ROBOTICS
ENEX 412

Lecture : 3 **Year : IV**
Tutorial : 1 **Part : I**
Practical : 1.5

Course Objectives:
The objective of this course is to provide students with a fundamental understanding of robotics principles, including robot configurations, spatial transformations, kinematics, dynamics, automation and control. The course develops knowledge of robotic components, power sources, actuators, sensors, robot programming, and simulation. Students will develop ability to analyse, model, simulate, and control robotic systems.

1 **Introduction to Robotics** **(3 hours)**
- 1.1 Definitions, historical development, and evolution of robotics
- 1.2 Robot anatomy: links, joints, manipulators, end-effectors, sensors, and controllers
- 1.3 Robot classifications and configurations: Cartesian, cylindrical, spherical, SCARA, and articulated
- 1.4 Degrees of freedom, workspace, reachability, and basic performance measures
- 1.5 Industrial, service, medical, mobile, and aerial robot applications
- 1.6 Overview of robotics safety, ethics, and human interaction

2 Robot Components, Power Sources, Actuators and Sensors (4 hours)
- 2.1 Electrical, pneumatic, and hydraulic power sources for robotic systems
- 2.2 Actuators: DC motors, servo motors, stepper motors, and basic motor drivers
- 2.3 Torque, speed, power, transmissions, and end-effectors
- 2.4 Sensors: position, velocity, force, proximity, distance, and inertial sensors
- 2.5 Sensor characteristics, calibration, noise, and basic data acquisition
- 2.6 Embedded controllers and interfaces: UART, I2C, SPI and CAN (overview)

3 Spatial Descriptions and Robot Kinematics (8 hours)
- 3.1 Coordinate systems, reference frames, position, and orientation
- 3.2 Rotation matrices, composition of rotations, and homogeneous transformations
- 3.3 Translation, rigid-body motion, and transformations between coordinate frames
- 3.4 Denavit–Hartenberg (DH) convention and coordinate-frame assignment
- 3.5 Forward kinematics of serial manipulators
- 3.6 Inverse kinematics: analytical solutions, multiple solutions, and reachability
- 3.7 Velocity kinematics and the Jacobian matrix
- 3.8 Manipulator workspace, singularities, and basic applications

4 Robot Dynamics and Trajectory Generation (6 hours)

4.1 Introduction to robot dynamics: force, torque, mass, and inertia
4.2 Newton–Euler formulation for robot motion (introductory treatment)
4.3 Euler–Lagrange formulation and equations of motion for simple mechanisms
4.4 Holonomic and non-holonomic constraints (basic concepts)
4.5 Joint-space and Cartesian paths; distinction between path and trajectory
4.6 Time scaling and cubic-polynomial trajectory generation with motion constraints

5 Robot Control and Automation Systems (5 hours)

5.1 Open-loop and closed-loop control of robotic systems

5.2 Position and velocity control of robot joints
5.3 PID controller design, tuning, and performance measures
5.4 State-space representation and introductory state-feedback control
5.5 Trajectory tracking and introduction to force, compliant, and impedance control

6 **Robot Programming and Simulation (5 hours)**

6.1 Robot programming paradigms: online and offline programming
6.2 ROS 2 concepts: nodes, topics, services, actions, packages, and launch files
6.3 Robot modelling using URDF: links, joints, limits, and sensor descriptions
6.4 Robot simulation in Gazebo and visualization using RViz
6.5 Introductory Python/PyBullet simulation of robot joints, trajectories, and control

7 Mobile Robotics, Localization and Path Planning (5 hours)

7.1 Mobile robot platforms and differential-drive kinematics
7.2 Odometry, localization, state estimation, and sources of drift
7.3 Mapping, occupancy grids, and introductory SLAM concepts
7.4 Grid-based path planning using A*, obstacle avoidance, and global/local planning
7.5 Navigation pipeline and use case: autonomous indoor delivery robot

8 Robotics-Oriented Computer Vision and Drone Technology (5 hours)

8.1 Camera model, image coordinates, acquisition, resolution, and frame rate
8.2 Image processing: colour spaces, filtering, thresholding, and segmentation
8.3 Feature extraction: edges, corners, contours, and object detection overview
8.4 Camera calibration, robot–camera transformations, and hand–eye configurations

8.5 Visual servoing: image-based and position-based concepts
8.6 Introduction to UAV components, basic flight control, GPS, telemetry, and applications

9 Advanced Robotics and Applications (4 hours)

9.1 Industrial automation and robotic manipulation case studies
9.2 Collaborative robots, human–robot interaction, and safety considerations
9.3 Field and service robotics: agriculture, inspection, healthcare, and logistics
9.4 Introduction to artificial intelligence, multi-robot systems, and emerging trends
9.5 Robotics design challenges and ethical issues

Tutorial (15 hours)

1. Define robotics, automation, and programmable logic controllers (PLCs), and give one industrial example of each.
2. For a 2R planar arm with a1 = 0.5 m, a2 = 0.3 m, θ1 = 30° and θ2 = 60°, calculate the end-effector position using forward kinematics.
3. Determine a homogeneous transformation for a specified rotation and translation, and explain the coordinate frames involved.
4. Derive the equation of motion for a simple one-degree-of-freedom pendulum robot using the Euler–Lagrange formulation.
5. Compare P, PI, and PID controllers for robot joint position control in terms of steady-state error, overshoot, and settling time.
6. Explain ROS 2 nodes, topics, services, and actions with one robotics example of each.
7. Generate a cubic trajectory from 0° to 90° in 2 s, assuming zero initial and final velocities.
8. Explain localization, mapping, path planning, and obstacle avoidance for an autonomous indoor delivery robot.

Practical (22.5 hours)

1. Lab Work 1: ROS 2 and Robot Simulation
   1.1 Create a ROS 2 package and implement basic publisher/subscriber or motion-command nodes.
   1.2 Load a robot model in Gazebo and inspect its links, joints, and sensor frames in RViz.
2. Lab Work 2: Robot Kinematics and Trajectory Generation
   2.1 Implement forward and inverse kinematics for a simple manipulator.
   2.2 Simulate joint-space trajectories and a robotic-arm pick-and-place or assembly task.
   2.3 Demonstrate a pick-and-place or assembly trajectory for a simple product.
3. Lab Work 3: Sensors, Actuators, and Embedded Interfacing
   3.1 Interface a sensor and actuator with a controller and acquire sensor data.
   3.2 Calibrate sensor readings and examine measurement noise and response.
   3.3 Implement a feedback response that adjusts gripper force for different objects.

4. Lab Work 4: Robot Control
    4.1 Implement and tune a PID controller for a simulated robot joint or mobile robot.
    4.2 Evaluate tracking performance using overshoot, settling time, and steady-state error.
    4.3 Test path following for a mobile robot and assess tracking error.
5. Lab Work 5: Robotics-Oriented Computer Vision
    5.1 Implement image acquisition, filtering, and segmentation using a suitable vision library.
    5.2 Develop a vision-based system to identify and sort different objects.
    5.3 Build a vision system to identify and sort different objects.
6. Lab Work 6: Mobile Robot Navigation
    6.1 Configure a mobile robot simulation and examine odometry and localization.
    6.2 Implement path planning and obstacle avoidance for an indoor delivery robot.
    6.3 Demonstrate an indoor delivery robot navigation task.
7. Lab Work 7: Integrated Robotics Design Project
    7.1 Select an industrial, agricultural, inspection, or service-robotics problem.
    7.2 Integrate a robot model, sensors, control, and navigation in ROS 2 and Gazebo.
    7.3 Demonstrate the solution and document design choices, limitations, and safety considerations.

Final Exam

The questions will cover all the chapters in the syllabus. The evaluation scheme will be as indicated in the table below:

Chapter	Hours	Marks distribution*
1	3	4
2	4	6
3	8	10
4	6	8
5	5	6
6	5	6
7	5	6
8	5	8
9	4	6
Total	**45**	**60**

* There may be minor deviation in marks distribution.

References

1. Siciliano, B., Sciavicco, L., Villani, L., & Oriolo, G. (2009). Robotics: Modelling, Planning and Control. Springer.

2. Correll, N., Heckman, C., & Roncone, A. (2022). Introduction to Autonomous Robots: Mechanisms, Sensors, Actuators, and Algorithms. MIT Press.
3. Lynch, K. M., & Park, F. C. (2017). Modern Robotics: Mechanics, Planning, and Control. Cambridge University Press.
4. Corke, P. (2017). Robotics, Vision and Control: Fundamental Algorithms in MATLAB (Latest ed.). Springer.