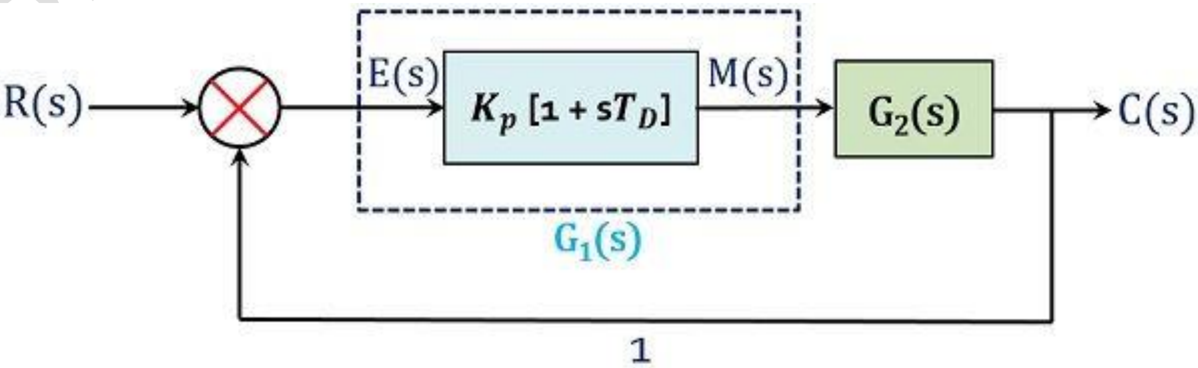
$$s^3+3s^2+2s+K=0$$

- If the Routh-Hurwitz is applied in this characteristics equation, then the range of 'K' for the stability can be found as 0<K<6. (It implies that for the values K>6 system will be unstable; for the value of K=0, the system will bemarginally stable).

Proportional and Derivative Controller (PD)

- As the name suggests it is a combination of proportional and a derivativecontroller the output (also called the actuating signal) is equals to the summation of proportional and derivative of the error signal.
- Analyze proportional and derivative controller mathematically.
- As we know in a proportional and derivative controller output is directly proportional to the summation of proportional of error and differentiationof the error signal, writing this mathematically we have, Removing the sign of proportionality we have, where Kd and Kp proportional constant and derivative constant respectively.

$$A(t)\alpha\ (de(t))/dt + A(t)\ \ \alpha\ \ e(t)$$
$$A(t) = Kd\ (de(t))/dt + Kpe(t)$$

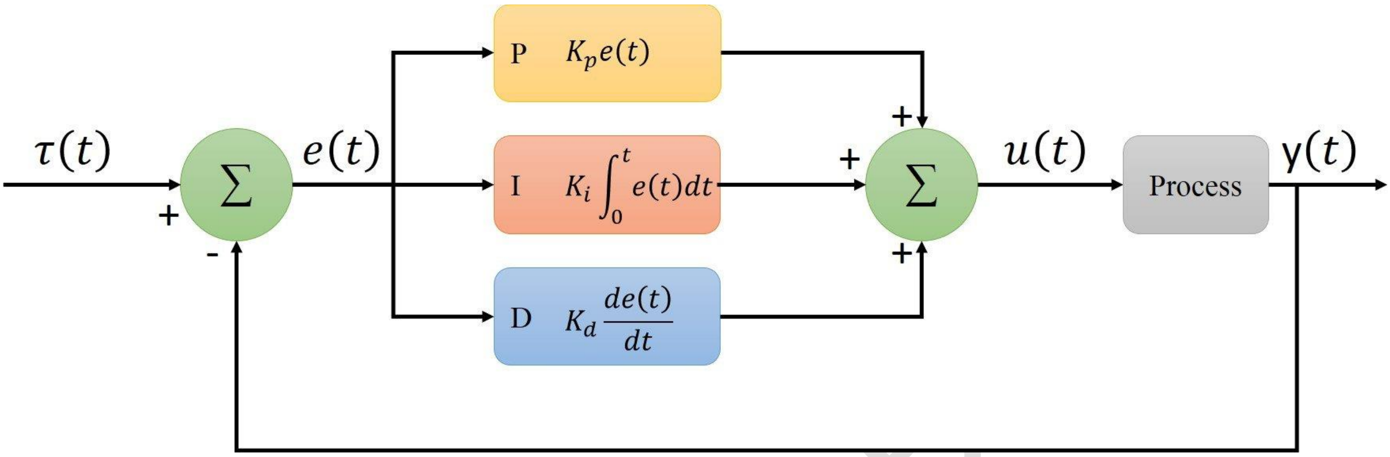


Proportional plus Integral Plus Derivative Controller (PIDController)

- A PID controller is generally used in industrial control applications to regulate temperature, flow,

$$Tds + K + Ki/s \ or \ (Tds\char`^2 + Ks + Ki)/s$$

- Pressure, speed, and other process variables.
- The transfer function of the PID Controller can be found as:

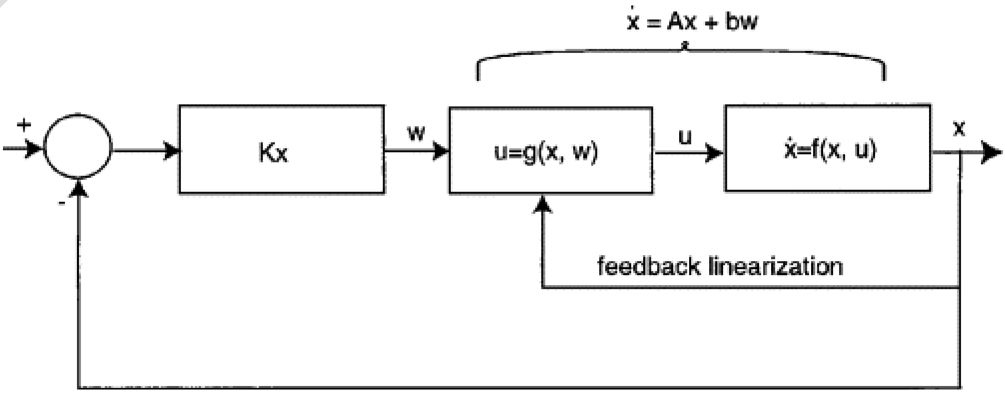


- In this case, we can keep two complex zeros or two real zeros as per the requirement, hence PID controller can provide better tuning.
- In the olden days, the PI controller was one of the best choice of control engineers, because designing (tuningof parameters) of the PID controller was a little difficult, but nowadays, due to the development of software designing of PID controllers have become an easy task.

6.2-Non-Linear and Advance Controls

Non-Linear and Advance Controls-

- Nonlinear control theory is the area of control theory which deals with systems thatare nonlinear, time-variant, or both. Control theory is an interdisciplinary branch of engineering and mathematics that is concerned with the behavior of dynamical systems withinputs, and how to modify the output by changes in the input using feedback, feedforward, or signal filtering.
- The system to be controlled is called the "plant". One way to make the output of a system follow a desired reference signal is to compare the output of the plant to the desired output, and provide feedback to the plant to modify the output .



- Control theory is divided into two branches. Linear control theory applies to systems made of devices which obey the superposition principle.

Some properties of nonlinear dynamic systems are

- They do not follow the principle of superposition (linearity and homogeneity).
- They may have multiple isolated equilibrium points.
- They may exhibit properties such as limit cycle, bifurcation, chaos.
- Finite escape time: Solutions of nonlinear systems may not exist for all times.

6.3-Actuators-Electric, hydraulic and Pneumatic; transmission: Gear, Timing belt and Bearings

Actuators-Electric-

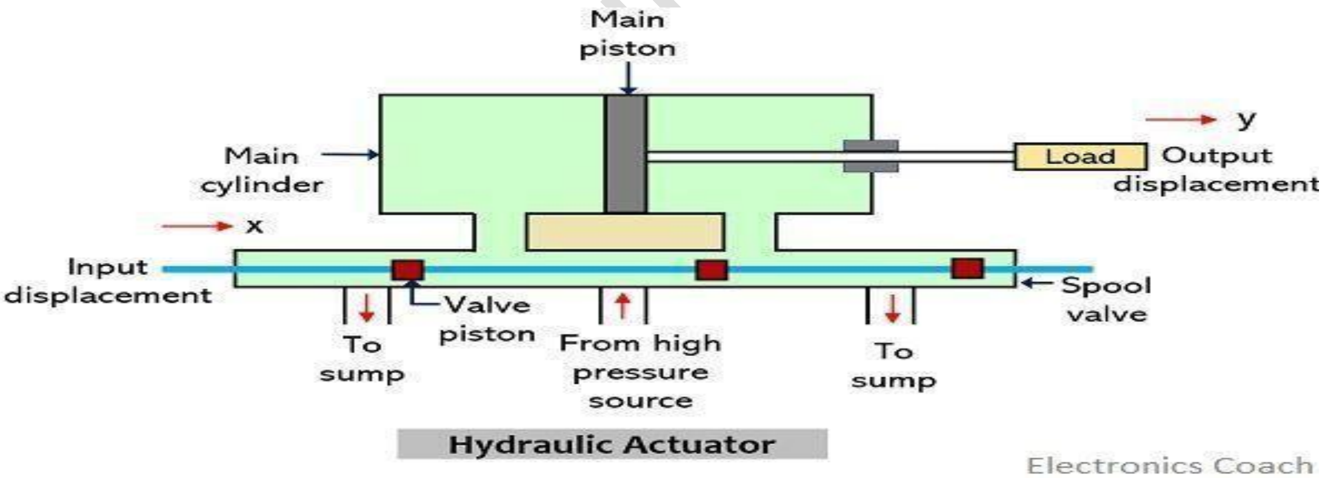
- An actuator is a device that uses a form of power to convert a control signal into mechanical motion.
- From electric door locks in automobiles, to ailerons on aircraft, actuators are all aroundus.
- Industrial plants use actuators to operate valves, dampers, fluid couplings, and other devicesused in industrial process control.
- Robotics, considered to be one of the drivers of the so-called fourth industrial revolution, is starting to find no limitations in regards to the variety of applications.
- Electrical actuators or gear motors are key when controlling positions and speeds demanded by several mechanisms and actuations for each robot.

Hydraulic:

- They are used in large robots which require speed when executing repetitive tasks,as well as great stability and mechanical strength for heavy loads.
- These actuators are classified as hydraulic cylinders, hydraulic motors and hydraulic valves.

Working of Hydraulic Actuator

- The figure below represents the schematic representation of the hydraulic actuator:



- The major component of the unit is pilot valve also known as spool valve andmain cylinder (or power cylinder).
- It operates in a way that difference in pressure created at the two regions of the main cylinder leads to the occurrence of translational motion of the piston.
- As we have already mentioned that the main cylinder has two regions.
- Thus, there are two chambers of the main cylinder.
- The rate with which the fluid flows inside the cylinder is controlled by the spoolvalve. The spool valve has 4 ports and each port is connected to a different part of the system.
- Two separate ports are connected to the fluid supply and drain region respectively.
- While the other two ports are connected separately to the twochambers of the main cylinder.

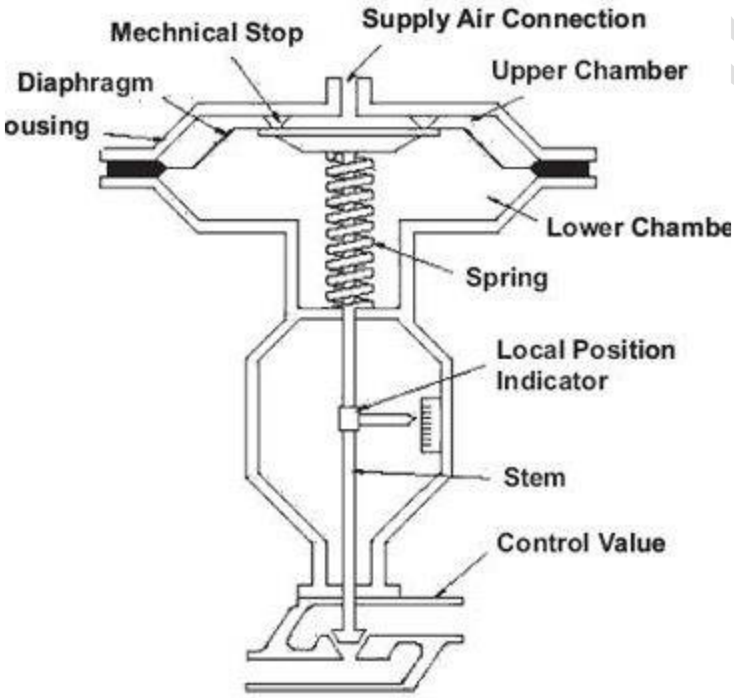
- Initially, the spool is present at the neutral position say x = 0 and at this position, there will be no flow of fluid inside the main cylinder.
- The assembly ofthe hydraulic actuator is such that the load will move according to the fluid flow.

Pneumatic:

- It is used in small-sized robots and actuator mechanisms that generally require two states.Pneumatic actuators can be broken down into pneumatic cylinders and pneumatic motors.

Pneumatic Actuators:

- A simplified diagram of a pneumatic actuator is shown in Figure.
- It operates by a combinationof force created by air and spring force.
- The actuator positions a control valve by transmitting its motion through the stem.
- A rubber diaphragm separates the actuator housing into two air chambers. The upper chamber receives supply air through an opening in the top of the housing.



Pneumatic Actuator: Air-to-Close/Spring-to-Open

- The bottom chamber contains a spring that forces the diaphragm against mechanical stops in theupper chamber.
- Finally, a local indicator is connected to the stem to indicate the position of the valve.
- The position of the valve is controlled by varying supply air pressure in the upper chamber.
- This results in a varying force on the top of the diaphragm.
- As supply air pressure is increased from zero, its force on top of the diaphragm begins to overcome the opposing force of the spring.

Transmission: Gears-

Functions of a Gear Drive:

- A gear drive has three main functions: to increase torque from the driving equipment (motor) tothe driven equipment, to reduce the speed generated by the motor, and/or to change the directionof the rotating shafts.
- The connection of this equipment to the gear box can be accomplished bythe use of couplings, belts, chains, or through hollow shaft connections.

- The heart of a gear drive is obviously the gears within it. Gears operate in pairs, engaging one another to transmit power.

Spur Gear

- Spur gears transmit power through shafts that are parallel.
- The teeth of the spur gears are parallel to the shaft axis.
- This causes the gears to produce radial reaction loads on the shaft, but not axial loads. Spur gears tend to be noisier than helical gears because they operate with a single line of contact between teeth.
- While the teeth are rolling through mesh, they roll off of contact with one tooth and accelerate to contact with the next tooth.

Helical Gear

- Helical gears have teeth that are oriented at an angle to the shaft, unlike spur gears which are parallel.
- This causes more than one tooth to be in contact during operation and helical gears are capable of carrying more load than spur gears.
- Due to the load sharing between teeth, this arrangement also allows helical gears to operate smoother and quieter than spur gears.
- Helical gears produce a thrust load during operation which needs to be considered when they are used. Most enclosed gear drives use helical gears.

Double Helical Gear

- Double helical gears are a variation of helical gears in which two helical faces are placed next to each other with a gap separating them. Each face has identical, but opposite, helix angles.
- Employing a double helical set of gears eliminates thrust loads and offers the possibility of even greater tooth overlap and smoother operation. Like the helical gear, double helical gears are commonly used in enclosed gear drives.
- Diagram of Double Helical Gear.

Herringbone Gear

- Herringbone gears are very similar to the double helical gear, but they do not have a gap separating the two helical faces.
- Herringbone gears are typically smaller than the comparabledouble helical, and are ideally suited for high shock and vibration applications.
- Herringbone gearing is not used very often due to their manufacturing difficulties and high cost.

Bevel Gear-

- Bevel gears are most commonly used to transmit power between shafts that intersect at a 90-degree angle.
- They are used in applications where a right angle gear drive is required.
- Bevel gears are generally costlier and are notable to transmit as much torque, per size, as a parallel shaft arrangement.

Timing Belt and Bearing-

Timing Belt-

- A timing belt is made of rubber with hard teeth capable of interlocking with camshafts and crankshafts cogwheels.
- It is an integral component of an internal combustion engine responsible for synchronizing the rotation of the camshaft and the crankshaft.
- It enables the proper opening and closing of the valves of the engine during both the intake and exhaust strokes of each cylinder.
- The timing belt also plays an important role in preventing the piston from striking the valves, in an interference engine. A timing belt is usually a toothed belt with teeth on one or either side of the surface.

Stages in Designing a Timing Belt

The stages in designing timing belts are:

Stage 1: Peak Torque

- The first stage is the determination of the peak torque for the drive.
- This is mostly the starting torque of the motor.
- However there may also be momentary or shock loads that are unusual occurring during normal operation.

Stage 2: Diameter Determination

- The second stage is the determination of the diameters of the largest pulley that can be utilized.
- This is done in consideration of the space limitations and the system’s drive ratio.
- This helps by increasing the drive’s torque capacity and prolonging the service life of the belt.

Stage 3: Tooth Profile Selection

- The third stage is the selection of the tooth profile of the belt.
- If for the selected profile, the torque for the peak drive is at the upper limits of torque transmission capability, consider making use of the next higher torque rated profile.
- For the selected profile, find the corresponding pitch.
- For the calculation of the required number of belt teeth, this value will be needed.

Stage 4: Calculating T.I.M

- Calculate the T.I.M (teeth in mesh), bearing in mind the teeth in mesh factor.
- The peak torque from stage one must now be divided by the T.I.M. factor in order to determine the design torque.
- An important point to note is to check the belt pitch again to ensure that your application has not been moved outside the limits of the pitch that is desired for the chosen pulleys by this adjustment in torque.

Stage 5: Belt Pitch Length

- This stage involves the calculation of the belt pitch length based on the distance of the design center of the drive.

Stage 6: Belt Width Selection

- This stage involves the selection of the belt width that is able to handle the torque of the design with the selected size of the pulley.
- An important point to note is that the required width of the belt for the system will be wider of the two.

Rubber Timing Belt

Bearing--

- The bearing in its current form was developed towards the end of the 19thcentury.
- It was initially made by hand
- Nowadays, bearings are one of the most commonly used machine parts because their rollingmotion make almost all movements easier and they help reduce friction.

Bearings have two key functions:

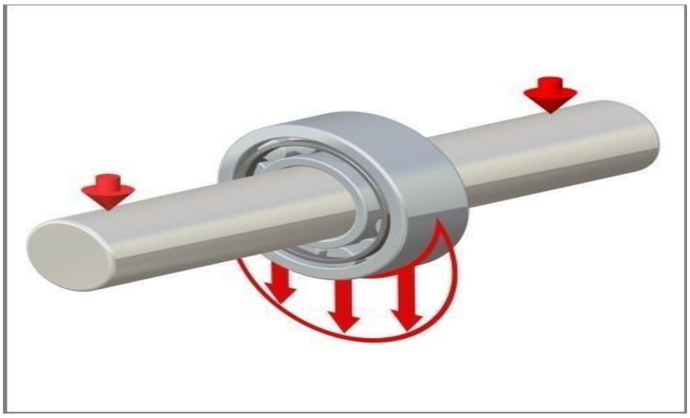
- They transfer motion, i.e. they support and guide components which turn relative to one anotherThey transmit forces.

Rolling bearings and sleeve bearings

- In a sleeve or plain bearing, the axle and the bearing move in opposite directions on a sliding surface.
- By contrast, the two components of a rolling bearing that move towards one another – the inner and outer rings – are separated by rolling elements.

Radial bearings and axial bearings

- Bearings can transmit loads in a radial direction or an axial direction (thrust)and in many casesthere is a combination of both radial and axial loads to transmit.
- Both designs are available as ball bearings or roller bearings.



- Bearings usually consist of the following components:
  Two rings or discs with raceways
  Rolling elements in the form of rollers or balls
  A cage which keeps the rolling elements apart and guides them
- Inner Ring / Outer Ring
  The inner and outer ring are usually made from a special high-purity, chrome alloy steel.
- Thismaterial has the necessary hardness and purity – both important factors for a high load rating and a long service life.

6.4-Parameters for selection of actuators

Parameters for selection of actuators-

- Valves are used to control the flow of fluid in process systems.
- During routine operations, theposition of valves often needs to be opened or closed regularly. In large plants, manually adjusting these valves can be time- consuming and largely impractical.
- In these cases, valve actuators are used in place of hand-operated wheels and levers.
- Valve actuators are mechanical devices used to adjust valve positions. Instead of having operators physically locate and reposition valves, valve positions can be adjusted from a remotely locatedcontrol room.
- The actuator itself is a mechanism that produces a particular motion to control valve.
- Water/waste water treatment facilities Power plantsOil refineries Food and beverage Oil andgas

Types of Valve Actuators

- The working principle of actuator valves primarily depends on their driving force. The two most common types of valve actuators are pneumatic and electric.

Pneumatic Valve Actuators

- Pneumatic valve actuators are the most common type of actuator used in process systems.
- Theseactuators use air (or other gas) pressure as a main power source. Air pressure is used to produce motion to control the position of the valve.
- For double acting and spring return models, we offer two different styles of rack and pinionpneumatic actuators. Rack and pinion pneumatics are excellent for a variety of industrial applications in fields such as chemical & plastic, food & beverage, and a whole breadth of general industrial sectors.

Electric Valve Actuators (Motor Driven Actuators)

- Electric actuators use electricity as their primary power source.
- Electricity is used to produce themotion which opens or closes the valve as required.
- These types of actuators fall into two generalclassifications: solenoid actuators or motor driven actuators.

Power source

- One of the first factors to consider is the most effective power source for the actuator.
- Power source availability, control access, valve size, frequency of operation, and required torque are all factors to consider when choosing between pneumatic or electric actuators.
- For pneumatic actuators, an air pressure generally between 40 and 120 psi would need to be provided. Most electric actuators would require available access to a 110 AC power supply, although different sized AC and DC motors are available.

Temperature range

- The operating temperature range for pneumatic actuators is typically between -4° and 174° F (-20° to 80° C). With appropriately rated seals, bearings, and grease, this temperature range may increase to -40° to 250° F (-40° to 121° C).
- In low temperatures, the dewpoint in relation to the environmental temperature should be considered, as frozen condensate can affect the ability of the air supply port to provide sufficient air pressure.
- Electric motors are typically available in temperature ranges between -40° to 150°F (-40° to 65°C). Special care should be given to electric motors in outdoor applications.

POSSIBLE SHORT TYPE QUESTION: -

Q1-Define Transfer function.

- The transfer function of a control system is defined as the ratio of the Laplace transform of the output variable to Laplace transform of the input variable assuming all initial conditions tobe zero

Q2-Define PD , PID.

- PI-PD controller is designed by approximating the PID feedback control to take advantagesof excellent capabilities of a PID feedback control mechanism in predicting and controlling future error as well as eliminating the steady-state error.
- PID stands for Proportional, Integral, Derivative. PID control provides a continuous variationof output within a control loop feedback mechanism to accurately control the process, removing oscillation and increasing process efficiency

Q3-Define Non- linear control in robotics.

- In nonlinear control field, a. common strategy is called model based control, which can be derived from the. mathematical model of the system.
- However, in case of robot manipulator,it is weakened. by inaccuracies present in the robot model, where the performance of the control algorithm.

Q4-Define Actuators and name different Actuators.

- Similar to pneumatic actuators, they also create precise motion as the flow of electricalpower is constant.
- The different types of electrical actuators include: ...

Electrohydraulic actuators:

- This type of actuator is also powered electrically but gives movement to a hydraulic actuator.

Comb drive.
Hydraulic piston.
Electric motor.
Relay.
Thermal bimorph.

Q5-what is the function of pneumatic Actuators.(S-23)

- A Pneumatic actuator mainly consists of a piston or a diaphragm which develops the motive power.
- It keeps the air in the upper portion of the cylinder, allowing air pressure to force the diaphragm or piston to move the valve stem or rotate the valve control element.

Q6 What are the 4 types of gears?

- Different Types of Gears are

Spur gears.
Helical gears.
Bevel gears.
Worm gears.

Q7 What are the 3 types of bearings?

- Plain Bearings. The most basic type, plain bearings consist of a flat surfacewithout any balls or rollers.

Ball Bearings.
Roller Bearings
Fluid Bearings.
Magnetic Bearings.

Q8 What is Grippers? (S-24)

- It is a mechanical or Robotic device designed to grasp, hold, manipulate or transport objects.
- It serves as the hand or end effector of a robotic arm.

Q9 What is the requirements of arc welding Robots? (S-24)

- Normally six axes industrial Robots comprising a three axes lower arm and a three axis wrist.

- The arc welding enables the tourch mounted at the wrist to achieve all the positions necessary for three dimensional welding.

POSSIBLE LONG TYPE QUESTIONS-

Q-1-Outline the characteristics of second order linear system. (S-22,23)
Q-2-write the working principle of Hydraulic actuators.
Q-3-state the working principle of Pneumatic Actuators.(S-23)
Q-4-Explain different types of Gears Bearing.
Q-5- Write a short not on conceptual dependency.(S-24)
Q-6- Describe the computed Torque Control.(S-24)

Chapter No.-07
Control Hardware and Interfacing

Learning objectives

7.1-Embedded systems: Architecture, Integration with sensors

7.2-Programming for Robot Application

7.1-Embedded systems: Architecture, Integration with sensors

Embedded systems-

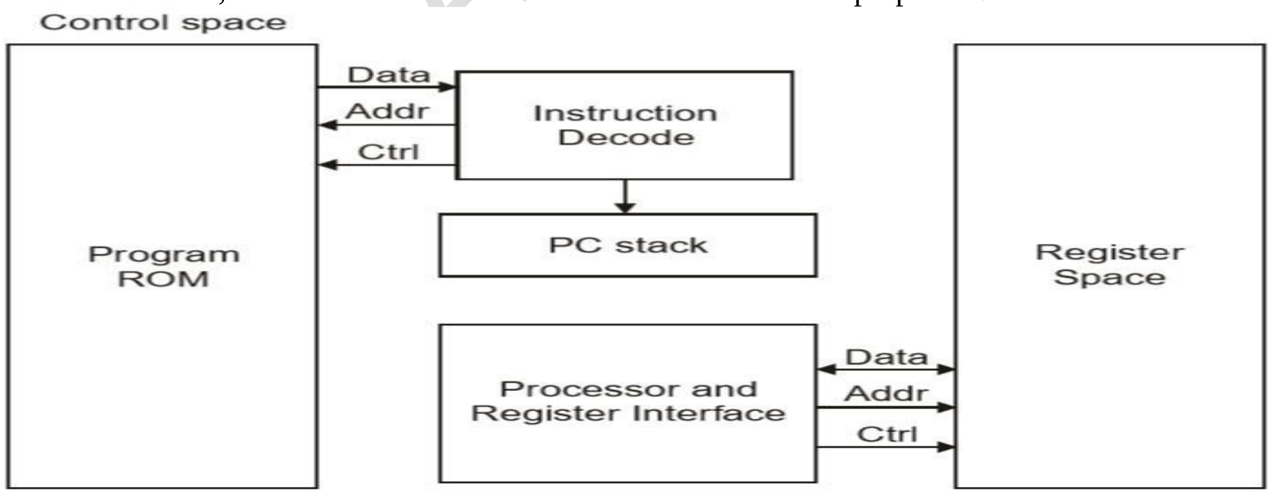
- An embedded system is a microprocessor- or microcontroller-based system of hardware and software designed to perform dedicated functions within a larger mechanical or electrical system.
- At the core is an integrated circuit designed to carry out computationfor real-time operations.
- Complexities range from a single microcontroller to a suite of processors with connected peripherals and networks; from no user interface to complex graphical user
- As much as 98 percent of all microprocessors manufactured are usedin embedded systems.

Architecture of Embedded System-

- Typical embedded system mainly has two parts i.e., embedded hardware and embedded software.
- Embedded hardware's are based around microprocessors and microcontrollers, also include memory, bus, Input/Output, Controller,
- Whereas embedded software includes embedded operating systems, different applications and device drivers. Basically these two types of architecture i.e.,
  1- Harvard architecture and
  2- Von Neumann architecture are used in embedded systems.

Harvard Architecture

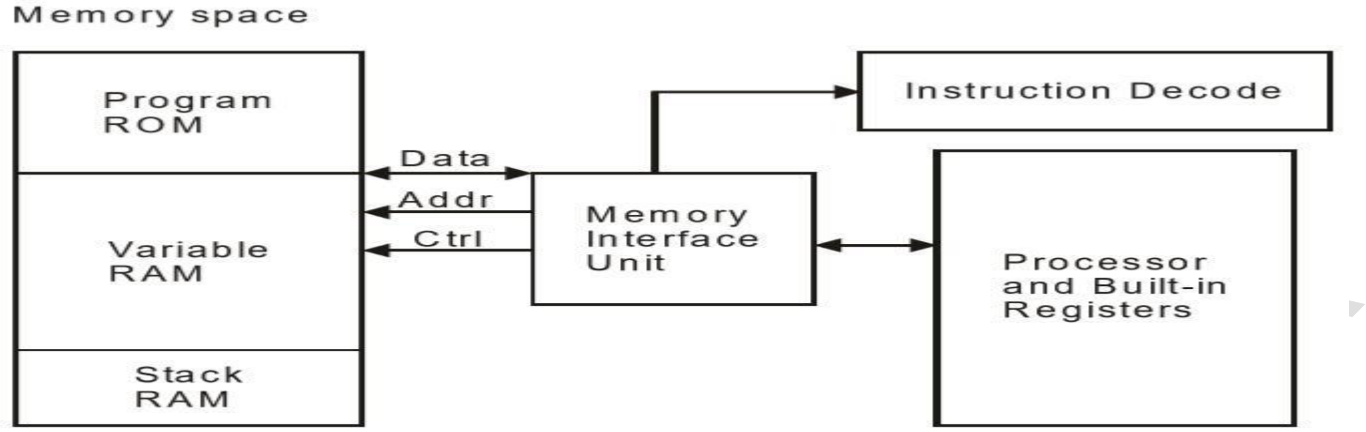
- The Harvard architecture offers separate storage and signal buses for instructions and data.
- This architecture has data storage entirely contained within the CPU, and there is no access to the instruction storage as data.
- Computers have separate memory areas for program instructions and data using internal data buses, allowing simultaneous access to both instructions and data.
- Programs needed to be loaded by an operator; the processor could not boot itself. In a Harvard architecture, there is no need to make the two memories share properties.



Von Neumann Architecture

- The Von Neumann architecture was first proposed by a computer scientist John von Neumann.
- In this architecture, one data path or bus exists for both instruction and data.
- As a result, the CPU does one operation at a time.

- It either fetches an instruction from memory, or performs read/write operation on data. So an instruction fetch and a data operation cannot occur simultaneously, sharing a common bus.



- Von-Neumann architecture supports simple hardware.
- It allows the use of a single, sequential memory.
- Processing speeds vastly outpace memory access times, and we employ a very fast but small amount of memory (cache) local to the processor.

Advantages of Embedded System:

- Embedded systems are fast in performance.
- These systems consume less power
- Small in shape and size.
- These systems are so scalable and reliable.
- Works on wide variety of sectors and environments.
- Performs specific tasks without error.

Disadvantages of Embedded System:

- Difficult to backup of embedded files.
- Sometimes complex to develop.
- Integration may be a problem.
- Offer very limited resources for processing.
- Troubleshooting may be difficult.
- Maintenance may be a problem.

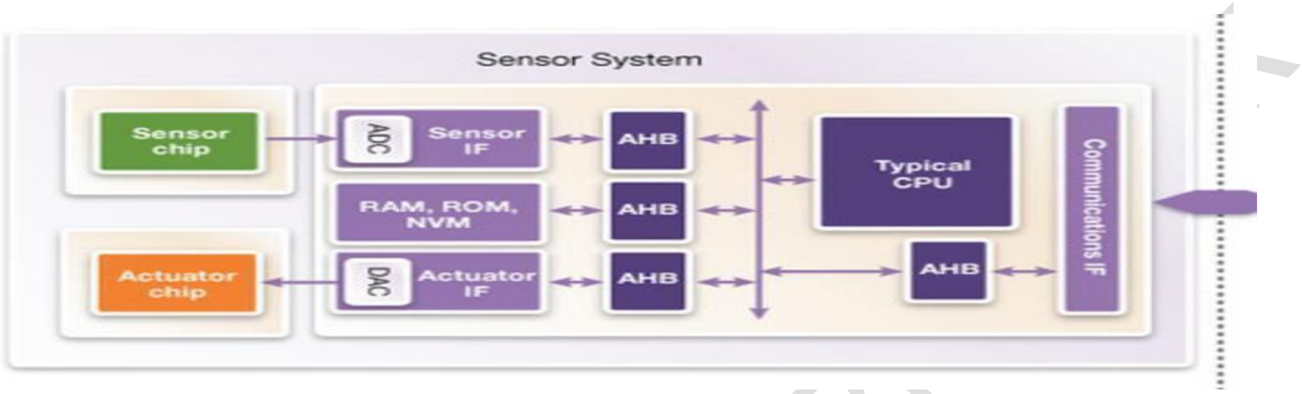
Difference between Von-Neumann Architecture and Harvard Architecture

Von-Neumann Architecture	**Harvard Architecture**
Single memory to be shared by both code and data.	Separate memories for code and data.
Processor needs to fetch code in a separate clock cycle and data in another clock cycle. So it requires two clock cycles.	Single clock cycle is sufficient, as separate buses are used to access code and data.
Higher speed, thus less time consuming.	Slower in speed, thus more time-consuming.
Simple in design.	Complex in design.

Integration with sensor.-

- An integrated sensor is the core technology of a sensor without the package.
- It allows for multiple sensor technologies to be combined or “integrated" into a singleplug-and-play assembly

- Within the sensor subsystem, the advantages of increased integration can differentiate a silicon vendor's device.
- This architecture generally includes a typical CPU, connected through an on-chip bus to peripheral interfaces (ADCand DAC) as well as on-chip memories (ROM, RAM, Flash).
- The processor is connected to a standard bus (typically AMBA based) and all of the peripherals are connected to the bus.
- Transactions between the processor and peripherals take three toseven clocks or more due to bus latency and traffic on the bus. This is very inefficient in terms of performance and power consumption.



Sensor implementation using discrete components

- The Design Ware Sensor Subsystem offers three distinct advantages to help ease integration effort while reducing on-chip latency and power consumption compared totypical bus-based systems.

Closely coupled memories (I-CCM / D-CCM):

- The ARC EM4 core provides an option to integrate tightly coupled memories for bothinstructions and data to reduce access times going across the AHB bus to ROM and RAM in a bus-based topology.

Tightly integrated I/O:

- Starting from existing bus-based I/O peripheral, an ARC processor implementation caneliminate the interface to on-chip bus by replacing load/store instructions to the I/O peripheral with register move instructions.
- This implementation effectively pulls the I/O peripheral interface functionality into theCPU complex, eliminating the buses and bridges.
- Tightly coupling the I/O in this manner also enables single cycle access to all peripheral functions – increasing performance while reducing power consumption and die area to use fewer gates.

7.2-Programming for Robot Application

Robot programming-

- Robot programming refers to the process of developing a control scheme for how a machine interacts with its environment and achieve its goals.
- It usually requires a basic knowledge of mathematics and a programming language.
- For example, Python is one of the most popular robot programming languages today.
- Besides developing machine learning, Python can also be used to create Robot Operating System packages.
- Before we explore other programming languages, let's consider the software first.

Software is Used to Program Robots

Robots Operating System (ROS)

1- Robot Operating System is a middleware — a collection of software frameworks for robot software development.

2- While it's not an operating system, ROS provides services designed for a heterogeneous computer cluster.

These include:

- Hardware abstraction
- Low-level device control
- Implementation of commonly used functionality
- Message-passing between processes
- Package management

For example,

- The open-source project, ROS-Industrial extends the capabilities of ROS to manufacturing automation and robotics.
- These include industrial manipulators, grippers, sensors, and device networks.
- The critical advantage of the robot operating system is the way the software runs and communicate. It allows programmers to design advanced software without knowing how specific hardware work.

Robot Control Software

- **A** robot control software is a program for controlling robots.
- It's the set of coded commands that tells the machine what tasks to perform autonomously.

location and **data sharing**.

- Robot software has a highly proprietary nature. As such, robot hardware manufacturers usually have to provide their own software to work with the machine.
- From over 1,500 programming languages in the world, only ten are popular in the fields of robotics.
- These include Pascal, Scratch, Industrial Robot Language, LISP and Prolog.
- There's also C / C++, Python, JAVA, C# /.NET, MATLAB, **and** Hardware Description Language**.**

Application-

Python

- Python is one of the most popular programming languages,
- The significant advantage of this programming language is its ease of use.
- With Python, things that take up time in programming — such as defining and casting variable types.
- An extensive amount of free libraries is available for Python. As a result, programmers won't have to "reinvent the wheel" to implement some basic functionality.
- Python is useful in robotics because it's one of the main programming languages in ROS (besides C++). Yet, it could become even more popular as more robotic-friendly electronics support the language by default.

MATLAB

- **Robotics** engineers rely on MATLAB for analyzing data and developing control systems.
- Aside from data processing, some university courses also use this programming language for research purposes.
- However, robotics engineers use MATLAB and Simulink to design for various purposes. These include:

Tuning algorithms

- Model real-world systems
- Generating codes automatically
- Furthermore, they perform these functions from one software environment.

Hardware Description Language

- Engineers who create low-level electronics for robots use Hardware Description Languages to describe their prototypes.
- programmers can quickly describe a circuit using words and symbols.
- Development software can then convert that textual description into configuration data for implementation.

- The most popular Hardware Description Languages are Verilog and VHDL. And they're widely used to program Field Programmable Gate Arrays (FPGAs).

POSSIBLE SHORT TYPE QUESTIONS WITH ANSWER

Q1-Define Embedded System with Example.(S-23)

- An embedded system is a microcontroller or microprocessor based system which is designed to perform a specific task.
- For example, a fire alarm is an embedded system; it will sense only smoke.
- A small scale embedded system may not have RTOS.

Q2-Define degree of Freedom. (S-24)

- It is an independent joint that can provide freedom of movement for the manipulator either in a rotational or translational sense.

Q3-What is Assembly Task? (S-24)

- It involves a Robot that constructs a variety of products ranging from large scale systems to microscopic items in the most efficient operation.

Q4-State Difference between Von-Neumann Architecture and Harvard Architecture.(S-22,23)

Von-Neumann Architecture	**Harvard Architecture**
Single memory to be shared by both code and data.	Separate memories for code and data.
Processor needs to fetch code in a separate clock cycle and data in another clock cycle. So it requires two clock cycles.	Single clock cycle is sufficient, as separate buses are used to access code and data.
Higher speed, thus less time consuming.	Slower in speed, thus more time-consuming.
Simple in design.	Complex in design.

Q5 -What are R-joint and P-Joint? (S-24)

- R-joint- It stands for Rotational joint which provides rotational relative motion with the axes of rotational perpendicular to the axes of the input and output links.
- P-Joint- It stands for Prismatic joint which constrains the motion of two bodies to sliding along a common axis without rotation.

POSSIBLE LONG TYPE QUESTIONS

Q1-Draw and explain internal Architecture of Embedded System.(S-23)

Q2-Explain the Types of Embedded System.(S-22)

Q-3-Explain the Robotic Configuration.(S-24)

Q-4-Name the types of basic configuration of Arm and describe all types of configuration.(S-24)