Industrial Robotics: Manipulator Design, Kinematics and Motion Planning

Target Audience

This hands-on training program is intended for mechanical engineers, robotics engineers, automation professionals, and mechatronics students who want practical exposure to articulated robotic manipulators. The course is suitable for learners interested in robotic arm design, motion mathematics, and automation systems that use multi-degree-of-freedom manipulators commonly found in industrial robotics applications.

Course Objectives

- Introduce the fundamental concepts of robotic manipulators and industrial robotics systems
- Understand robot mobility through degrees of freedom and joint configurations
- Study the mechanical structure and design considerations of robotic arms
- Learn coordinate systems and mathematical transformations used in robotics
- Understand forward and inverse kinematic modelling of manipulators
- Explore forces, torques, and dynamic behavior of robotic systems
- Learn about actuators, sensors, and feedback systems used in robotic arms
- Understand motion control strategies and trajectory generation for robotic tasks

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Course Outcomes

By the end of this course, participants will be able to:

- Understand the structure and operation of articulated robotic manipulators
- Analyze robot configurations based on joints and degrees of freedom
- Apply coordinate transformations to represent robotic link motion
- Perform forward and inverse kinematic calculations
- Understand dynamic forces and actuator requirements in robotic systems
- Plan and control robotic arm movement for industrial tasks

KOENIG
step forward

Course Description

The course comprises **40 hours** of theory and labs and is divided into **12 chapters.** Each chapter will be followed by hands-on lab exercises to reinforce learning and gauge understanding of the topics covered

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Software Platforms (Indicative)

The following software platforms may be used for demonstrations and hands-on exercises. Equivalent tools available with the client organization may also be used.

- **Fusion 360** – Robotic arm CAD modeling and mechanical design
- **MATLAB / Simulink (Robotics Toolbox)** – Kinematic calculations and trajectory planning
- **ANSYS Mechanical / Workbench** – Structural and dynamic analysis of robotic components
- **Robotics simulation environments (e.g., ROS–Gazebo or similar platforms)** – Virtual simulation of robot motion and control strategies

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Table of Contents (TOC)

- Structure of articulated robotic arms
- Mechanical arrangement of joints and links
- Multi-axis robotic arm architecture
- Serial manipulators used in industrial robots
- Relationship between mechanical structure and robot motion

Chapter 3: Degrees of Freedom and Robot Mobility

- Definition of degrees of freedom in mechanical systems
- Relationship between joints and motion capability
- Independent joint variables defining robot configuration
- Revolute joints and their motion characteristics
- Prismatic joints and linear motion
- 5-DOF manipulators used in simple industrial tasks
- 6-DOF manipulators for full spatial movement
- 7-DOF manipulators and redundant robotic systems

DOF = Number of independent joint variables defining robot configuration

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Chapter 4: Mechanical Design Considerations

- Structural design principles of robotic arms
- Load and payload considerations in robot design
- Mechanical transmission systems in manipulators
- Gear drives and harmonic drives
- Belt and pulley transmission mechanisms
- Structural stiffness and rigidity requirements
- Effects of vibration on robotic arm performance
- Mechanical safety considerations in robotic design

Chapter 5: Coordinate Systems in Robotics

- Reference coordinate systems in robotic applications
- Global coordinate frames
- Local coordinate frames assigned to robot links
- Frame assignment for robotic manipulators
- Relationship between coordinate frames
- Representation of robotic arm movement in 3D space
- Orientation representation using coordinate systems

Chapter 6: Transformation Mathematics

- Mathematical representation of robot motion
- Rotation matrices used in robotics
- Translation vectors in robotic movement
- Homogeneous transformation matrices
- Combining rotation and translation in transformations
- Transformation relationships between robot links
- Transformation chains used in robotic arms

Chapter 7: Forward Kinematics

- Concept of forward kinematics in robotic manipulators
- Determining end-effector position from joint variables
- Transformation chains along robot links
- Mathematical representation of link motion
- Denavit–Hartenberg parameter method
- Position calculation of the end-effector
- Orientation calculation of the end-effector
- Applications of forward kinematics in robotics

Chapter 8: Inverse Kinematics

- Concept of inverse kinematics
- Determining joint angles for a desired end-effector position
- Analytical approaches for solving inverse kinematics
- Geometric methods used for manipulator analysis
- Numerical methods for complex manipulators
- Multiple solutions in robot configurations
- Singularities in robotic manipulators
- Limitations of inverse kinematic solutions

Chapter 9: Robot Dynamics

- Forces and torques acting on robotic joints
- Dynamic behavior of robotic manipulators during motion
- Relationship between motion and actuator forces
- Newton–Euler formulation for robotic dynamics
- Lagrangian method for deriving dynamic equations
- Dynamic modeling of robotic arms
- Importance of dynamic analysis in robotic design

Chapter 10: Actuators and Sensors in Robotics

- Types of actuators used in robotic manipulators
- Servo motors used in industrial robotic arms
- Stepper motors and BLDC motors
- Transmission mechanisms for robotic motion
- Encoders for position feedback
- Torque sensors used in robotic joints

- Inertial measurement units used for motion sensing
- Sensor feedback systems for robot control

Chapter 11: Robot Motion Control

- Basic concepts of robotic motion control
- Joint-space control methods
- Cartesian control of end-effector movement
- PID control in robotic systems
- Control loops used in robotic manipulators
- Motion tracking and precision positioning
- Stability and accuracy in robotic motion control

Chapter 12: Trajectory Planning and Task Execution

- Concept of trajectory planning in robotics
- Path planning for robotic manipulators
- Polynomial trajectory generation
- Velocity constraints in robotic motion
- Acceleration and jerk limitations
- Coordinated motion of multiple joints
- Motion planning for industrial robotic tasks
- Execution of tasks such as pick-and-place operations
- Robotic assembly operations and automated workflows