National University of Sciences & Technology (NUST)
School of Electrical Engineering and Computer Science (SEECS)
Department of Electrical Engineering

EE 381: Robotics I

Course Code:	EE-381	**Semester:**	Spring 2024
Credit Hours:	3+1	**Prerequisite:**	None
Instructor:	Dr. Hafsa Iqbal	**Discipline:**	Electrical Engineering
Office:	A-225 Faculty block	**Telephone:**	----------
Lecture Days:	Tuseday and Wednesday	**E-mail:**	Hafsa.iqbal@seecs.edu.pk
Class Room:	Lecture hall 1 (PG block)	**Consulting Hours:**	
Lab Engineer:	Engr. Munadi Ahmad Sial	**Lab Engr. Email:**	Munadi.sial@seecs.edu.pk
Knowledge Group:	EPC	**Updates on LMS:**	Weekly

Course Description:

Robotics, as a field of study, is undergoing massive research and development to improve the dynamic, perceptual and behavioral aspects of robots. Students will learn the basics to model, simulate and design various robotic systems (with an emphasis on robotic manipulators).
The course will cover introduction to different types of robots and their applications. It will also reflect upon coordinate systems, kinematic principles, locomotion, and robot perception techniques (which will include robotic sensors, data acquisition, use of computer vision techniques in robotics, image processing applied to robotic perception, and feature extraction from various sensor data). In addition, an introduction to Robot localization problem will also be discussed in detail.

Course Objective:

The course material and associated lab-work is aimed to enable the students to simulate the kinematic and dynamic responses as well as the control of the robotics systems. It is also desired that the students are motivated by getting introduced with state-of-the-art in the field of robot automation.

Course Learning Outcomes (CLOs)

CLO	Description After the completion of the course the students will be able to:	BT Level	PLOs
1.	**Explain** the mathematical modelling of the robots.	C2	1
2.	**Analyze** the capabilities of robotic systems from the perspective of kinematics and dynamics.	C4	2
3.	**Describe** the role of sensors, actuators, computation and control in an autonomous robot.	C2	1
4.	**Design** and implement basic techniques for robot mechanisms.	C6	5
5.	**Execute** ROS (Robot Operating System)-based projects in teams.	P4	5
6.	**Exhibit** good professional ethics while **adhering** to lab safety rules.	A3	8
7.	**Function** effectively both individually and as a member of a team	A3	9

PLOs/CLOs	CLO1	CLO2	CLO3	CLO4	CLO5	CLO6	CLO7
PLO 1 (Engineering Knowledge)	✓		✓				
PLO 2 (Problem Analysis)		✓					
PLO 3 (Design/Development of Solutions)							
PLO 4 (Investigation)							
PLO 5 (Modern tool usage)				✓	✓		
PLO 6 (The Engineer and Society)							
PLO 7 (Environment and Sustainability)							
PLO 8 (Ethics)						✓	
PLO 9 (Individual and Team Work)							✓
PLO 10 (Communication)							
PLO 11 (Project Management)							
PLO 12 (Lifelong Learning)							

Books:

Text Book:

1. "Robot Dynamics and Control"~~.~~ by M.W. Spong, **[John Wiley & Sons], 20028.**
2. "Robot Modeling and Control"~~.~~ by M. W. Spong, **[John Wiley & Sons], 2020.**

Reference Books:

3. "Robotics, Vision and Control" by Peter Corke~~.~~, **[Springer], 2017**.
4. "Introduction to Robotics, Mechanics and Control", by John J. Craig **[Pearson Education International], 1987.**
5. "Introduction to Autonomous Mobile Robots (Intelligent Robotics and Autonomous Agents series)" by Roland Siegwart, Illah Reza Nourbakhsh, Davide Scaramuzza~~.~~, **[The MIT Press], 2011.**
6. "Learning ROS for Robotics Programming" by Aaron Martinez, Enrique Fernández. **[Packet Publishing], 2015.**

Main Topics to be Covered:

The course spans over a number of topics as under:

Topic 1 --- Course Introduction, Locomotion

- Introduction to Robotics
- History of Robotics
  - Robots Classification
  - Robot Accessories and Coordinates
  - ~~o~~ Robot Programming

Topic 2 --- Transformations and Robot Kinematics

- Kinematic models and constraints
- Robot maneuverability
- Robot Workspace

- Degrees of freedom
- Holonomic constraints in robotics

- Robot Motion Control

Topic 3 --- Learning ROS (Robot Operating System) for Robotic Programming

- Getting started with ROS / Installation
- Understanding ROS file system
- Debugging and visualization
- Using sensors and actuators with ROS

Topic 4 --- Robot Perception

- Sensors for robots, their use and classification
- Computer vision techniques to process sensor data
- Image processing techniques to process sensor data
- Feature extraction from images / sensor data

Topic 5 --- Robot Localization and Locomotion

- The challenge of localization
- Probabilistic map-based localization
  - Belief representation
  - Map representation
  - Markov localization
  - Kalman filter based localization
- Landmark based localization
- Positioning beacon system
- Route based localization
- Locomotion / Key issues in locomotion

Lecture Breakdown:

	Textbook	Topics	Lectures Hours
		Week 1	
		Topic 1 --- Course Introduction, Locomotion	
	[Spong] Chap 1 – 2	• An overview of the course contents • Robot History, Taxonomy, Classification and Configuration	3
		Week 2	
		Topic 1 --- Course Introduction, Locomotion	
	[Spong] Chap 1 – 2	• Current Trends in Robotics • Applications • Industrial robots • Locomotion	3
		Week 3	
		Topic 2 --- Transformations and Robot Kinematics	

	[Spong] Chap 3 - 4	• Representation and Homogenous Transformations
		• Kinematic Models and Constraints
		  ○ Representing robot position
		  ○ Forward Position kinematic model
		  ○ Inverse Position Kinematics
		  ○ Robot kinematic constraints
			3

Week 4			
Topic 2 --- Transformations and Robot Kinematics			

	[Spong] Chap 3 - 4	• Robot maneuverability
		  ○ Degree of mobility
		  ○ Degree of steerability
		• Robot workspace
		  ○ Degree of freedom
		  ○ Holonomic robots
		• Robot Motion Control
		  ○ Open loop control
		  ○ Feedback Control
		  ▪ Kinematic Model
		  ▪ The Control Law
		• Local Stability Issues
			3

Week 5			
Topic 3 --- Learning ROS (Robot Operating System) for Robotic Programming			

	[Martinez] Chap -1,2	• Getting started with ROS / ROS Installation
		• ROS Architecture with examples
		  ○ ROS file system
		  ○ ROS community level
			3

Week 6			
Topic 3 --- Learning ROS (Robot Operating System) for Robotic Programming			

	[Martinez] Chap -3,4	• Debugging and Visualization in ROS
		  ▪ Debugging ROS nodes / messages
		  ▪ Plotting scalar data
		  ▪ Visualization of images
		  ▪ 3D visualization
		• Using sensors and actuators with ROS
		  ▪ Using Kinect sensor to view in 3D
		  ▪ Using servomotors
		  ▪ Using IMU
			3

Week 7			
Topic 4 --- *Robot Perception - Sensors and Their Usage*			
	[Spong] Chap – 10	• Sensors for Robots • Sensor classification • Characterization of sensor performance	3
Week 8			
Topic 4 --- *Robot Perception - Sensors and Their Usage*			

	[Spong] Chap – 10, 11	• Wheel / motor sensors • Heading sensors • Inertial measurement unit (IMU) • Ground Beacon	3
		Week 9	
		Topic 4 --- *Robot Perception - Sensors and Their Usage*	
	[Spong] Chap – 10, 11	• Active ranging ▪ Time-of-flight active ranging ▪ Laser rangefinder ▪ 3D laser rangefinder ▪ Time-of-flight camera • Motion / speed sensors ▪ Doppler effect sensing ▪ Vision sensor	3
		Week 10	
		Topic 4 --- *Robot Perception - Sensors and Their Usage*	
	[Spong] Chap – 11	• Computer vision techniques in robot perception • The digital camera • Image formation • Omnidirectional cameras • Structure from stereo • Motion and optical flow • Color tracking • Image processing techniques in robot perception •	3
		Week 11	
		Topic 5 --- *Robot Localization*	
	[Spong] Chap – 11	• Image filtering • Edge detection • Computing image similarity • Image feature extraction • Properties of ideal feature detector • Corner detectors • Invariance to photometric and geometric changes • Blob detectors	
		Week 12	
		Topic 5 --- *Robot Localization*	
	[Siegwart] Chap – 5	• Challenges in Localization – Noise and Aliasing • Belief Representation • Map Representation • Probabilistic Map Based Localization •	3
		Week 13	
		Topic 5 --- *Robot Localization*	
	[Siegwart] Chap – 5	• Landmark based localization • Positioning beacons systems • Route based localization	3

Week 14			
Topic 5 --- *Robot Localization*			
	[Craig] Chap – 5/6	• Locomotion / Key issues in locomotion • Legged Mobile Robots • Leg configuration and stability • Consideration of dynamics • Examples of legged robots (one leg, two legs, four legs and six legs robots)	3
Week 15			
Topic 5 --- *Robot Localization*			
	[Craig] Chap – 5/6	• Wheel Mobile Robots • Wheel geometry, stability, maneuverability, and controllability • Wheeled locomotion: Case Studies	3
Week 16			
Topic 5 --- *Robot Localization*			
	[Craig] Chap – 6	• Aerial Mobile Robots (only top level discussion) • Research challenges discussion	**3**
Week 17			
		Student Presentations	**3**
		Total:	51

Lab Experiments

	01	Python Programming and Installing Linux Terminal
	02	Data Structures and Modules in Python programming
	03	Installing, Configuration and Introduction of Robot Operating System
	04	Publishing and Subscribing Topics and Messages in Robot Operating System
	05	Intro to Gazebo Simulator and Twist Messages
	06	Custom Teleportation, Launch Files and RQt Plots
	07	Laser Range Finder and Wall Following in Robot Operating System
	08	Parameter Server and Services in Robot Operating System
	09	Localization and Mapping in Robot Operating System
	10	Introduction to OpenCV
	11	OpenCV and Robot Operating System CV Bridge
	12	Line Follower in Robot Operating System USINF Visual Feedback
	13	Forward and Inverse Kinematics in Robot Operating System
	14	Robot Operating System Programming in C++
	15	Semester Project Demonstration and Defense

Mapping of CLOs to Assessment Modules

Assessments/CLOs	CLO1	CLO2	CLO3	CLO4	CLO5	CLO6	CLO7
Quizzes : 10-15% of the theory part	✓	✓	✓				
Assignments: 5-10% of the theory part	✓	✓	✓				
Mid Exam: 25-40 % of the theory part	✓	✓	✓				
End Semester Exam: 40-50% of theory part	✓	✓	✓				
Labs: 25% of the course			✓	✓	✓	✓	✓
Project: 0 – 20%			✓	✓	✓	✓	✓

Grading Policy:

Quiz Policy:	A number of quizzes will take place in the class to measure the learning progress of the students. These quizzes, which may be announced or unannounced, will usually last for 10 minutes.
Assignment Policy:	The course website will be the primary source for announcements and submitting assignments.
Lab Conduct:	The labs will be conducted for three hours every week. A lab handout will be given in advance for study and analysis. The lab handouts will also be placed on LMS. The students are to submit their lab tasks at the end of lab for evaluation. One submission per group will be required. However, students may also be evaluated by oral viva during the lab.
Plagiarism:	SEECS maintains a strict no tolerance plagiarism policy. While collaboration in this course is highly encouraged, you must ensure that you do claim other people's work/ idea as your own. Plagiarism occurs when the words, ideas, assertions, theories, figures, images, programming codes of others is presented as your own work. You must cite and acknowledge all sources of information in your assignments. Failing to comply with the SEECS plagiarism policy will lead to strict penalties including zero marks in assignments and report to the academic coordination office.