End Module C Syllabus

NLP & LLM

- **Sequence Models – Importance, Autoregressive models, Markov Model**
- **Text Processing – Tokenization, vocabulary building, n-grams, perplexity**
- **RNNs & Training – Architecture, BPTT, vanishing gradients, GRUs, LSTMs**
- **Word Embeddings – Similarity, GloVe, applications in NLP**
- **Advanced Architectures – Deep RNNs, Bi-Directional RNNs, Transformers**
- **Practical Applications – Sentiment classification, next-word prediction, machine translation, speech recognition**
- **Attention Mechanisms – Self-Attention, Multi-head Attention, Encoder-Decoder models**
- **Transformers and Attention Mechanisms**
- **Training Large Language Models (LLMs)**
- **Prompt Engineering**
- **Applications and Limitations of LLMs**
- **Evaluation Techniques**
- **Efficiency Techniques**
- **Retrieval-Augmented Generation (RAG)**
- **Building RAG Systems**
- **RAG Applications and Challenges**
- **Semi-supervised Learning: Introduction to Semi-Supervised Learning (SSL)**
- **SSL Assumptions and Fundamentals**
- **Ladder Networks and Π-Models**
- **Proxy Label Methods (Self-Training, Co-Training)**
- **Variational Autoencoders (VAEs) for SSL**
- **Graph-Based Semi-Supervised Learning (GNNs and Label Propagation)**
- **Reinforcement Learning: Introduction to Reinforcement Learning (RL)**
- **Exploration vs. Exploitation: The Multi-Armed Bandit Problem**
- **Markov Decision Processes (MDPs)**

- **Solving MDPs with Dynamic Programming**
- **Monte Carlo Methods in Reinforcement Learning**
- **Temporal Difference Learning and Deep Reinforcement Learning**

General Applications of AI: Syllabus & Learning Outcomes

1	**AI in Search and Recommendation Systems (Focus Area: E-commerce, OTT, and Filtering Techniques)** **Topics**: Content-based, Collaborative, and Hybrid Filtering, Real-time personalization and ranking algorithms, and Case studies: Netflix and Amazon pipelines, **Hands-on**: Recommender system architecture + Python demo **Learning Outcomes**: - Understand filtering techniques (collaborative, content-based, hybrid). - Build and evaluate a basic recommender system. - Analyze how Netflix and Amazon personalize content in real time.
2	**Natural Language Processing (NLP) (Focus Area: Sentiment Analysis & Chatbots)** **Topics**: Text preprocessing, tokenization, transformers, Sentiment classification, intent recognition, Chatbot architectures: Rule-based vs AI-driven **Hands-on**: Hugging Face pipeline + chatbot demo **Learning Outcomes**: - Apply NLP techniques for text classification and chatbots. - Understand transformer-based models and intent recognition. - Develop a sentiment analysis pipeline or chatbot using pre-trained models.
3	**AI in Computer Vision (Focus Area: Healthcare and Surveillance)** **Topics**: Applications of AI in Healthcare and Surveillance, CNNs for tumor detection, face recognition, Transfer learning, object detection, and Teachable Machine: real-time image classifier **Hands-on**: Leaf disease or mask detection using webcam input **Learning Outcomes**: - Use CNNs and image classification models for real-world tasks. - Understand applications in healthcare (e.g., X-ray analysis) and surveillance. - Implement basic objects or face detection using camera input.
4	**AI in Finance (Focus Area: Credit Risk Scoring & Fraud Detection)** **Topics**: Applications of AI in Finance, Logistic regression, Random Forest, Isolation Forest, Fraud pattern detection and credit scoring, Use cases: Mastercard, Betterment, PayPal **Hands-on**: Build a credit risk ML model with synthetic data **Learning Outcomes**: - Understand ML models for credit scoring and fraud detection. - Evaluate fairness and accuracy in financial predictions. - Develop a fraud detection or credit scoring ML model.
5	**AI in Agriculture (Focus Area: Crop Monitoring, Drone Vision)** **Topics**: NDVI, precision agriculture, yield prediction, Drone-based monitoring and health mapping **Hands-on**: Google Earth Engine demo and ML for Yield prediction and Crop disease detection

	Learning Outcomes: - Apply remote sensing and NDVI for crop health assessment. - Use AI models for yield prediction and resource optimization. - Visualize crop zones and simulate AI decisions for agriculture.
6	**AI in Smart Cities (Focus Area: Traffic, Energy, Waste Management)** **Topics**: AI in traffic signal optimization, energy efficiency, Real-time traffic prediction, smart transportation and waste management **Hands-on**: **Learning Outcomes**: - Explore AI applications in traffic control, waste, and energy systems. - Model and simulate AI-based urban traffic optimization. - Evaluate the scalability of smart city AI solutions.
7	**AI in Robotics & Automation (Focus Area: Delivery Bots, Drones)** **Topics**: Path planning, SLAM, object avoidance, Real-time control using AI models **Hands-on**: Webots or Gazebo demo of a mobile robot **Learning Outcomes**: - Explain AI's role in path planning and autonomous navigation. - Simulate delivery bot or drone navigation using Webots/Gazebo. - Design AI behavior for a specific robotics task
8	**AI in Learning and Creativity (Focus Area: Education, Content Generation)** **Topics**: AI tutors, adaptive quizzes, LLMs, MusicGen, Text, image, and music generation **Hands-on**: GPT prompt engineering + DALL·E generation **Learning Outcomes**: - Demonstrate how AI personalizes education via adaptive learning. - Generate creative content using GPT, DALL·E, or MusicGen. - Understand ethical concerns in AI-generated content.
9	**Climate & Sustainability Applications (Focus Area: Weather, Crops, Environment)** **Topics**: Climate modeling, NDVI, forest monitoring, Google AI for Earth case studies **Hands-on**: NDVI and forest cover analysis using Earth Engine **Learning Outcomes**: - Apply AI models to environmental challenges (e.g., deforestation, drought). - Use platforms like Google Earth Engine for data-driven sustainability. - Propose AI-based solutions for climate resilience.
10	**AI Bias, Fairness & Regulation (Focus Area: Ethics, Bias, Laws)** **Topics**: Causes and mitigation of AI bias, EU AI Act and India's DPDP Act **Hands-on**: Biased dataset simulation and fairness evaluation **Learning Outcomes**: - Identify and mitigate bias in AI models and datasets. - Understand key AI legal frameworks (EU AI Act, DPDP Act). - Simulate and correct a biased AI system.

TinyML Topics:

- **TinyML Fundamentals:** Motivation, Scope, and Challenges
- **Hardware for TinyML:** Microcontrollers and Edge Devices
- **ML Model Design for Embedded Systems**
- **Model Compression:** Quantization and Pruning
  Tiny Model Development
- **TinyML Software Frameworks and Tools**
- **Model Deployment Pipeline on Microcontrollers**
- **Advanced Topics in TinyML**
    - **Responsible TinyML:** Ethics, Privacy, Sustainability

IoT Topics:

- Fundamentals of IoT and AI Integration
- Sensors, Actuators, and Edge Devices
- IoT System Architecture and Communication Protocols
- Data Collection and Management in IoT
- IoT Analytics
- IoT Networks
- AI Techniques for IoT Applications
- Deployment of AI Models on IoT Edge Devices
- Case Studies
- Security, Privacy, and Ethical Challenges in AIoT

Syllabus: Mechanics for Robotics

Course Type: Core / Minor in AI

This course introduces students to fundamental physics and mechanical principles essential for understanding and designing robotic systems. It builds a strong foundation in classical mechanics, enabling students to analyze how forces, torques, and motion interact in robotic structures and influence control, stability, and performance.

Introduction to Mechanics for Robotics

- Role of mechanics in robotics: motion generation, control, and stability
- Importance of physics-based modeling in robotic systems
- Concepts of physical quantities, motion, forces, and Newton's laws
- Mechanics as the basis for trajectory planning and robot behavior

Vectors, Coordinate Frames & Kinematics

- Position and displacement: vector representation, direction, and conventions
- Vector algebra in 1D, 2D, and 3D
- Coordinate frames: world vs local frames; frame conventions
- Transformations between coordinate frames
- Translation and rotation in 2D and 3D
- Homogeneous coordinates and transformation matrices
- Chaining of transformations (frame-to-frame composition)

Linear and Angular Motion

- Linear motion: position, velocity, and acceleration
- Angular motion: angular velocity and angular acceleration
- Relationship between linear and angular quantities
- Torque and rotational motion
- Moment of inertia and radius of gyration

Statics & Center of Mass

- Static equilibrium and conditions for stability
- Free-body diagrams and force/moment balance
- Center of mass (COM): definition and calculation
- Applications in robot balance and payload distribution

Dynamics & Newton-Euler Formulation

- Newton's second law (F = ma), torque = Ialpha
- Equations of motion for rigid bodies

Syllabus: Mechanics for Robotics

- Force and torque analysis in robotic links
- Introduction to the Newton-Euler formulation for dynamics

Energy, Work, and Power

- Kinetic and potential energy in mechanical systems
- Work-energy theorem
- Mechanical work done by force and torque
- Power: instantaneous and average
- Efficiency in mechanical motion and actuation

Friction, Contact & Compliance

- Types of friction: static, kinetic, and rolling
- Modeling contact forces and reaction dynamics
- Hooke's law and spring-based compliance
- Damping models: viscous and Coulomb
- Compliance in robotic joints and end-effectors

Linkages, Mechanisms & Drives

- Common mechanical linkages: 4-bar, crank-slider, gear trains
- Degrees of freedom and constraint-based analysis
- Gear systems, belts, and pulley mechanisms
- Gear ratios and torque-speed transformation

Inverse Dynamics & Actuator Analysis

- Inverse dynamics using the Newton-Euler method for manipulators
- Estimating joint torques based on motion and external loads
- Torque-speed characteristics of actuators
- Criteria for actuator selection and performance evaluation

Foundations of Robotics

Specialization Course Syllabus

Dr. Niranjan Deshpande
Minor in AI, IIT Ropar

June 5, 2025

Contents

1 Course Overview

This specialization course introduces students to the fundamentals of robotics through an interdisciplinary lens, integrating core mechanical concepts, control theory, software frameworks, and learning-based approaches. Emphasis is placed on both theoretical understanding and hands-on simulation/demonstration exercises.

2 Introduction to Robotics & Ethics

ACM Mapping: IS.RF, IS.SA

Key Topics:

- Definition and domains of robotics
- Applications across industry, healthcare, defense, and service robots
- Robotics system components: sensors, actuators, controllers
- ACM ethical guidelines: autonomy, privacy, transparency

Hands-on:

- Real-world robot demo (e.g., Boston Dynamics)
- Arduino simulator with sensor-actuator interaction

3 Sensors and Actuators

ACM Mapping: IS.SA

Key Topics:

- Types of sensors: Ultrasonic, IMU, Encoders, IR
- Types of actuators: DC, Servo, Pneumatic
- Feedback and calibration

Hands-on:

- Arduino/Tinkercad for sensor readout and motor control

4 Degrees of Freedom, Joints, and Coordinate Frames

ACM Mapping: IS.KD

Key Topics:

- Degrees of Freedom (DOF) and workspace
- Joint types: Revolute, Prismatic
- World and Local coordinate frames

Hands-on:

- Visualize robot configuration in RoboAnalyzer

5 Kinematics: Forward and Inverse

ACM Mapping: IS.KD
Key Topics:

- DH Parameters and transformation matrices
- Forward Kinematics (FK)
- Inverse Kinematics (IK): Geometric vs Numeric

Hands-on:

- Python-based 2-link arm (NumPy, Matplotlib)

6 Control Systems and PID Feedback

ACM Mapping: IS.RC
Key Topics:

- Open vs closed loop control
- PID control: tuning, applications

Hands-on:

- PID control simulation (e.g., inverted pendulum)

7 Introduction to ROS (Robot Operating System)

ACM Mapping: IS.RF, IS.RC
Key Topics:

- ROS architecture: Nodes, Topics, Services
- ROS workspace, launch files, package structure

Hands-on:

- Run and modify turtlesim using ROS Noetic

8 Mobile Robot Locomotion

ACM Mapping: IS.KD
Key Topics:

- Wheeled robot models: Differential drive
- Holonomic vs non-holonomic constraints

Hands-on:

- Webots/V-REP simulation for mobile robot

9 Motion Planning Algorithms

ACM Mapping: IS.PN
Key Topics:

- Pathfinding vs sampling approaches
- A*, RRT algorithms
- Configuration space (C-space)

Hands-on:

- A*/RRT demo on maze environment

10 Simultaneous Localization and Mapping (SLAM)

ACM Mapping: IS.SL
Key Topics:

- SLAM basics and problem formulation
- Kalman Filter, Particle Filter methods
- Sensor fusion and ROS bag file usage

Hands-on:

- Run gmapping in ROS using sample bag

11 Learning in Robotics + Human-Robot Interaction (HRI)

ACM Mapping: IS.RC, IS.RF
Key Topics:

- Reinforcement learning: Q-learning, policy learning
- Gesture and voice control interfaces
- HRI safety, trust, and ethical aspects

Hands-on:

- Implement Q-learning for navigation
- Use simple HRI interface models