SCHEME : K

Name : ____________________

Roll No. : ______________ Year : 20___ 20___

Exam Seat No. : ______________

LABORATORY MANUAL FOR

PRINCIPLES OF ROBOTICS (314334)

ELECTRONICS ENGINEERING GROUP

MAHARASHTRA STATE BOARD OF
TECHNICAL EDUCATION, MUMBAI
(Autonomous) (ISO 9001: 2015) (ISO/IEC 27001:2013)

VISION

To ensure that the Diploma level Technical Education constantly matches the latest requirements of Technology and industry and includes the all-round personal development of students including social concerns and to become globally competitive, technology led organization.

MISSION

To provide high quality technical and managerial manpower, information and consultancy services to the industry and community to enable the industry and community to face the challenging technological & environmental challenges.

QUALITY POLICY

We, at MSBTE are committed to offer the best-in-class academic services to the students and institutes to enhance the delight of industry and society. This will be achieved through continual improvement in management practices adopted in the process of curriculum design, development, implementation, evaluation and monitoring system along with adequate faculty development programmes.

CORE VALUES

MSBTE believes in the following

- Skill development in line with industry requirements
- Industry readiness and improved employability of Diploma holders
- Synergistic relationship with industry
- Collective and Cooperative development of all stake holders
- Technological interventions in societal development
- Access to uniform quality technical education

A Laboratory manual

for

Principles of Robotics

(314334)

K-Scheme

Semester – IV

(AO)

Maharashtra State

Board of Technical Education, Mumbai

(Autonomous) (ISO 9001:2015) (ISO/IEC 27001:2013)

Maharashtra State Board of Technical Education, Mumbai
(Autonomous) (ISO 9001:2015) (ISO/IEC 27001:2013)
4th Floor, Government Polytechnic Building, 49,
Kherwadi, Bandra (East), Mumbai- 400051.

MAHARASHTRA STATE BOARD OF TECHNICAL EDUCATION

Certificate

This is to certify that Mr./Ms.…………………………………….............
Roll. No.…………. of Fourth Semester of Diploma in ……....
.....…..…………………………………..
of Institute ……..……………………………………………… (Code: ………) has completed the term work satisfactorily in course **Principles of Robotics (314334)** for the academic year 20…….to 20…… as prescribed in the curriculum.

Place: …………….   Enrollment No: ………………
Date: ………………   Exam Seat No: ……………….

Subject Teacher **Head of department** **Principal**

Seal
of
Institute

Preface

The primary focus of any engineering laboratory/field work in the technical education system is to develop the much-needed industry relevant competencies and skills. With this in view, MSBTE embarked on this innovative 'K' Scheme curricula for engineering diploma programmes with outcome-based education as the focus and accordingly, a relatively large amount of time is allotted for the practical work. This displays the great importance of laboratory work making each teacher, instructor and student realize that every minute of the laboratory time needs to be effectively utilized to develop these outcomes, rather than doing other mundane activities. Therefore, for the successful implementation of this outcome- based curriculum, every practical course has been designed to serve as a ***'vehicle'*** to develop this industry identified competency in every student. The practical skills are difficult to develop through "chalk and duster" activity in the classroom situation. Accordingly, the ‘K’ scheme laboratory manual development team designed the practical to focus on the outcomes, rather than the traditional age-old practice of conducting practical to 'verify the theory" (which may become a byproduct along the way).

This laboratory manual is designed to help all stakeholders, especially the students, teachers and instructors to develop in the student the predetermined outcomes. It is expected. from each student that at least a day in advance, they have to thoroughly read through the concerned practical procedure that they will do the next day and understand the minimum theoretical background associated with the practical. Every practical in this manual begins by identifying the competency, industry relevant skills, course outcomes and practical outcomes which serve as a key focal point for doing the practical. The students will then become aware about the skills they will achieve through the procedure shown there and necessary precautions to be taken, which will help them to apply in solving real-world problems in their professional life.

This manual also provides guidelines to teachers and instructors to effectively facilitate student-centered lab activities through each practical exercise by arranging and managing necessary resources in order that the students follow the procedures and precautions systematically ensuring the achievement of outcomes in the students.

The basic aim of the course Principles of Robotics (314334) is to facilitate the diploma students to acquire an understanding of the fundamental concepts, theories, and principles that govern the design, operation, and application of robotic systems.

Although the best possible care has been taken to check for errors (if any) in this laboratory manual, perfection may elude us as this is the first edition of this manual. Any errors and suggestions for improvement are solicited and highly welcome.

Program Outcomes (POs)

PO1 Basic and Discipline specific knowledge: Apply knowledge of basic mathematics, science and engineering fundamentals and engineering specialization to solve the broad-based Electronic Engineering group program problems.

PO2 Problem analysis: Identify and analyze well-defined Electronic Engineering group program problems using codified standard methods.

PO3 Design/ development of solutions: Design solutions for well-defined technical problems and assist with the design of Electronic Engineering group program systems components or processes to meet specified needs.

PO4 Engineering Tools, Experimentation and Testing: Apply modern Electronic Engineering group program tools and appropriate technique to conduct standard tests and measurements.

PO5 Engineering practices for society, sustainability and environment: Apply appropriate Electronic Engineering group program technology in context of society, sustainability, environment and ethical practices.

PO6 Project Management: Use Electronic Engineering group program management principles individually, as a team member or a leader to manage projects and effectively communicate about well-defined engineering activities.

PO7 Life-long learning: Ability to analyze individual needs and engage in updating in the context of Electronic Engineering group program technological changes.

List of relevant expected psychomotor domain skills

The following industry relevant skills of the identified competency "Use different types of controllers ensuring the stability of the given control system" are expected to be developed in student by undertaking the laboratory work as given in laboratory manual.

1. Identify the basic anatomy of a robotic system
2. Apply the concepts of engineering mechanics in robotic system
3. Interpret the transformations used in robotics
4. Analyse the kinematics of the robotic arm.
5. Interpret the dynamics and motion planning of the robotic arm
6. Proper handling of instruments.
7. Measure the physical quantities accurately.
8. Observe the phenomenon and list the observations in proper tabular form.
9. Adopt proper procedure while performing the experiment.

Practical-Course outcome matrix

COURSE LEVEL LEARNING OUTCOMES (COs)

CO1. Identify the basic anatomy of a robotic system
CO2. Apply the concepts of engineering mechanics in robotic system
CO3. Interpret the transformations used in robotics
CO4. Analyse the kinematics of the robotic arm
CO5. Interpret the dynamics and motion planning of the robotic arm

Sr. No.	Title of the Practical	CO1	CO2	CO3	CO4	CO5
1	*Analysis of robot manipulator movement using 3D model based open source software (OSS)	✓	-	-	-	-
2	*Working of different type of joints used in robots using 3D model based OSS	✓	-	-	-	-
3	Operation of a 2-finger pneumatic and vacuum parallel gripper of a robot	✓	-	-	-	-
4	*Verification of law of moment of forces using law of moment apparatus	-	✓	-	-	-
5	Verification of centroid of given plane	-	✓	-	-	-
6	Determination of the rotation matrix of the given manipulator along any given axis using OSS	-	-	✓	-	-
7	*Determination of the HTM for rotation and translation for the given robot manipulator using 3D model based OSS	-	-	✓	-	-
8	Analysis of DH table for different values of DH parameters of a given robot manipulator using 3D model based OSS	-	-	✓	-	-
9	*Determine the HTM for different values of DH parameters of a given robot manipulator for various links using 3D model based OSS	-	-	✓	-	-
10	*Determination of the position and orientation of end effector of a 4 axis/6 axis robot using forward kinematics	-	-	-	✓	-
11	*Determination of the joint angle for the given position of the end effector of a 4 axis/6 axis robot using inverse kinematics	-	-	-	✓	-
12	Derivation of Jacobian matrix using OSS for the given manipulator	-	-	-	✓	-
13	*Determination of the position and orientation of the end effector for the given force at the joint of a 4 axis/6 axis robot using forward dynamics	--	--	--	-	✓
14	Determination of the forces required at the joint from the position and orientation of the end effector of a 4 axis/6 axis robot using inverse dynamics	-	-	-	-	✓
15	Interpolation of Cartesian space trajectories of the given 4axis/6axis robot manipulator	-	-	-	-	✓
16	Interpolation of the joint space trajectories of the given 4 axis/6 axis robot manipulator	-	-	-	-	✓

Guidelines to Teachers

1. Teacher should provide the guideline with demonstration of practical to the students with all features.
2. Teacher shall explain prior concepts to the students before starting of each experiment
3. Involve students in performance of each experiment.
4. Teacher should ensure that the respective skills and competencies are developed in. the students after the completion of the practical exercise.
5. Teachers should give opportunity to students for hands on experience after the demonstration.
6. Teacher is expected to share the skills and competencies to be developed in the students.
7. Teacher may provide additional knowledge and skills to the students even though not covered in the manual but are expected the students by the industry.
8. Finally give practical assignment and assess the performance of students based on task assigned to check whether it is as per the instructions.
9. Teacher is expected to refer complete curriculum document and follow guidelines for implementation
10. At the beginning of the practical which is based on the simulation, teacher should make the students acquainted with any simulation software environment.

Instructions for Students

1. Listen carefully the lecture given by teacher about subject, curriculum, learning structure, skills to be developed.
2. Organize the work in the group and make record all programs.
3. Students shall develop maintenance skill as expected by industries.
4. Student shall attempt to develop related hand-on skills and gain confidence.
5. Student shall develop the habits of evolving more ideas, innovations, skills etc. those included in scope of manual
6. Student shall refer technical magazines.
7. Student should develop habit to submit the practical on date and time.
8. Student should well prepare while submitting write-up of exercise.
9. Attach/paste separate papers wherever necessary.

Content Page

List of Practical's and Progressive Assessment Sheet

Note: Out of above suggestive LLOs -

- '*' Marked Practicals (LLOs) Are mandatory.
- Minimum 80% of above list of lab experiment are to be performed.
- Judicial mix of LLOs are to be performed to achieve desired outcomes.

Practical No.1: Analysis of robot manipulator movement using 3D model based open source software (OSS)

I Practical Significance

To familiarize the students with the 3D model based Open source software to observe robot manipulator movement

II Industry/Employer Expected Outcome(s)

Apply the principles of Robotics to automate various industries

III Course Level Learning Outcome(s)

Identify the basic anatomy of a robotic system

IV Laboratory Learning Outcome(s)

- Install 3D model based open source software (Ex. RoboAnalyzer)
- Observe the movement of a robot manipulator using virtual robot module with the help of 3D model based open source software.

V Relevant Affective Domain related outcome(s)

Follow ethical practices

Handle tools and equipment carefully.

VI Relevant Theoretical Background

A Robot is defined by the International Standard of Organization (ISO) as a reprogrammable multifunctional manipulator designed to perform the orders given to it by the human being through the programmed motion. The manipulator is the physical/mechanical structure of the Robot which moves around. It is similar to the human arm. It consists of several links connected in series by joints

VII Actual Circuit diagram used in laboratory with related equipment rating

NA

VIII Required Resources/apparatus/equipment with specifications

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Desktop PC loaded with 3D model based open source software for robotics	- -	**1**

IX Precautions to be followed

1) Ensure proper earthing.
2) Use standard Electrical symbols.
3) Check the power supply before connection.

X Procedure

1. Install 3D model based open-source software in the computer
2. Open the 3D model based open-source software in the computer
3. Observe the robot manipulator movement for various DOF

XI Resources Used

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity

XII Actual Procedure

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XIII Observations and Calculations (use blank sheet provided if space not sufficient)

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XIV Result(s)

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XV Interpretation of results

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XVI Conclusion and recommendation

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XVII Practical related questions

Note: Below given are few sample questions for reference. Teacher must design more such questions so as to ensure the achievement of identifies CO.

1. Write the name of the 3D model based open source software used in the laboratory
2. Write few names of manufacturers of robots
3. State the laws of robotics

[Space for Answers]

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XVIII References/Suggestions for further reading

1. https://archive.nptel.ac.in/courses/112/104/112104298
2. Introduction to Robotics by Saha, S.K.

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related: 15 Marks		**60 %**
1	Handling of the components	10%
2	Identification of components	20%
3	Measuring value using suitable instrument	20%
4	Working in teams	10%
Product Related: 10 Marks		**40%**
5	Calculated theoretical values of given component	10%
6	Interpretation of result	05%
7	Conclusion	05%
8	Practical related questions	15%
9	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			Dated signature of Teacher
Process related (15)	**Product related (10)**	**Total (25)**	

Practical No.2: *Working of different types of joints used in robots using 3D model-based OSS

I Practical Significance

To familiarize the students with the 3D model based Open source software to observe Working of different types of joints used in robots

II Industry/Employer Expected Outcome(s)

Apply the principles of Robotics to automate various industries

III Course Level Learning Outcome(s)

Identify the basic anatomy of a robotic system

IV Laboratory Learning Outcome(s)

Observe the movement of joints in robots using 3D model based open source software

V Relevant Affective Domain related outcome(s)

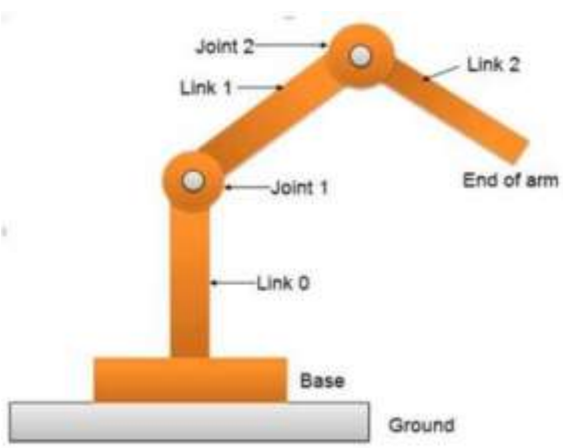
Follow ethical practices

Handle tools and equipment carefully.

VI Relevant Theoretical Background

The manipulator is the physical/mechanical structure of the Robot which moves around. It is similar to the human arm. It consists of several links connected in series by joints. It is a collection of mechanical linkages connected by movable joints to perform the assigned task. Each link is made up of steel or aluminum. Types of joints are:

1. Linear joint
2. Orthogonal joint
3. Rotational joint
4. Twisting joint
5. Revolving joint



VII Actual Circuit diagram used in laboratory with related equipment rating

NA

VIII Resources Required

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Desktop PC loaded with 3D model based open-source software for robotics	- -	1

IX Precautions to be followed

1) Verify power ratings.
2) Ensure proper earthing.
3) Check the power supply before connection.

X Procedure

1. Install 3D model based open-source software in the computer
2. Open the 3D model based open-source software in the computer
3. Observe the working of different types of joints used in robots

XI Resources Used

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity

XII Actual Procedure

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XIII Observations and Calculations (use blank sheet provided if space not sufficient)

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XIV Result(s)

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XV Interpretation of results

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XVI Conclusion and recommendation

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XVII Practical related questions

Note: Below given are few sample questions for reference. Teacher must design more such questions so as to ensure the achievement of identifies CO.

1. Name the types of joints used in robotics

2. Draw any three types of joints used in Robotics

[Space for Answers]

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XVIII References/Suggestions for further reading

1. https://archive.nptel.ac.in/courses/112/104/112104298
2. Introduction to Robotics by Saha, S.K.

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related: 15 Marks		**60 %**
1	Handling of the components	10%
2	Identification of components	20%
3	Measuring value using suitable instrument	20%
4	Working in teams	10%
Product Related: 10 Marks		**40%**
5	Calculated theoretical values of given component	10%
6	Interpretation of result	05%
7	Conclusion	05%
8	Practical related questions	15%
9	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			**Dated signature of Teacher**
Process related (15)	**Product related (10)**	**Total (25)**	

Practical No.3: Operation of a 2-finger pneumatic and vacuum parallel gripper of a robot

I Practical Significance

To familiarize the students with the operation of a 2-finger pneumatic and vacuum parallel gripper of a robot

II Industry/Employer Expected Outcome(s)

Apply the principles of Robotics to automate various industries

III Course Level Learning Outcome(s)

Identify the basic anatomy of a robotic system

IV Laboratory Learning Outcome(s)

1. Operate a 2-finger pneumatic parallel gripper of a robot
2. Operate a 2-finger vacuum parallel gripper of a robot

V Relevant Affective Domain related outcome(s)

Follow ethical practices

Handle tools and equipment carefully.

VI Relevant Theoretical Background

- A pneumatic gripper uses compressed air and pistons to operate its 'jaws' (also known as 'fingers'). Pneumatic grippers hold the object with the help of suction cups.
- The vacuum grippers use suction cups (vacuum cups) as pick up devices. The vacuum is generated by an electromechanical pump or a compressed air-driven pump. Vacuum grippers are suitable to handle large flat objects. But the object's surface should not have any holes.

VII Actual Circuit diagram used in laboratory with related equipment rating

NA

VIII Resources Required

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
	Parallel link gripper kit containing pneumatic and vacuum gripper		1

IX Precautions to be followed

1) Verify power ratings.
2) Ensure proper earthing.
3) Check the power supply before connection.

X Procedure

1. Connect the kit to the power supply
2. Place the workpiece at the suitable point
3. Start the compressor
4. Observe the movement of the jaws which grasp the workpiece

XI Resources Used

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity

XII Actual Procedure

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XIII Observations and Calculations (use blank sheet provided if space not sufficient)

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XIV Result(s)

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XV Interpretation of results

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XVI Conclusion and recommendation

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XVII Practical related questions

Note: Below given are few sample questions for reference. Teacher must design more such questions so as to ensure the achievement of identifies CO.

1. Draw the vacuum gripper
2. Compare the vacuum gripper with pneumatic gripper

[Space for Answers]

XVIII References/Suggestions for further reading

1. https://archive.nptel.ac.in/courses/112/104/112104298
2. Introduction to Robotics by Saha, S.K.

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related: 15 Marks		**60 %**
1	Handling of the components	10%
2	Identification of components	20%
3	Measuring value using suitable instrument	20%
4	Working in teams	10%
Product Related: 10 Marks		**40%**
5	Calculated theoretical values of given component	10%
6	Interpretation of result	05%
7	Conclusion	05%
8	Practical related questions	15%
9	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			Dated signature of Teacher
Process related (15)	**Product related (10)**	**Total (25)**	

Practical No.4: Verification of law of moment of forces using law of moment apparatus

I Practical Significance

To familiarize the students with the concept of law of moment of forces

II Industry/Employer Expected Outcome(s)

Apply the principles of Robotics to automate various industries

III Course Level Learning Outcome(s)

Apply the concepts of engineering mechanics in robotic system

IV Laboratory Learning Outcome(s)

Verify law of moment of forces using law of moment apparatus for given forces

V Relevant Affective Domain related outcome(s)

Follow ethical practices

Handle tools and equipment carefully.

VI Relevant Theoretical Background

The Principle of Moments states that when a body is balanced, the total clockwise moment of a point equals the total anticlockwise moment about the same point. The real examples of moment of force in real life are the opening and closing of a door along a fixed hinge, a seesaw and unscrewing a nut with a spanner. The moment of force is found by multiplying the force by its distance from the pivot. In robotics, torque is used to control the movement of robot arms and joints.

VII Circuit diagram / Layout of Laboratory

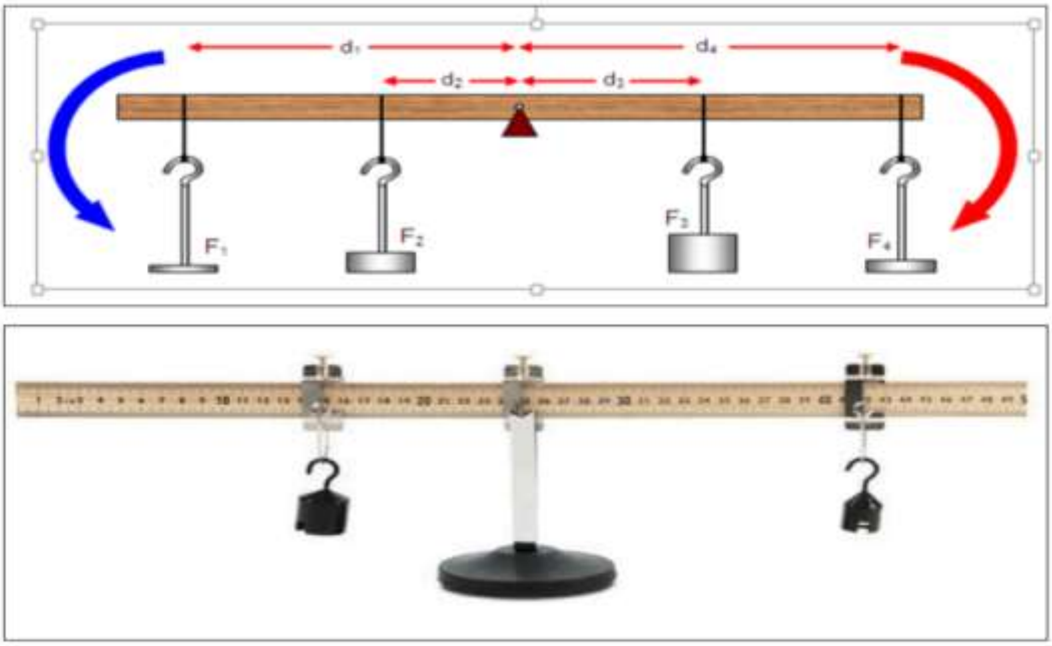

Fig: 4:1

VIII Resources Required

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Law of moment's apparatus consisting of a stainless-steel graduated beam 12.5 mm square in section, 1m long, pivoted at centre	-	1

IX Precautions to be followed

1. Verify power ratings.
2. Ensure proper earthing.
3. Check the power supply before connection.

X Procedure

1. Place unequal weights on each side of the pivot
2. Move the weight until the meter rule balances
3. When this occurs take note of the anti-clockwise and clockwise moments
4. Repeat several times by changing distance on each side and take more sets of observations

XI Resources Used

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity

XII Actual Procedure

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XIII Observations and Calculations (use blank sheet provided if space not sufficient)

Sr. No.	Force F_1(N)	Force F_2 (N)	Distance d_1(cm)	Distance d_2 (cm)	Anti-clockwise Moment F_1d_1 (Ncm)	Clockwise Moment F_2d_2 (Ncm)

XIV Result(s)

Anticlockwise moment and Clockwise moment are...............................
(Equal/Nearly equal/Not equal).
The difference in anticlockwise moment and Clockwise moment is because of
.... (Error of manipulation/Instrument error/observation error)

XV Interpretation of results

If the body is in equilibrium, then anticlockwise and clockwise moments are nearly the same.

XVI Conclusion and recommendation

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XVII Practical related questions

Note: Below given are few sample questions for reference. Teacher must design more such questions so as to ensure the achievement of identifies CO.

1. State the Law of moment
2. Explain Clockwise and Anticlockwise moment.

[Space for Answers]

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XVIII References/Suggestions for further reading

1. Engineering Mechanics by Khurmi, R.S.; Khurmi, N
2. https://www.schoolphysics.co.uk/age11-14/Mechanics/Statics/text/Balancing_/index.html

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related: 15 Marks		**60 %**
1	Handling of the components	10%
2	identification of components	20%
3	Measuring value using suitable instrument	20%
4	working in teams	10%
Product Related: 10 Marks		**40%**
5	Calculated theoretical values of given component	10%
6	Interpretation of result	05%
7	Conclusion	05%
8	Practical related questions	15%
9	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			Dated signature of Teacher
Process related (15)	**Product related (10)**	**Total (25)**	

Practical No.5: Verification of centroid of given plane

I Practical Significance

To familiarize the students with the concept of centroid of the given plane

II Industry/Employer Expected Outcome(s)

Apply the principles of Robotics to automate various industries

III Course Level Learning Outcome(s)

Apply the concepts of engineering mechanics in robotic system

IV Laboratory Learning Outcome(s)

Verify centroid of given plane

V Relevant Affective Domain related outcome(s)

Follow ethical practices

Handle tools and equipment carefully.

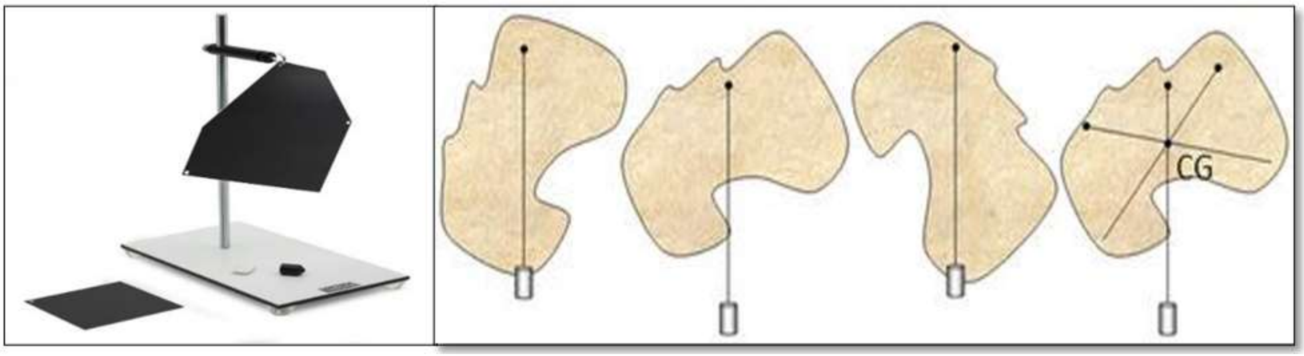
VI Relevant Theoretical Background

Centre of gravity: The centre of gravity of a body is that point through which the resultant of the system of parallel forces formed by the weights of all the particles of the body passes for all positions of the body.

Centre of Mass: The point at which the whole mass of a body is supposed to be concentrated is known as centre of mass.

Centroid: It is the point at which whole area of the body is supposed to be concentrated.

VII Circuit diagram / Layout of Laboratory



VIII Resources Required

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Models of geometrical figures of square, rectangle, triangle, circle, semicircle, quarter circle	- -	1
2	Plumb bob with string	-	1

IX Precautions to be followed

1) Lines should be connected to each other accurately.
2) Drawing errors should be reduced to minimum to get correct results.

X Procedure

1. Mark holes on model of any geometrical figures
2. Hang that on a peg through the desired hole.
3. Hang a plumb bob and mark plumb line with marker.
4. Repeat same procedure for other holes.
5. Mark the point of intersection of these lines. This point gives the centroid of that lamina experimentally.
6. Also calculate the center of gravity of that plane lamina analytically.

XI Resources Used

Sr.No.	Name of Resource	Suggested Broad Specification	Quantity

XII Actual Procedure

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XIII Observations and Calculations (use blank sheet provided if space not sufficient)

Sr. No.	Shape	Dimensions (mm)	X Coordinate (mm)	Y Coordinate (mm)
1	Square			
2	Rectangle			
3	Triangle			
4	Circle			
5	Semicircle			
6	Quarter circle			

XIV Result(s)

1. Centroid of Square =
2. Centroid of Rectangle =
3. Centroid of Triangle =
4. Centroid of Circle =
5. Centroid of Semicircle =
6. Centroid of Trapezium =

XV Interpretation of results

Centroids of plane figures calculated by using formula are nearly equal to measured value of centroid with plumb line.

XVI Conclusion and recommendation

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XVII Practical related questions

Note: Below given are few sample questions for reference. Teacher must design more such questions so as to ensure the achievement of identifies CO.

1. Define Centroid and Centre of gravity.
2. Find the position of centroid of a quarter circle having 100cm as diameter.
3. Find centre of gravity of solid cylinder diameter 100mm and height 150mm.

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XVIII References/Suggestions for further reading

1. Engineering Mechanics by Khurmi, R.S.; Khurmi, N
2. https://www.youtube.com/watch?v=R8wKV0UQtlo&t=50s

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related: 15 Marks		**60 %**
1	Handling of the components	10%
2	identification of components	20%
3	Measuring value using suitable instrument	20%
4	working in teams	10%
Product Related: 10 Marks		**40%**
5	Calculated theoretical values of given component	10%
6	Interpretation of result	05%
7	Conclusion	05%
8	Practical related questions	15%
9	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			Dated signature of Teacher
Process related (15)	**Product related (10)**	**Total (25)**	

Practical No.6: Determination of the rotation matrix of the given manipulator along any given axis using OSS

I Practical Significance

To familiarize the students with the concept of rotation matrix of the given manipulator along any given axis

II Industry/Employer Expected Outcome(s)

Apply the principles of Robotics to automate various industries

III Course Level Learning Outcome(s)

Interpret the transformations used in robotics

IV Laboratory Learning Outcome(s)

1. Determine rotation matrix along X axis using open-source software for the given manipulator.
2. Determine rotation matrix along Y axis using open-source software for the given manipulator.
3. Determine rotation matrix along Z axis using open-source software for the given manipulator.

V Relevant Affective Domain related outcome(s)

Follow ethical practices

Handle tools and equipment carefully.

VI Relevant Theoretical Background

Elementary rotation matrix about X axis:

- Expression for rotation about X axis by θ in anticlockwise direction is given by the matrix R $(\bar{X}, \theta)$:

$$Rot(\bar{X},\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\theta & -sin\theta \\ 0 & sin\theta & cos\theta \end{bmatrix}$$

  - Here, the row and column associated with X axis is empty which indicates that any vectors along X axis remains unchanged

Elementary rotation matrix about Y axis:

Expression for rotation about Y axis by θ in anticlockwise direction is given by the matrix R $(\bar{Y}, \theta)$:

$$Rot(\bar{Y},\theta) = \begin{bmatrix} cos\theta & 0 & sin\theta \\ 0 & 1 & 0 \\ -sin\theta & 0 & cos\theta \end{bmatrix}$$

- Here, the row and column associated with Y axis is empty which indicates that any vectors along Y axis remains unchanged.

Elementary rotation matrix about Z axis:

Expression for rotation about Z axis by θ in anticlockwise direction is given by the matrix R $(\bar{Z}, \theta)$:

$$Rot(\bar{Z},\theta) = \begin{bmatrix} cos\theta & -sin\theta & 0 \\ sin\theta & cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Here, the row and column associated with the Z axis is empty which indicates that any vectors along the Z axis remain unchanged

VII Circuit diagram Layout of Laboratory

NA

VIII Resources Required

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Any desktop or laptop with basic configuration and open source software for robotics	- -	1

IX Precautions to be followed

1) Ensure proper earthing.
2) Check the power supply before connection.

X Procedure

1. Open the open source software in the computer
2. Open HTM module
3. Rotate about X axis, Y axis, Z axis for various angles
4. Verify the result

XI Resources Used

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity

XII Actual Procedure

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XIII Observations and Calculations (use blank sheet provided if space not sufficient)

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XIV Result(s)

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XV Interpretation of results

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XVI Conclusion and recommendation

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XVII Practical related questions

Note: Below given are few sample questions for reference. Teacher must design more such questions so as to ensure the achievement of identifies CO.

1. Derive the rotational operator matrix for ROT (Z , θ).
2. If the rotation about X axis is by an angle 45 degree, find out Rot (X, 45)

[Space for Answers]

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XVIII References/Suggestions for further reading

1. https://archive.nptel.ac.in/courses/112/104/112104298
2. Introduction to Robotics by Saha, S.K.

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related: 15 Marks		**60 %**
1	Handling of the components	10%
2	Identification of components	20%
3	Measuring value using suitable instrument	20%
4	Working in teams	10%
Product Related: 10 Marks		**40%**
5	Calculated theoretical values of given component	10%
6	Interpretation of result	05%
7	Conclusion	05%
8	Practical related questions	15%
9	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			Dated signature of Teacher
Process related (15)	**Product related (10)**	**Total (25)**	

Practical No.7: Determination of the HTM for rotation and translation for the given robot manipulator using 3D model based OSS

I Practical Significance

To familiarize the students with the concept of HTM for rotation and translation of the given manipulator

II Industry/Employer Expected Outcome(s)

Apply the principles of Robotics to automate various industries

III Course Level Learning Outcome(s)

Interpret the transformations used in robotics

IV Laboratory Learning Outcome(s)

1. Determine Homogeneous Transformation Matrix (HTM) for pure translation using 3D model based open source software.
2. Determine HTM for pure rotation using 3D model based open source software.
3. Determine HTM for rotation and translation using 3D model based open source software.

V Relevant Affective Domain related outcome(s)

Follow ethical practices

Handle tools and equipment carefully.

VI Relevant Theoretical Background

- Transformation matrix: The relation between the body coordinate frames B of the rigid body with the base frame of reference (the universal reference coordinate frame U) is described by Transformation matrix.
- Homogeneous transformation represents the pose (position and orientation) of a frame (rigid body) with respect to another frame.
- Matrix which takes care of both the translation and rotation of the frame attached to the body with respect to the fixed frame is called the Homogeneous Transformation Matrix.

Homogeneous Transformation Matrix (HTM) T:

$$T = \begin{bmatrix} {}^{U}_{B}R & \bar{t}_B \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Rotation of frame B with respect to frame U:

$${}^{U}_{B}R = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}$$

- The position vector denoting the translation of the origin of frame B from that of frame U:

$$\bar{t}_B = \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix}$$

VII Actual Circuit diagram used in a laboratory with related equipment rating

NA

VIII Resources Required

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Any desktop or laptop with basic configuration and open source software for robotics	-	**1**

IX Precautions to be followed

1) Ensure proper earthing.
2) Check the power supply before connection.

X Procedure

1. Open the open source software for robotics in the computer
2. Open HTM module
3. Translate along X axis, Y axis, Z axis for various distances
4. Observe the HTM
5. Rotate about X axis, Y axis, Z axis for various angles
6. Observe the HTM
7. Rotate and translate together for various values
8. Observe the HTM

XI Resources Used

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
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XII Actual Procedure

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XIII Observations and Calculations (use blank sheet provided if space not sufficient)

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XIV Result(s)

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XV Interpretation of results

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XVI Conclusion and recommendation

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XVII Practical related questions

Note: Below given are few sample questions for reference. Teacher must design more such questions so as to ensure the achievement of identifies CO.

1. Define Homogeneous Transformation Matrix (HTM) T. State its equation. Explain each terms
2. Find out HTM for rotation about X axis by 60 degrees and translation along X axis by 5

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XVIII References/Suggestions for further reading

1. https://archive.nptel.ac.in/courses/112/104/112104298
2. Introduction to Robotics by Saha, S.K.

XIX Assessment Scheme

	Performance Indicators	Weightage
	Process Related: 15 Marks	**60 %**
1	Handling of the components	10%
2	Identification of components	20%
3	Measuring value using suitable instrument	20%
4	Working in teams	10%
	Product Related: 10 Marks	**40%**
5	Calculated theoretical values of given component	10%
6	Interpretation of result	05%
7	Conclusion	05%
8	Practical related questions	15%
9	Submitting the journal in time	05%
	Total (25 Marks)	**100 %**

Marks Obtained			**Dated signature of Teacher**
Process related (15)	**Product related (10)**	**Total (25)**	

Practical No.8: Analysis of DH table for different values of DH parameters of a given robot manipulator using 3D model based OSS

I Practical Significance

To familiarize the students with the concept of DH parameters of the given manipulator

II Industry/Employer Expected Outcome(s)

Apply the principles of Robotics to automate various industries

III Course Level Learning Outcome(s)

Interpret the transformations used in robotics

IV Laboratory Learning Outcome(s)

Verify DH table for different values of DH parameters of a given robot manipulator using 3D model based open source software

V Relevant Affective Domain related outcome(s)

Follow ethical practices

Handle tools and equipment carefully.

VI Relevant Theoretical Background

DH parameters:

a) **Joint offset** (d or bi): (Translation along Z axis):

It is the translation along the previous Z-axis needed to make the previous X axis intersect with the current X axis.

b) **Joint angle** (θi): (Rotation along Z axis)

It is the rotation about the previous Z axis needed to make the previous X axis parallel with the current X axis.

c) **Link length** (ai or r): (Translation along X axis)

It is the translation along the current X-axis needed to make the previous Z axis intersect with the current Z axis.

d) **Twist angle** (α i): (Rotation along X axis)

It is the rotation about the current X axis needed to make the previous Z axis parallel with the current Z axis. It is the axis twist angle of two adjacent joints.

VII Circuit diagram Layout of Laboratory

NA

VIII Resources Required

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Any desktop or laptop with basic configuration and open source software for robotics	- -	1

IX Precautions to be followed

1) Ensure proper earthing.
2) Check the power supply before connection.

X Procedure

1. Open the open source software for robotics in the computer
2. Select the manipulator by choosing the desired degree of freedom and the type of joints
3. Redefine the values of D-H parameters
4. Visualize each DH parameter by selecting a joint and then selecting a DH parameter
5. Observe the corresponding DH parameter which is highlighted in the DH parameter input table
6. Observe the movement of the corresponding coordinate frame in the 3D robot model
7. Click on **Together** button to see the movement of coordinate frame covering all four DH parameters corresponding to the selected joint.
8. Click on **Base Frame to End-Effector** button to see the movement of coordinate frame moving from base frame to the end-effector frame covering all the DH parameters of the robot model
9. Repeat from step 2 for different manipulator

XI Resources Used

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity

XII Actual Procedure

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XIII Observations and Calculations (use blank sheet provided if space not sufficient)

Set 1.

	Joint no.	Type of joint	Joint offset	Joint angle	Link length	Twist angle
Manipulator DOF=						
Selected Robot type = (ex. 3R, 3P, RRP etc.)						

Set 2.

	Joint no.	Type of joint	Joint offset	Joint angle	Link length	Twist angle
Manipulator DOF= Selected Robot type = (ex. 3R, 3P, RRP etc.)						

XIV Result(s)

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XV Interpretation of results

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XVI Conclusion and recommendation

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XVII Practical related questions

Note: Below given are few sample questions for reference. Teacher must design more such questions so as to ensure the achievement of identifies CO.

1. Name and define DH parameters.
2. Find out the DH parameters of SCARA robot

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XVIII References/Suggestions for further reading

1. https://archive.nptel.ac.in/courses/112/104/112104298
2. Introduction to Robotics by Saha, S.K.

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related: 15 Marks		**60 %**
1	Handling of the components	10%
2	Identification of components	20%
3	Measuring value using suitable instrument	20%
4	Working in teams	10%
Product Related: 10 Marks		**40%**
5	Calculated theoretical values of given component	10%
6	Interpretation of result	05%
7	Conclusion	05%
8	Practical related questions	15%
9	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			Dated signature of Teacher
Process related (15)	**Product related (10)**	**Total (25)**	

Practical No.9: Determine the HTM for different values of DH parameters of a given robot manipulator for various links using 3D model based OSS

I Practical Significance

To familiarize the students with the concept of HTM and DH parameters of the given manipulator

II Industry/Employer Expected Outcome(s)

Apply the principles of Robotics to automate various industries

III Course Level Learning Outcome(s)

Interpret the transformations used in robotics

IV Laboratory Learning Outcome(s)

Determine the HTM for different values of DH parameters of a given robot manipulator for various links using 3D model based OSS

V Relevant Affective Domain related outcome(s)

Follow ethical practices

Handle tools and equipment carefully.

VI Relevant Theoretical Background

DH parameters:

a) **Joint offset** (d or bi): (Translation along Z axis):
It is the translation along the previous Z-axis needed to make the previous X axis intersect with the current X axis.

b) **Joint angle** (θi): (Rotation along Z axis)
It is the rotation about the previous Z axis needed to make the previous X axis parallel with the current X axis.

c) **Link length** (ai or r): (Translation along X axis)
It is the translation along the current X-axis needed to make the previous Z axis intersect with the current Z axis.

d) **Twist angle** (α i): (Rotation along X axis)
It is the rotation about the current X axis needed to make the previous Z axis parallel with the current Z axis. It is the axis twist angle of two adjacent joints.

Homogeneous Transformation Matrix:

- Transformation matrix: The relation between the body coordinate frames B of the rigid body with the base frame of reference (the universal reference coordinate frame U) is described by Transformation matrix.

- The transformation matrix or the HTM, Ti, of the frame i + 1 attached to the link i=

$$T_i = \begin{bmatrix} cos\theta_i & -sin\theta_i cos\alpha_i & sin\theta_i sin\alpha_i & a_i cos\theta_i \\ sin\theta_i & cos\theta_i cos\alpha_i & -cos\theta_i sin\alpha_i & a_i sin\theta_i \\ 0 & sin\alpha_i & cos\alpha_i & b_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad for \;\; i = 1,2,3..$$

VII Circuit diagram Layout of Laboratory

NA

VIII Resources Required

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Any desktop or laptop with basic configuration and open source software for robotics	**-**	**1**

IX Precautions to be followed

1) Ensure proper earthing.
2) Check the power supply before connection.

X Procedure

1. Open the open source software for robotics in the computer
2. Select the manipulator by choosing the desired degree of freedom and the type of joints
3. Redefine the values of D-H parameters
4. Visualize Link Configuration to get the value of HTM by selecting the Link and the Previous Link Frame and then click on **Update**
5. Repeat by choosing another Link

XI Resources Used

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity

XII Actual Procedure

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XIII Observations and Calculations (use blank sheet provided if space not sufficient)

Manipulator DOF=	Joint no.	Type of joint	Joint offset	Joint angle	Link length	Twist angle
Selected Robot type = (ex. 3R, 3P, RRP etc.)						

The transformation matrix or the HTM, Ti, of the frame i + 1 attached to the link i=

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XIV Result(s)

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XV Interpretation of results

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XVI Conclusion and recommendation

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XVII Practical related questions

Note: Below given are few sample questions for reference. Teacher must design more such questions so as to ensure the achievement of identifies CO.

1. Derive the transformation matrix or the HTM, Ti, of the frame i + 1 attached to the link i
2. Find the D-H parameters and transformation matrix for a 2R planar robot arm.

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XVIII References/Suggestions for further reading

1. https://archive.nptel.ac.in/courses/112/104/112104298
2. Introduction to Robotics by Saha, S.K.

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related: 15 Marks		**60 %**
1	Handling of the components	10%
2	Identification of components	20%
3	Measuring value using suitable instrument	20%
4	Working in teams	10%
Product Related: 10 Marks		**40%**
5	Calculated theoretical values of given component	10%
6	Interpretation of result	05%
7	Conclusion	05%
8	Practical related questions	15%
9	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			Dated signature of Teacher
Process related (15)	**Product related (10)**	**Total (25)**	

Practical No.10: *Determination of the position and orientation of end effector of a 4 axis/6 axis robot using forward kinematics

I Practical Significance

To familiarize the students with the forward kinematics of a given robot manipulator

II Industry/Employer Expected Outcome(s)

Apply the principles of Robotics to automate various industries

III Course Level Learning Outcome(s)

Analyse the kinematics of the robotic arm

IV Laboratory Learning Outcome(s)

1. Analyse forward kinematics of PUMA 560 robot using virtual lab (http://vlabs.iitkgp.ac.in/mr/exp1/index.html#).
2. Determine the position and orientation of end effector of a 4 axis/6 axis robot using forward kinematics

V Relevant Affective Domain related outcome(s)

Follow ethical practices

Handle tools and equipment carefully.

VI Relevant Theoretical Background

- In forward position analysis or forward kinematics or direct kinematics, the end-effector's orientation and position (configuration or location) has to be found out from the given joint variables.

Steps to find out forward position analysis:

- Find out the DH parameters.
- Find out the individual HTM, Ti, as T_1, T_2. . . Tn (for the frame i = 1, …, n) for each frame (from the four elementary transformations corresponding to the DH parameters) where Ti = Tbi *Tθi *Tai *Tαi
- The overall HTM, T, of the end effector (frame n + 1) with respect to the base or frame 1 is obtained from the post-multiplication of the above individual HTM. This is the frame transformation.
- It is given by T = T_1 * T_2 *. . . Tn
- This is the forward kinematics result.

VII Actual Circuit diagram used in laboratory with related equipment rating-

NA

VIII Resources Required

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Any desktop or laptop with basic configuration and open source software for robotics	**-**	**1**

IX Precautions to be followed

1) Ensure proper earthing.
2) Check the power supply before connection.

X Procedure

1. Open the open source software for robotics in the computer http://vlabs.iitkgp.ac.in/mr/exp1/forward-kinematics-of-puma-560.html
2. Insert different values of θ within the joint range as prescribed in theory part and then click ok to get the output orientation and position of the end effector.
3. To see the individual movements of the links drag the sliders on the controller panel.
4. The Transformation matrix for a particular position and orientation can be obtained either through input panel or via the controller.
5. Manipulator position is shown in a 3D graph for every submission of joint values.
6. The view can be rotated about a point by keeping the left mouse button pressed and rotating the mouse.
7. The view can be translated by keeping the right mouse button pressed and translating the mouse in the desired direction.
8. The scroll button or middle mouse button can be used for zooming.

XI Resources Used

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity

XII Actual Procedure

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XIII Observations and Calculations (use blank sheet provided if space not sufficient)

- Puma 560 D-H parameter table:

$L \in k_i$	α_{i-1}	$a_i - 1$(M)	d_i(M)	θ_i
1	0	0	0	θ_1
2	-90	0	0	θ_2
3	0	a_2	d_3	θ_3
4	-90	a_3	d_4	θ_4
5	90	0	0	θ_5
6	-90	0	0	θ_6

Transformation matrices of six joints for Puma 560 robot

$$T_1 = \begin{bmatrix} \cos(\theta_1) & -\sin(\theta_1) & 0 & 0 \\ \sin(\theta_1) & \cos(\theta_1) & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} T_2 = \begin{bmatrix} \cos(\theta_2) & -\sin(\theta_2) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -\sin(\theta_2) & -\cos(\theta_2) & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_3 = \begin{bmatrix} \cos(\theta_3) & -\sin(\theta_3) & 0 & a_2 \\ \sin(\theta_3) & \cos(\theta_3) & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} T_4 = \begin{bmatrix} \cos(\theta_4) & -\sin(\theta_4) & 0 & a_3 \\ 0 & 0 & 1 & d_4 \\ -\sin(\theta_4) & -\cos(\theta_4) & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_5 = \begin{bmatrix} \cos(\theta_5) & -\sin(\theta_5) & 0 & 0 \\ 0 & 0 & -1 & 0 \\ \sin(\theta_5) & \cos(\theta_5) & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} T_6 = \begin{bmatrix} \cos(\theta_6) & -\sin(\theta_6) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -\sin(\theta_6) & -\cos(\theta_6) & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Final Transformation Matrix $T = T_1 \cdot T_2 \cdot T_3 \cdot T_4 \cdot T_5 \cdot T_6$

The orientation and position of the end effector with reference to the base coordinate is obtained from the final matrix:

$$T = \begin{bmatrix} n & s & a & p \\ 0 & 0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} n_x & s_x & a_x & p_x \\ n_y & s_y & a_y & p_y \\ n_z & s_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

XIV Result(s)

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XV Interpretation of results

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XVI Conclusion and recommendation

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XVII Practical related questions

Note: Below given are few sample questions for reference. Teacher must design more such questions so as to ensure the achievement of identifies CO.

1. Define forward position analysis
2. Analyse the forward position of 2R Planar arm by deriving the final transformation matrix of 2R Planar arm

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XVIII References/Suggestions for further reading

1. https://archive.nptel.ac.in/courses/112/104/112104298
2. Introduction to Robotics by Saha, S.K.
3. http://vlabs.iitkgp.ac.in/mr/exp1/forward-kinematics-of-puma-560.html

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related: 15 Marks		**60 %**
1	Handling of the components	10%
2	Identification of components	20%
3	Measuring value using suitable instrument	20%
4	Working in teams	10%
Product Related: 10 Marks		**40%**
5	Calculated theoretical values of given component	10%
6	Interpretation of result	05%
7	Conclusion	05%
8	Practical related questions	15%
9	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			Dated signature of Teacher
Process related (15)	**Product related (10)**	**Total (25)**	

Practical No.11: Determination of the joint angle for the given position of the end effector of a 4 axis/6 axis robot using inverse kinematics

I Practical Significance

To familiarize the students with the inverse kinematics of a given robot manipulator

II Industry/Employer Expected Outcome(s)

Apply the principles of Robotics to automate various industries

III Course Level Learning Outcome(s)

Analyse the kinematics of the robotic arm

IV Laboratory Learning Outcome(s)

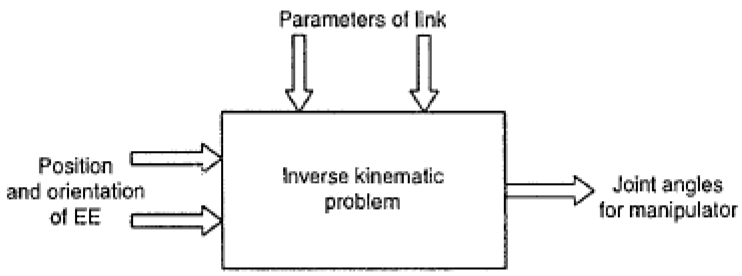
1. Analyse inverse kinematics of PUMA 560 robot for various inputs of the manipulator position using virtual labs (http://vlabs.iitkgp.ac.in/mr/exp3/index.html#).
2. Determine the joint angle for the given position of the end effector of a 4 axis/6 axis robot using inverse kinematics.

V Relevant Affective Domain related outcome(s)

- Follow ethical practices
- Handle tools and equipment carefully.

VI Relevant Theoretical Background

- In the Inverse position analysis or inverse kinematics, the joint variables have to be found out from the given end-effector's orientation and position.
- Inverse kinematics problem deals with the determination of joint variables given a desired position and orientation for the tool.



VII Actual Circuit diagram used in laboratory with related equipment rating

NA

VIII Resources Required:

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Any desktop or laptop with basic configuration and open source software for robotics	–	**1**

IX Precautions to be followed

1) Ensure proper earthing
2) Check the power supply before connection.

X Procedure

1. Open the open source software for robotics in the computer http://vlabs.iitkgp.ac.in/mr/exp1/forward-kinematics-of-puma-560.html
2. Insert three position of the end-effector and click OK button to see the joint values.
3. Orientation of the manipulator can also be specified.
4. The view can be rotated about a point by keeping the left mouse button pressed and rotating the mouse.
5. The view can be translated by keeping the right mouse button pressed and translating the mouse in the desired direction.
6. The scroll button or middle mouse button can be used for zooming.

XI Resources Used

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity

XII Actual Procedure

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XIII Observations and Calculations (use blank sheet provided if space not sufficient)

- First, frame transformations are performed to find the wrist frame, {W}, relative to the base frame, {B}, and then the inverse kinematics are used to solve for the joint angles.

XIV Result(s)

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XV Interpretation of results

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XVI Conclusion and recommendation

XVII Practical related questions

Note: Below given are few sample questions for reference. Teacher must design more such questions so as to ensure the achievement of identifies CO.

1. Define inverse position analysis
2. Analyse the inverse position by deriving the final transformation matrix of 2R Planar arm

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XVIII References/Suggestions for further reading

1. https://archive.nptel.ac.in/courses/112/104/112104298
2. Introduction to Robotics by Saha, S.K.
3. http://vlabs.iitkgp.ac.in/mr/exp3/index.html#

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related: 15 Marks		**60 %**
1	Handling of the components	10%
2	Identification of components	20%
3	Measuring value using suitable instrument	20%
4	Working in teams	10%
Product Related: 10 Marks		**40%**
5	Calculated theoretical values of given component	10%
6	Interpretation of result	05%
7	Conclusion	05%
8	Practical related questions	15%
9	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			**Dated signature of Teacher**
Process related (15)	**Product related (10)**	**Total (25)**	

Practical No.12: Derivation of Jacobian matrix using OSS for the given manipulator

I Practical Significance

To familiarize the students with the Jacobian matrix of a given robot manipulator

II Industry/Employer Expected Outcome(s)

Apply the principles of Robotics to automate various industries

III Course Level Learning Outcome(s)

Analyse the kinematics of the robotic arm

IV Laboratory Learning Outcome(s)

Analyse Jacobian matrix using open source software for the given manipulator

V Relevant Affective Domain related outcome(s)

- Follow ethical practices
- Handle tools and equipment carefully.

VI Relevant Theoretical Background

- The Jacobian matrix relates angular and linear velocities of the end effector with the joint velocities
- Jacobian matrix is calculated by taking the derivative of each position equation of the end effector with respect to all joint variables.
- Jacobian matrix J is a '6n' dimensional matrix and it is a function of the joint variables.
- The number of columns 'n' in the Jacobian matrix is equal to the number of joints in the manipulator.
- Rows of the Jacobian matrix can be split into two parts. The first three rows are associated with linear velocities of the end-effector and the last three rows are associated with the angular velocities of the end-effector
- Jacobian matrix J=

$$J = \begin{bmatrix} \frac{\partial x}{\partial q_1} & \frac{\partial x}{\partial q_2} & \frac{\partial x}{\partial q_3} & \cdots\cdots & \frac{\partial x}{\partial q_n} \\ \frac{\partial y}{\partial q_1} & \frac{\partial y}{\partial q_2} & \frac{\partial y}{\partial q_3} & \cdots\cdots & \frac{\partial y}{\partial q_n} \\ \frac{\partial z}{\partial q_1} & \frac{\partial z}{\partial q_2} & \frac{\partial z}{\partial q_3} & \cdots\cdots & \frac{\partial z}{\partial q_n} \\ \frac{\partial \theta_x}{\partial q_1} & \frac{\partial \theta_x}{\partial q_2} & \frac{\partial \theta_x}{\partial q_3} & \cdots\cdots & \frac{\partial \theta_x}{\partial q_n} \\ \frac{\partial \theta_y}{\partial q_1} & \frac{\partial \theta_y}{\partial q_2} & \frac{\partial \theta_y}{\partial q_3} & \cdots\cdots & \frac{\partial \theta_y}{\partial q_n} \\ \frac{\partial \theta_z}{\partial q_1} & \frac{\partial \theta_z}{\partial q_2} & \frac{\partial \theta_z}{\partial q_3} & \cdots\cdots & \frac{\partial \theta_z}{\partial q_n} \end{bmatrix}_{6\times n}$$

$q_1, q_2 ... q_n$ are the joint variables.
X, Y Z are the end effector position in X, Y Z directions
θ_x, θ_y and θ_z are the end effector angular positions in X, Y Z directions

VII Actual Circuit diagram used in a laboratory with related equipment rating

NA

VIII Resources Required

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Any desktop or laptop with basic configuration and open source software for robotics	–	**1**

IX Precautions to be followed

1) Ensure proper earthing.
2) Check the power supply before connection.

X Procedure

1. Open the open source software for robotics in the computer
2. Write the code for the given problem
3. Execute the code
4. Verify the result

XI Resources Used

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity

XII Actual Procedure

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XIII Observations and Calculations (use blank sheet provided if space not sufficient)

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XIV Result(s)

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XV Interpretation of results

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XVI Conclusion and recommendation

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XVII Practical related questions

Note: Below given are few sample questions for reference. Teacher must design more such questions so as to ensure the achievement of identifies CO.

1. State the equation of Jacobian matrix and explain each term.
2. Determine the Jacobian matrix for a 2P (Prismatic) robotic manipulator

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XVIII References/Suggestions for further reading

1. https://archive.nptel.ac.in/courses/112/104/112104298
2. Introduction to Robotics by Saha, S.K.

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related: 15 Marks		**60 %**
1	Handling of the components	10%
2	Identification of components	20%
3	Measuring value using suitable instrument	20%
4	Working in teams	10%
Product Related: 10 Marks		**40%**
5	Calculated theoretical values of given component	10%
6	Interpretation of result	05%
7	Conclusion	05%
8	Practical related questions	15%
9	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			**Dated signature of Teacher**
Process related (15)	**Product related (10)**	**Total (25)**	

Practical No.13: Determination of the position and orientation of the end effector for the given force at the joint of a 4 axis/6 axis robot using forward dynamics

I Practical Significance

To familiarize the students with the forward dynamics of a given robot manipulator

II Industry/Employer Expected Outcome(s)

Apply the principles of Robotics to automate various industries

III Course Level Learning Outcome(s)

Interpret the dynamics and motion planning of the robotic arm

IV Laboratory Learning Outcome(s)

1. Analyse forward dynamics of the given robot manipulator using 3D model based open source software
2. Determine the position and orientation of the end effector for the given force at the joint of a 4 axis/6axis robot using forward dynamics

V Relevant Affective Domain related outcome(s)

Follow ethical practices

Handle tools and equipment carefully.

VI Relevant Theoretical Background

- Dynamic model of a robot is the study of relation between the forces/ torques applied at the joints by the actuators and the resulting motion of the manipulator.
- Forward dynamics determines the motion of a robot from a set of applied forces and torques
- It is the method to find out the resulting joint motions and trajectories of the end effector for a given set of forces / torques applied at the joints by the actuators.

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VII Actual Circuit diagram used in laboratory with related equipment rating

NA

VIII Resources Required

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Any desktop or laptop with basic configuration and open source software for robotics	-	1

IX Precautions to be followed

1) Ensure proper earthing.
2) Check the power supply before connection.

X Procedure

1. Open the open source software for robotics in the computer
2. Select a robot and redefine its DH parameters
3. Set the **initial** value of joint variables
4. Set **Time Duration** and **Number of Steps**
5. Set **Gravity** (all values should be in SI units, i.e., m/s2).
6. Select a robot-link to enter its Center of Gravity (CG) location.
7. Select **Mass Properties** of a robot-link. Set **Mass** of each robot-link (values should be in SI units, i.e., kg) and set **Inertia** tensor of each robot-link with respect to the coordinate frame attached at the CG of the robot-link
8. Click on **FDyn** button to perform Forward Dynamics
9. The robot is simulated for free-fall due to the action of gravity. In future, joint torques/forces can be set as input.
10. Click on **Play** button to see the animation.
11. Click on **Graph** tab to view the graph.

XI Resources Used

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity

XII Actual Procedure

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XIII Observations and Calculations (use blank sheet provided if space not sufficient)

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XIV Result(s)

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XV Interpretation of results

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XVI Conclusion and recommendation

XVII Practical related questions

Note: Below given are few sample questions for reference. Teacher must design more such questions so as to ensure the achievement of identifies CO.

1. State the comparison between Kinematic model and Dynamic model
2. Explain Lagrange-Euler & Newton-Euler formula

[Space for Answers]

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XVIII References/Suggestions for further reading

1. https://archive.nptel.ac.in/courses/112/104/112104298
2. Introduction to Robotics by Saha, S.K.

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related: 15 Marks		**60 %**
1	Handling of the components	10%
2	Identification of components	20%
3	Measuring value using suitable instrument	20%
4	Working in teams	10%
Product Related: 10 Marks		**40%**
5	Calculated theoretical values of given component	10%
6	Interpretation of result	05%
7	Conclusion	05%
8	Practical related questions	15%
9	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			Dated signature of Teacher
Process related (15)	**Product related (10)**	**Total (25)**	

Practical No.14 Determination of the forces required at the joint from the position and orientation of the end effector of a 4 axis/6 axis robot using inverse dynamics

I Practical Significance

To familiarize the students with the inverse dynamics of a given robot manipulator

II Industry/Employer Expected Outcome(s)

Apply the principles of Robotics to automate various industries

III Course Level Learning Outcome(s)

Interpret the dynamics and motion planning of the robotic arm

IV Laboratory Learning Outcome(s)

1. Analyse inverse dynamics of the given robot manipulator using 3D model based open source software
2. Determine the forces required at the joint from the position and orientation of the end effector of a 4axix/6axis robot using inverse dynamics

V Relevant Affective Domain related outcome(s)

Follow ethical practices

Handle tools and equipment carefully.

VI Relevant Theoretical Background

- Dynamic model of a robot is the study of relation between the forces/ torques applied at the joints by the actuators and the resulting motion of the manipulator.
- Inverse dynamics determines the forces and torques required to produce a desired motion of the end effector. It's used for robot control, trajectory design and optimization, and designing robot mechanisms.
- It is the evaluation of forces/ torques required to apply at the joints by the actuators for a set of desired joint motions and trajectory of the end effector.

VII Circuit diagram Layout of Laboratory

NA

VIII Resources Required

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Any desktop or laptop with basic configuration and open source software for robotics	–	**1**

IX Precautions to be followed

1) Ensure proper earthing.
2) Check the power supply before connection.

X Procedure

1. Open the open source software for robotics in the computer
2. Select a robot and redefine its DH parameters
3. Set the **initial** and **final** value of joint variables
4. Set **Time Duration** and **Number of Steps**

5. Set **Gravity** (all values should be in SI units, i.e., m/s2).
6. Select a robot-link to enter its Center of Gravity (CG) location.
7. Select **Mass Properties** of a robot-link. Set **Mass** of each robot-link (values should be in SI units, i.e., kg) and set **Inertia** tensor of each robot-link with respect to the coordinate frame attached at the CG of the robot-link and the coordinate frame is parallel to the one attached to the robot-link
8. Click on **FKin** button to perform Forward Kinematics (required to populate the input joint trajectory)
9. Click on **Play** button to see the animation.
10. Click on **IDyn** button to perform inverse dynamics
11. Click on **Graph** tab to view the graph.

XI Resources Used

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity

XII Actual Procedure

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XIII Observations and Calculations (use blank sheet provided if space not sufficient)

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XIV Result(s)

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XV Interpretation of results

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XVI Conclusion and recommendation

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XVII Practical related questions

Note: Below given are few sample questions for reference. Teacher must design more such questions so as to ensure the achievement of identifies CO.

1. State the difference between forward and inverse dynamics in robotics
2. State and explain the equations used in dynamics

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XVIII References/Suggestions for further reading

1. https://archive.nptel.ac.in/courses/112/104/112104298
2. Introduction to Robotics by Saha, S.K.

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related: 15 Marks		**60 %**
1	Handling of the components	10%
2	Identification of components	20%
3	Measuring value using suitable instrument	20%
4	Working in teams	10%
Product Related: 10 Marks		**40%**
5	Calculated theoretical values of given component	10%
6	Interpretation of result	05%
7	Conclusion	05%
8	Practical related questions	15%
9	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			**Dated signature of Teacher**
Process related (15)	**Product related (10)**	**Total (25)**	

Practical No.15: Interpolation of Cartesian space trajectories of the given 4axis/6axis robot manipulator

I Practical Significance

To familiarize the students with the interpolation of Cartesian space trajectories of a given robot manipulator

II Industry/Employer Expected Outcome(s)

Apply the principles of Robotics to automate various industries

III Course Level Learning Outcome(s)

Interpret the dynamics and motion planning of the robotic arm

IV Laboratory Learning Outcome(s)

1. Identify the workspace of the given robotic manipulator
2. Interpolate the Cartesian trajectories of the given robot manipulator

V Relevant Affective Domain related outcome(s)

Follow ethical practices

Handle tools and equipment carefully.

VI Relevant Theoretical Background

- Cartesian space is defined by a vector whose components are the position, orientation and their time derivatives of the end effector of a robot.
- Interpolation of Cartesian space trajectories refers to the process of generating a smooth, continuous motion path for a robot's end-effector in Cartesian coordinates (x, y, z, and sometimes orientation) by calculating intermediate points between a set of defined waypoints, creating a smooth curve connecting the desired start and end positions while considering constraints like velocity and acceleration along the path.

Example for applications of Cartesian space trajectory experiments:

- Pick and place tasks: Precisely moving a robot's end-effector to pick up an object and place it at a designated location.
- Robot painting: Following a complex path on a surface with a robotic arm holding a paintbrush.
- Surgical robotics: Precisely manipulating surgical instruments within a patient's body.

VII Circuit diagram Layout of Laboratory

NA

VIII Resources Required

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Any desktop or laptop with basic configuration and open source software for robotics	- -	**1**

IX Precautions to be followed

1) Ensure proper earthing.
2) Check the power supply before connection.

X Procedure

1. Open the open source software for robotics in the computer
2. Define a desired path for the robot's end-effector in Cartesian coordinates (x, y, z, and orientation)
3. Define the start and end points of the desired trajectory
4. Select a suitable interpolation method (like linear, cubic spline)

XI Resources Used

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity

XII Actual Procedure

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XIII Observations and Calculations (use blank sheet provided if space not sufficient)

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XIV Result(s)

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XV Interpretation of results

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XVI Conclusion and recommendation

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XVII Practical related questions

Note: Below given are few sample questions for reference. Teacher must design more such questions so as to ensure the achievement of identifies CO.

1. Explain Cartesian space trajectory in robot.
2. State the applications of Cartesian space trajectory interpolation

[Space for Answers]

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XVIII References/Suggestions for further reading

1. https://archive.nptel.ac.in/courses/112/104/112104298
2. Introduction to Robotics by Saha, S.K.

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related: 15 Marks		**60 %**
1	Handling of the components	10%
2	Identification of components	20%
3	Measuring value using suitable instrument	20%
4	Working in teams	10%
Product Related: 10 Marks		**40%**
5	Calculated theoretical values of given component	10%
6	Interpretation of result	05%
7	Conclusion	05%
8	Practical related questions	15%
9	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			Dated signature of Teacher
Process related (15)	**Product related (10)**	**Total (25)**	

Practical No.16: Interpolation of the joint space trajectories of the given 4 axis/6 axis robot manipulator

I Practical Significance

To familiarize the students with the interpolation of joint space trajectories of a given robot manipulator

II Industry/Employer Expected Outcome(s)

Apply the principles of Robotics to automate various industries

III Course Level Learning Outcome(s)

Interpret the dynamics and motion planning of the robotic arm

IV Laboratory Learning Outcome(s)

Interpolate the joint space trajectories of the given robot manipulator

V Relevant Affective Domain related outcome(s)

Follow ethical practices

Handle tools and equipment carefully.

VI Relevant Theoretical Background

- Joint space refers to the space defined by the robot's joint angles.
- Interpolation of the joint space trajectories of a robot manipulator refers to calculate a smooth, continuous path for a robot's joints by mathematically connecting a set of defined joint angle positions (waypoints) over time, creating a motion profile for each joint where the robot moves smoothly from one position to another. This is done in the joint space

- **Benefits of joint space interpolation:**
  - **Computational efficiency:**

    Solving inverse kinematics only at waypoints can be faster than solving it continuously for a task-space trajectory.
  - **Smooth motion:**

    By carefully selecting interpolation methods, the robot's motion can be made smooth and avoid jerky movements.
  - **Easy to implement:**

    Joint space trajectories are often easier to design and implement compared to task-space trajectories, especially for simple motions.

VII Circuit diagram Layout of Laboratory

NA

VIII Resources Required

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Any desktop or laptop with basic configuration and open source software for robotics	- -	**1**

IX Precautions to be followed

1) Verify power ratings.
2) Ensure proper earthing.
3) Check the power supply before connection.

X Procedure

1. Open the open source software for robotics in the computer
2. Select the manipulator by choosing the desired degree of freedom and the type of joints
3. Assign initial values of joint variables
4. Select a particular joint trajectory from the list available
5. Perform the joint trajectory of the selected robot

XI Resources Used

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity

XII Actual Procedure

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XIII Observations and Calculations (use blank sheet provided if space not sufficient)

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XIV Result(s)

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XV Interpretation of results

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XVI Conclusion and recommendation

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XVII Practical related questions

Note: Below given are few sample questions for reference. Teacher must design more such questions so as to ensure the achievement of identifies CO.

1. Explain Joint space trajectory in robot.
2. State the advantages of Joint space trajectory interpolation

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XVIII References/Suggestions for further reading

1. https://archive.nptel.ac.in/courses/112/104/112104298
2. Introduction to Robotics by Saha, S.K.

XIX Assessment Scheme

	Performance Indicators	Weightage
	Process Related: 15 Marks	**60 %**
1	Handling of the components	10%
2	Identification of components	20%
3	Measuring value using suitable instrument	20%
4	Working in teams	10%
	Product Related: 10 Marks	**40%**
5	Calculated theoretical values of given component	10%
6	Interpretation of result	05%
7	Conclusion	05%
8	Practical related questions	15%
9	Submitting the journal in time	05%
	Total (25 Marks)	**100 %**

Marks Obtained			**Dated signature of Teacher**
Process related (15)	**Product related (10)**	**Total (25)**	