San Jose State University Department of Mechanical Engineering

ME 192 Robotics and Manufacturing Systems

Fall 2021

Lecture Instructor Dr. Winncy Du, 408-924-3866; winncy.du@sjsu.edu; Office: E310F

Online Office Hours MW: 12:50-13:20 PM (E310F); MW: 17:45 – 18:15 PM

Instructor Lin Jiang, Email: lin.jiang@sjsu.edu
Office Hours M: 4:00-5:00 PM; W: 12:00-1:00 PM or by email appointment (Location: E192 or Zoom)

Course Code & Schedule

ME192 Section 4 (Seminar, by Dr. Winncy Du) 50109	MW 12:00-12:50, E192
ME192 Section 2 (Lab, by Dr. Lin Jiang) 47478	M 13:30-16:15, E192
ME192 Section 5 (Lab, by Dr. Lin Jiang) 50110	W 9:00-11:45, E192

Prerequisites ME 106, ME 130 with C- or better in each

Course Description

Scientific and engineering principles of industrial (serial) robots/manipulators. Homogenous transformation, robot kinematics, statics, dynamics, Jacobin, trajectories, control and programming. Lab experiments to support the lectures, verify the theories taught, and provide the students with hands-on robot operation, control (both computer and manual), and programming experiences and skills. Robot design, sensing (especially machine vision system), actuation, and applications. Other types of robots and applications.

Textbook *Introduction to Robotics: Mechanics and Control*, 3rd Edition, John J. Craig, Prentice Hall, 2005. ISBN 0-201-54361-3

Robotics Lab Manuals: To be posted on Canvas

Grading Scheme

Homework	20%
Midterm Exam	20%
Final Exam	20%
Hands-on Lab Exercises	20 %
Term Project	15 %
Lab Quizzes	5%

A+:	95-100;	A: 90-94.9;	A-:	87-89.9;			
B+:	85-86.9;	B: 80-84.9;	B-:	77-79.9;			
C+:	75-76.9;	C: 70-74.9;	C-:	67-69.9;			
D+:	65-66.9;	D: 60-64.9;	D-:	57-59.9;		F:	< 57

Learning Objective

Upon successful completion of the course, the students will be able to:

- Know the history and types of industrial robots and their applications
- Distinguish various robots' configurations (Cartesian, SCARA, Articulated, Cylindrical, Spherical, and Parallel) and their workspace
- Describe a homogenous transformation matrix and its meaning for each joint
- Perform joint-to-joint transformations to find the end-effector's position and orientation
- Mathematically express the kinematics and dynamics of a robot
- Calculate the force or torque required at each joint in order for a robot to move with the desired velocity and acceleration
- Find the Jacobian of a robot
- Describe a robot's workspace and singularity
- Derive robot dynamics equation using both Newton-Euler's law and Lagrangian methods

- Describe the dynamic equation of a robot in a state-space form
- Control an industrial robot both manually and automatically (through a computer program)
- Design a robot's trajectory with the desired velocity, acceleration, and via points.
- Write a code using Matlab, ACE, and V+ programming tools to control and simulate an industry robot.
- Know how to use a virtual lab to control robots.

Late Policy: Unless otherwise specified for a particular assignment, work that is submitted late will be accepted with reduced credit accordingly:

Homework

- 12 hours late -10%
- 24 hours late -25%
- 36 hours late: -50%
- 37~48 hours late: -100%

Midterm & Final Exam

- 1 ~ 5 minutes late: -10%
- 6 ~ 10 minutes late: -25%
- 11~15 minutes late: -50%
- Over 15 minutes late: -100%

Exceptions: Any grading appeals or petitions must be communicated promptly in writing (or email). Exceptions will normally be evaluated at the very end of the semester in context with overall semester track record and all other exceptions class-wide. Special consideration for truly unavoidable and extenuating circumstances will depend on timeliness and strength of supporting documentation (e.g., doctor's note, policereport, military orders).

Course Requirements and Assignments

According to the Office of Graduate and Undergraduate Programs http://www.sjsu.edu/gup/syllabusinfo/, "*Success in this course is based on the expectation that students will spend, for each unit of credit, a minimumof 45 hours over the length of the course (normally 3 hours per unit per week with 1 of the hours used for lecture) for instruction or preparation/studying or course related activities including but not limited to internships, labs, clinical practice. Other course structures will have equivalent workload expectations as described in the syllabus*."

- Homework: Homework problems are usually assigned on each Thursday and due by the midnight of the following Wednesday. They will be assigned corresponding to lecture topics. Some of the homework may be software-based. Students are encouraged to discuss general strategies collaboratively, but each student is expected to prepare and submit his or her own individual work. Your lowest HW grade will be dropped when calculating your final grade.
- Midterm & Final Exams: All students are expected to complete one midterm and one final exams inclass as scheduled. Special accommodations for disabilities must be coordinated through the Accessible Education Center http://www.sjsu.edu/aec/.

Classroom Protocol

Although University Policy F15-12 at http://www.sjsu.edu/senate/docs/F15-12.pdf states that "Attendance shallnot be used as a criterion for grading", the policy also states, "Students are expected to attend all meetings for the courses in which they are enrolled as they are responsible for material discussed therein" and furthermore, "Participation may be used as a criterion for grading when the parameters and their evaluation are clearly defined in the course syllabus and the percentage of the overall grade is stated."

University Policies

Per University Policy S16-9, university-wide policy information relevant to all courses, such as academic integrity, accommodations, etc. will be available on Office of Graduate and Undergraduate Programs' Syllabus Information web page at http://www.sjsu.edu/gup/syllabusinfo/

Tentative Schedule for Seminar Section

WEEK #	TOPICS
Week #1 08/23, 8/25	Course syllabus & overview; Ch.1 Introduction Ch.2 Robot Link Descriptions & Homogenous Transformation Matrix
Week #2 08/30, 09/01	Ch.3a Denavit-Hartenberg Convention to Assign Frames to Links
Week #3 09/08	Ch.3b Manipulator Forward Kinematics
Week #4 09/13, 09/15	Ch.3C Examples of Manipulator Forward Kinematics
Week #5 09/20, 09/22	Ch 4a Manipulator Inverse Kinematics: Closed-form Solution
Week #6 09/27, 09/29	Ch.4b Inverse Kinematics: Piper's Solution
Week #7 10/04, 10/06	Review for Midterm Exam (Ch.2-4); **Midterm Exam 12-2 pm (Online, Zoom Proctor)**
Week #8 10/11, 10/13	Ch.5a Jacobians and Velocity
Week #9 10/18, 10/20	Ch.5b Velocity "Propagation" from Link to Link Ch. 5c Robots' Singularities
Week #10 10/25, 10/27	Ch.5c Static Forces
Week #11 11/01, 11/03	Ch.6a Manipulator Dynamics: Newton's and Euler's Equations
Week #12 11/08, 11/10	Ch.6b Iterative Newton-Euler Formulation for Manipulators' Motion Equations
Week #13 11/15, 11/17	Ch.6c Lagrangian Formulation for Manipulators' Motion Equations
Week #14 11/22	Ch.7a Trajectory Generation: Cubic Polynomials and MATLAB
Week #15 11/29, 12/01	Ch.7b Trajectory Generation: Linear Function with Parabolic Blends
Week #16 12/06	Course Review for Final Exam (Ch.5-7)
Final Exam Time, Date, and Location: 9:45-12:00, Friday, December 10. Online (Zoom Proctor)	

ME 192 Robotics and Manufacturing Systems Laboratory

Fall 2021

Lab Exercises

To enhance classroom learning and to provide the students hands-on experience in industrial robots. The students are divided into three-member teams. The lab exercise includes:

- Using an Excel model, learn robot positioning through a series of homogeneous transformation matrices incorporating the reach, twist, and offsetting of each link and joint angle.
- Using the ACE emulation software, experiment with real time movement of robot arm, and learn to program and debug the robot motion.
- Perform routine pick & place task and path control using teach pendant. Also, calculate the end effector offset using inverse transformation equation.
- Apply robot vision process to track and pick randomly placed stationary or moving objects. Also, learn to determine the camera position offset from the gripper or the robot base.
- Hybrid mode lab exercise description: Students will be divided into two groups (Group A and Group B) in each lab section on the first week of lab. For online classes, students will asynchronously work on the class material posted on Canvas. For **onsite** classes, students will work with the robots in E 192 Lab.

Term Project

The following restrictions in selecting and carrying out a term project applies to the term projects that are considered as an outgrowth of one or more of the lab exercises. An instructors' permit is required to take on a special project that is considered as a research and development work in nature which is beyond the scope of a term project.

The qualification of the term project is as follows:

a) The project is for ME192 only, not in conjunction with any other course such as senior design course.
b) The project is not work related for any team member. It is a common interest to the team members.
c) Most of the project work, excluding part fabrication, can be done in the lab using the available robots.
d) If executed property, the project plan will yield tangible results in a four-week period during which no prescribed lab exercises will be conducted.

Lab Conduct, Rules, and Expectations

Teamwork: The lab exercises are done in teams of three students. The team members are expected to attend all lab sessions and participate in all team activities. The instructor may solicit team feedback regarding individual member participation. Unapproved non-emergency absence will result in a zero credit for the missed lab session. However, there will be a make-up session toward the end of the term. Those who want to make up for a missed lab will meet with the instructor for a special assignment. An emergency or medical absence will receive a full lab credit for the lab.

Programming: Any robot program created during lab hours must be saved on the team's USB memory module. The instructor may erase any team programs left on a PC or a robot controller.

Reports: Reports must contain a cover sheet, a general description, the approach taken, any program code with comments, any helpful flowchart or a picture, and a summary. Submit a hard copy (for grading and feedback) two days from the second week of each lab. A soft copy may be accepted with preapproval.

Safety: Adhere to the safety rules set by the lab instructor. Never execute a robot motion program if any part of a person is reachable by the robot arm. Leave all cable connections and wiring changes with the instructor. Do not exceed the speed limit of a robot specified by the instructor. Read the Safety Rules and sign the agreement form prior to starting the first lab.

Lab Activities and Grade Assignment

Hands-on lab exercises (4) - 20% weight on the course grade
- 2-week duration for each exercise
- Manual, programmed, and vision assisted arm manipulation.
- 3-person teams. Random team assignment with exceptions.

Lab quizzes (2) - 5% weight
- Robot arm kinematics and manipulation.
- Gripper offset and camera offset. Robot vision processing.

Term project (1) - 15% weight
- 4-week duration following 2 week planning period.
- Team initiated projects with instructor assistance
- 3-person teams. The students form teams.

Demonstration of robotic tools and applications
- To introduce various robotic equipment and application software, not covered in the lab exercises.
- To provide tips for term project ideas and use of special tools.

Lab Exercise – General Description

Lab 1: Introduction to Robots

Online:	**Onsite**:
• Industrial Robot types and configurations • Robot applications • Software interface to control Robots: MATLAB, V+, etc.	• Robot coordinate systems (World-, Joint-, and tool-coordinates) • Robot's controller, driver, amplifiers • Robot control using a teaching pedant

Lab 2: Robot's Forward Kinematics and Programming using ACE

Online:	**Onsite**:
• Robot Programming Software and Emulation • Adept ACE programming environment • V+ learning • Writing a simple program to move a robot on emulation. • Understand the different coordination systems in the emulation program.	• Setting up a coordinate system to each joint of a robot • Measure a robot's parameters (link length, twist angle, offset, or joint angle) • Establish a Denavit-Hartenberg table for the given robot • Derive a 4x4 transformation matrix for each joint • Find the robot's forward kinematics using excel kinematics model or MATLAB model

Lab 3: Robot Motion Control Using a computer

Online	**Onsite**
• Write a robot's pick-and-place program with the position indexing and the gripper offset • Calculate the transformation needed in order to place a robot's end-effecter in a desired position and orientation • Input the transformation into the programming code	• Write and run the V+ program on ACE, and transfer program file to robots. • Debug and Troubleshoot the V+ program • Run the pick and place motion with the robots.

• Demonstrate (using emulation) the robot is placed and orientated in the desired position and direction with the transformation code	

Lab 4: Robotic Control with Digital I/O (**onsite**)

- Use the robot's controller's digital output ports to turn on indications
- Design a circuit (or use a pre-designed circuit) integrated with the robot controller
- Control the robots with external sensors via digital input & output ports
  Such as:
    - Read three different inputs from toggle switches.
    - Direct the robot to a distinct location depending on button pressed.
    - Indicate location by turning on appropriate indicator lamp.

Lab 5: Introduction to Machine Vision (**online)**

- Vision system basics (lens, imaging, lens equation, focal length, depth of field, illuminators)
- Pixels, image, resolutions, aspect ratio, image processing and transformation
- Object description and recognition
- Geometric test for shape recognition

ME192 Course Projects

Term Projects (Pick one)

Project 1: Robot Control with the Machine Vision Feedback

Project 2: Robot Control with the Convey Belt Moving

Project 3: Soft Pneumatic Grippers

Project 4: Haptics Feedback with Robot Control

ME 192 Lab Schedule

Wk	*Dates*	**ME192-02 Monday**		**ME192-05 Wednesday**		*Contents*
		Group A	***Group B***	***Group A***	***Group B***	
1	8/23	Lab introduction				Tour the lab, introduce lab policy, syllabus and etc.
2	8/30	Lab 1 online	Lab 1 **onsite**	Lab 1 online	Lab 1 **onsite**	Download ACE & Excel model. Understand Joint framing, Power up procedure. Manual Control Pendant Manipulate robot. Understand the coordinate systems.
3	9/6	No Lab		Lab 1 **onsite**	Lab 1 online	
4	9/13	Lab 1 **onsite**	Lab 1 online	No Lab		
5	9/20	Lab 2 online	Lab 2 **onsite**	Lab 2 online	Lab 2 **onsite**	Understanding ACE software and using V+ monitor command in ACE. Measure Robot parameters. Create D-H table. Derive transformation matrix for each joint. Find forward kinematics. Quiz on robot manipulation, program commands. **Lab report 1 due.**
6	9/27	Lab 2 **onsite**	Lab 2 online	Lab 2 **onsite**	Lab 2 online	
7	10/4	Midterm				Introduce course projects. Grouping and choose project topic. **Lab report 2 due.**
8	10/11	Lab 3 online	Lab 3 **onsite**	Lab 3 online	Lab 3 **onsite**	Pick & place with Gripper offset, Link twist/offset. Joint rotation. Use Excel kinematics model. V+ program control. FTP program file transfer. **Submit term project proposals and plans.**
9	10/18	Lab 3 **onsite**	Lab 3 online	Lab 3 **onsite**	Lab 3 online	
10	10/25	Lab 4 **onsite**	Project	Lab 4 **onsite**	Project	Use the robot's controller's digital output ports to turn on indications. Control the robots with external sensors via digital input & output ports. **Lab report 3 due.**
11	11/1	Project	Lab 4 **onsite**	Project	Lab 4 **onsite**	
12	11/8	Lab 5 online	Project	Lab 5 online	Project	Robot vision process. Geometric test for shape recognition. Transformation equation for Camera offset. Vision guided pick & place. Quiz on gripper offset, vision processing and camera offset. **Lab report 4 due.**
13	11/15	Project	Lab 5 online	Project	Lab 5 online	
14	11/22	Project		Project		Troubleshooting, trial and error and project completion. **Lab report 5 due.**
15	11/29	Project		Project		**Submit a progress report & consult with the instructor.**
16	12/6	Term project presentation and demonstrations				**Group evaluation and class evaluation.**