Programme Name/s : **Automation and Robotics**
Programme Code : **AO**
Semester : **Fourth**
Course Title : **PRINCIPLES OF ROBOTICS**
Course Code : **314334**

I. RATIONALE

Robotics is the engineering discipline dealing with the design, construction, and operation of robots. The "Principles of Robotics" course will facilitate diploma students to acquire an understanding of the fundamental concepts, theories, and principles that govern the design, operation, and application of robotic systems. This course will also enable the students to get acquaints the basic concepts of engineering mechanics that is used in robotic system.

II. INDUSTRY / EMPLOYER EXPECTED OUTCOME

The aim of this course is to attain the following industry/ employer expected outcome through various teaching learning experiences:
Apply the principles of Robotics to automate various industries.

III. COURSE LEVEL LEARNING OUTCOMES (COS)

Students will be able to achieve & demonstrate the following COs on completion of course based learning

- 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.

IV. TEACHING-LEARNING & ASSESSMENT SCHEME

Course Code	Course Title	Abbr	Course Category/s	Learning Scheme					Credits	Assessment Scheme											
				Actual Contact Hrs./Week			SLH	NLH		Paper Duration	Theory				Based on LL & TL				Based on SL		Total Marks
															Practical						
				CL	TL	LL					FA-TH	SA-TH	Total		FA-PR		SA-PR		SLA		
											Max	Max	Max	Min	Max	Min	Max	Min	Max	Min	
314334	PRINCIPLES OF ROBOTICS	POR	DSC	4	-	2	2	8	4	3	30	70	100	40	25	10	25#	10	25	10	175

Total IKS Hrs for Sem. : Hrs
Abbreviations: CL- ClassRoom Learning , TL- Tutorial Learning, LL-Laboratory Learning, SLH-Self Learning Hours, NLH-Notional Learning Hours, FA - Formative Assessment, SA -Summative assessment, IKS - Indian Knowledge System, SLA - Self Learning Assessment
Legends: @ Internal Assessment, # External Assessment, *# On Line Examination , @$ Internal Online Examination
Note :

1. FA-TH represents average of two class tests of 30 marks each conducted during the semester.
2. If candidate is not securing minimum passing marks in FA-PR of any course then the candidate shall be declared as "Detained" in that semester.
3. If candidate is not securing minimum passing marks in SLA of any course then the candidate shall be declared as fail and will have to repeat and resubmit SLA work.
4. Notional Learning hours for the semester are (CL+LL+TL+SL)hrs.* 15 Weeks
5. 1 credit is equivalent to 30 Notional hrs.
6. * Self learning hours shall not be reflected in the Time Table.
7. * Self learning includes micro project / assignment / other activities.

V. THEORY LEARNING OUTCOMES AND ALIGNED COURSE CONTENT

Sr.No	Theory Learning Outcomes (TLO's)aligned to CO's.	Learning content mapped with Theory Learning Outcomes (TLO's) and CO's.	Suggested Learning Pedagogies.
1	TLO 1.1 Describe the robot anatomy by specifying the functions of various basic elements of robot systems. TLO 1.2 Classify the robot arm configurations. TLO 1.3 Describe the robot joints. TLO 1.4 Describe the specifications related to robotics. TLO 1.5 Select appropriate gripper for the given application. TLO 1.6 Identify the safety measures to be adopted for given robotic application.	**Unit - I Fundamentals of Robotics** 1.1 Definition, brief history, Asimov‘s laws of robot, robot anatomy: Base, manipulator arm, end effectors, sensors, control system, actuators 1.2 Robot arm configurations: Cartesian coordinate, polar, cylindrical, jointed arm, SCARA (Selective Compliance Assembly Robot Arm) 1.3 Types of mechanical joints in robotics system: Linear, orthogonal, rotational, twisting, revolving 1.4 Robot specification: Degree of freedom, work envelope, payload, resolution, accuracy, repeatability 1.5 End effectors of robot: Types of end effectors, mechanical grippers, pneumatic gripper, magnetic grippers, vacuum grippers, adhesive grippers 1.6 Bureau of Indian Standards (BIS) for safety in robotics: Design, safegaurds, awareness means, provisions for emergency movements of robot	Lecture using Chalk-Board Video Demonstrations Collaborative learning Flipped Classroom
2	TLO 2.1 Describe the characteristics of forces. TLO 2.2 Describe the moment of forces in the given force system. TLO 2.3 Determine the equilibrium of forces of the given system. TLO 2.4 Describe centroids and centre of gravity of the given system.	**Unit - II Basics of Engineering Mechanics for Robotics** 2.1 Introduction of mechanics: Engineering mechanics, statics, concept of rigid body, force: Definition, unit, Bow’s notation, characteristics, types of force system 2.2 Moment of force: Definition, unit, sign conventions 2.3 Equilibrium of forces: Definition, conditions, simple numerical on equilibrium 2.4 Centroids and centre of gravity: Concept, definition	Lecture using Chalk-Board Video Demonstrations Collaborative learning
3	TLO 3.1 State the significance of kinematics. TLO 3.2 Calculate rotation matrices about various axes.	**Unit - III Transformations used in Robotics** 3.1 Kinematics: Definition and significance, coordinate system and frames in robotics, reference and body frames, pose of a rigid body	Lecture using Chalk-Board Video Demonstrations

Sr.No	Theory Learning Outcomes (TLO's)aligned to CO's.	Learning content mapped with Theory Learning Outcomes (TLO's) and CO's.	Suggested Learning Pedagogies.
	TLO 3.3 Calculate the coordinate transformation matrix and HTM of a given frame of robot manipulator. TLO 3.4 Calculate the DH parameters of a given frame of robot manipulator. TLO 3.5 Calculate the transformation between the given DH frames of robot manipulator.	3.2 Rotation matrix: Representation of orientation, concept of roll, pitch, yaw motion, elementary rotation matrix about Z axis (derivation), elementary rotation matrix about X axis and Y axis (only formula) 3.3 Coordinate transformation matrix: Description, equation, homogeneous transformation matrix (HTM)-equation, description, numerical 3.4 DH (Denavit–Hartenberg) parameters, DH rules, DH table for the given manipulator such as 2R, 2P,3P, 3R, SCARA 3.5 Transformation between DH frames and the corresponding HTM	Collaborative learning
4	TLO 4.1 Differentiate between forward and inverse kinematics. TLO 4.2 Perform forward position analysis of the given manipulator. TLO 4.3 Describe Jacobian matrix. TLO 4.4 Perform Jacobian computations for a given manipulator.	**Unit - IV Kinematics of the Robotic Arm** 4.1 Position analysis: Concept of forward position analysis / kinematics and inverse position analysis / kinematics 4.2 Forward position analysis for 2P and 2R planar arm 4.3 Definition of linear and angular displacement, linear and angular velocity, linear and angular acceleration 4.4 Differential motion and velocities of robot: Jacobian equation in robotics, Jacobian matrix in robotics 4.5 Simple Numerical on Jacobian matrix based on the end-effector's coordinates and joint parameters	Lecture using Chalk-Board Video Demonstrations Collaborative learning
5	TLO 5.1 Differentiate between kinematics and dynamics. TLO 5.2 Describe dynamic equations of motion. TLO 5.3 Compare joint space planning and cartesian space planning. TLO 5.4 Describe point to point motion and continuous path motion.	**Unit - V Overview of Dynamics of the Robotic Arm and Motion Planning** 5.1 Dynamics: Definition, concept of forward and inverse dynamics 5.2 Dynamic equations of motion for joints of robot manipulators: Lagrange-Euler and Newton-Euler equations (no derivation, only simple numerical based on equations) 5.3 Motion planning: Concept, joint space planning, cartesian space planning 5.4 Cartesian trajectories: Concept, point to point and continuous path motion	Lecture using Chalk-Board Video Demonstrations Collaborative learning

VI. LABORATORY LEARNING OUTCOME AND ALIGNED PRACTICAL / TUTORIAL EXPERIENCES.

Practical / Tutorial / Laboratory Learning Outcome (LLO)	Sr No	Laboratory Experiment / Practical Titles / Tutorial Titles	Number of hrs.	Relevant COs
LLO 1.1 Install 3D model based open source software (Ex. RoboAnalyzer). LLO 1.2 Observe the movement of a robot manipulator using virtual robot module with the help of 3D model based open source software.	1	*Analysis of robot manipulator movement using 3D model based open source software (OSS)	2	CO1
LLO 2.1 Observe the movement of joints in robots using 3D model based open source software.	2	*Working of different type of joints used in robots using 3D model based OSS	2	CO1

Practical / Tutorial / Laboratory Learning Outcome (LLO)	Sr No	Laboratory Experiment / Practical Titles / Tutorial Titles	Number of hrs.	Relevant COs
LLO 3.1 Operate a 2-finger pneumatic parallel gripper of a robot. LLO 3.2 Operate a 2-finger vacuum parallel gripper of a robot.	3	Operatation of a 2-finger pneumatic and vacuum parallel gripper of a robot	2	CO1
LLO 4.1 Verify law of moment of forces using law of moment apparatus for given forces.	4	*Verification of law of moment of forces using law of moment apparatus	2	CO2
LLO 5.1 Verify centroid of given plane.	5	Verification of centroid of given plane	2	CO2
LLO 6.1 Determine rotation matrix along X axis using open source software for the given manipulator. LLO 6.2 Determine rotation matrix along Y axis using open source software for the given manipulator. LLO 6.3 Determine rotation matrix along Z axis using open source software for the given manipulator.	6	Determination of the rotation matrix of the given manipulator along any given axis using OSS	2	CO3
LLO 7.1 Determine Homogeneous Transformation Matrix (HTM) for pure translation using 3D model based open source software. LLO 7.2 Determine HTM for pure rotation using 3D model based open source software. LLO 7.3 Determine HTM for rotation and translation using 3D model based open source software.	7	* Determination of the HTM for rotation and translation for the given robot manipulator using 3D model based OSS	2	CO3
LLO 8.1 Verify DH table for different values of DH parameters of a given robot manipulator using 3D model based open source software.	8	Analysis of DH table for different values of DH parameters of a given robot manipulator using 3D model based OSS	2	CO3
LLO 9.1 Determine HTM for different values of DH parameters of a given robot manipulator for various links using 3D model based open source software.	9	*Determine the HTM for different values of DH parameters of a given robot manipulator for various links using 3D model based OSS	2	CO3
LLO 10.1 Analyse forward kinematics of PUMA 560 robot using virtual lab (http://vlabs.iitkgp.ac.in/mr/exp1/index.html#). LLO 10.2 Determine the position and orientation of end effector of a 4 axis/6 axis robot using forward kinematics.	10	*Determination of the position and orientation of end effector of a 4 axis/6 axis robot using forward kinematics	2	CO4
LLO 11.1 Analyse inverse dynamics of PUMA 560 robot for various inputs of the manipulator position using virtual labs (http://vlabs.iitkgp.ac.in/mr/exp3/index.html#). LLO 11.2 Determine the joint angle for the given position of the end effector of a 4 axis/6 axis robot using inverse 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	2	CO4
LLO 12.1 Analyse Jacobian matrix using open source software for the given manipulator.	12	Derivation of Jacobian matrix using OSS for the given manipulator	2	CO4
LLO 13.1 Analyse forward dynamics of the given robot manipulator using 3D model based open source software.	13	*Determination of the position and orientation of the end effector for the given force at the joint of a 4 axis/6 axis	2	CO5

Practical / Tutorial / Laboratory Learning Outcome (LLO)	Sr No	Laboratory Experiment / Practical Titles / Tutorial Titles	Number of hrs.	Relevant COs
LLO 13.2 Determine 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.		robot using forward dynamics		
LLO 14.1 Analyse forward dynamics of the given robot manipulator using 3D model based open source software. LLO 14.2 Determine 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.	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	2	CO5
LLO 15.1 Identify the workspace of the given robot manipulator. LLO 15.2 Interpolate the cartesian trajectories of the given robot manipulator.	15	Interpolation of Cartesian space trajectories of the given 4axis/6axis robot manipulator	2	CO5
LLO 16.1 Interpolate joint space trajectories of the given 4 axis/6 axis robot manipulator.	16	Interpolation of the joint space trajectories of the given 4 axis/6 axis robot manipulator	2	CO5

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.

VII. SUGGESTED MICRO PROJECT / ASSIGNMENT/ ACTIVITIES FOR SPECIFIC LEARNING / SKILLS DEVELOPMENT (SELF LEARNING)

Assignment

- Solve numerical on calculation of equilibrium of simple/composite solid bodies from given problem statement.
- Determine the homogeneous transformation matrix (HTM) of the given manipulator.
- Explain DH (Denavit–Hartenberg) parameters, DH rules, DH table for the given manipulator such as 2R, 2P, 3P, 3R, SCARA.
- Explain Cartesian trajectories concept, point to point and continuous path motion.
- Solve the examples on calculation of dynamic equations of motion for joints of robot manipulators.
- Determine Jacobian matrix of the given manipulator based on the end-effector’s coordinates and joint parameters.

Micro project

- Build junkbots from recycled materials.
- Prepare a prototype of basic robots.
- Build jumping robot which will jump like a frog using materials such as motors, springs etc.
- Build a robotic arm with two degrees of freedom.
- Prepare a prototype of line follower robot.
- Prepare a prototype of robot manipulator with pneumatic actuator.
- Prepare a prototype of robot manipulator with hydraulic actuator.
- Build a dancing robot which can dance, flip, and tumble around the floor using motors and suitable material for balancing.

Activity

- Prepare charts of safety measures in robots.
- Perform a survey and write a report on robots used in the packaging industry.
- Prepare charts showing comparison of end effectors of robot.

- Perform a survey and write a report on robots used in the automobile industry.
- Prepare charts or flex of Asimov's laws of robot.
- Prepare photographic charts showing real life applications robots in various sectors.
- Prepare charts showing various elements of robot, configurations, grippers etc.

Note :

- Above is just a suggestive list of microprojects and assignments; faculty must prepare their own bank of microprojects, assignments, and activities in a similar way.
- The faculty must allocate judicial mix of tasks, considering the weaknesses and / strengths of the student in acquiring the desired skills.
- If a microproject is assigned, it is expected to be completed as a group activity.
- SLA marks shall be awarded as per the continuous assessment record.
- For courses with no SLA component the list of suggestive microprojects / assignments/ activities are optional, faculty may encourage students to perform these tasks for enhanced learning experiences.
- If the course does not have associated SLA component, above suggestive listings is applicable to Tutorials and maybe considered for FA-PR evaluations.

VIII. LABORATORY EQUIPMENT / INSTRUMENTS / TOOLS / SOFTWARE REQUIRED

Sr.No	Equipment Name with Broad Specifications	Relevant LLO Number
1	Any open source software like Scilab to find out the rotation matrix and Jacobian matrix (https://www.scilab.org)	1,2,12
2	4 axis robotic arm manipulator and programming software Payload - Minimum 500g Maximum reach - 320mm	14,13,10,11,15,16
3	Silent pneumatic compressor Voltage 220 V, Frequency 50 Hz	14,13,10,11,15,16
4	Any 3D model based open source software like RoboAnalyzer to find out HTM, DH parameters, forward and inverse kinematics and dynamics etc. (http:// www.roboanalyzer.com/virtual- experiments.html.)	14,13,7,8,9,6
5	Parallel link gripper kit containing pneumatic and vacuum gripper	3
6	Law of moment's apparatus consisting of a stainless steel graduated beam 12.5 mm square in section, 1m long, pivoted at centre.	4
7	Models of geometrical figures such as square, rectangle, triangle, circle, semicircle,quarter circle	5

IX. SUGGESTED WEIGHTAGE TO LEARNING EFFORTS & ASSESSMENT PURPOSE (Specification Table)

Sr.No	Unit	Unit Title	Aligned COs	Learning Hours	R-Level	U-Level	A-Level	Total Marks
1	I	Fundamentals of Robotics	CO1	10	4	4	4	12
2	II	Basics of Engineering Mechanics for Robotics	CO2	8	2	4	4	10
3	III	Transformations used in Robotics	CO3	16	4	6	8	18
4	IV	Kinematics of the Robotic Arm	CO4	16	4	6	8	18
5	V	Overview of Dynamics of the Robotic Arm and Motion Planning	CO5	10	4	4	4	12
Grand Total				**60**	**18**	**24**	**28**	**70**

X. ASSESSMENT METHODOLOGIES/TOOLS

Formative assessment (Assessment for Learning)

- Two offline unit tests of 30 marks and average of two unit test marks will be considered for out of 30 marks. For formative assessment of laboratory learning 25 marks. Each practical will be assessed considering 60% weightage to process, 40% weightage to product.

Summative Assessment (Assessment of Learning)

- End semester summative assessment of 25 marks for laboratory learning End semester assessment is of 70 marks.

XI. SUGGESTED COS - POS MATRIX FORM

Course Outcomes (COs)	Programme Outcomes (POs)							Programme Specific Outcomes* (PSOs)		
	PO-1 Basic and Discipline Specific Knowledge	PO-2 Problem Analysis	PO-3 Design/ Development of Solutions	PO-4 Engineering Tools	PO-5 Engineering Practices for Society, Sustainability and Environment	PO-6 Project Management	PO-7 Life Long Learning	PSO-1	PSO-2	PSO-3
CO1	3	2	2	2	1	1	3			
CO2	3	2	2	2	-	1	2			
CO3	3	3	3	3	-	1	2			
CO4	3	3	3	3	-	1	2			
CO5	3	3	3	2	-	1	2			

Legends :- High:03, Medium:02,Low:01, No Mapping: -
*PSOs are to be formulated at institute level

XII. SUGGESTED LEARNING MATERIALS / BOOKS

Sr.No	Author	Title	Publisher with ISBN Number
1	Saha, S.K.	Introduction to Robotics	McGraw Hill Education Pvt. Ltd. 2008 978-0070140011
2	Craig, J.J.	Introduction to Robotics (Mechanics and Control)	Pearson Education Ltd. 2017 978-0133489798
3	Ghosal, A.	Robotics- Fundamental Concepts and Analysis	Oxford University Press 2009 978-0195673913
4	Khurmi, R.S.; Khurmi, N.	Engineering Mechanics	S.Chand & Co. New Delhi 2018 978-9352833962
5	Spong, Mark W.; Hutchinson, Seth; Vidyasagar, M.	Robot Modeling and Control	Wiley 2020 978-1119523994

XIII . LEARNING WEBSITES & PORTALS

Sr.No	Link / Portal	Description
1	http://www.roboanalyzer.com/virtual-experiments.html	A 3D model based open source software to teach robotics subjects
2	http://vlabs.iitkgp.ac.in/mr/	Virtual lab for Robotics developed by IIT Kharagpur
3	https://archive.nptel.ac.in/courses/112/104/112104298/	NPTEL study material for chapter 1,3,4,5
4	https://www.scilab.org/	Free ware open source software to find out Jacobian matrix

Sr.No	Link / Portal	Description
5	https://www.coursera.org/specializations/ modernrobotics	Modern Robotics: Mechanics, Planning, and Control Specialization
6	https://archive.org/details/gov.in.is.14530.1998/page/ n3/mod e/2up	BIS for safety in robotics

Note :

- Teachers are requested to check the creative common license status/financial implications of the suggested online educational resources before use by the students