San Jose State University Department of Mechanical Engineering

ME 192 Robotics and Manufacturing Systems
Fall 2019

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Office Hours MW: 9:30-10:00 AM; M: 5:50-6:20 PM; W: 3:45-4:15 PM (E310F or E192)

Course Code & Schedule

ME192 Section 1 (Seminar, by Dr. Du) 44340 MW 12:00-12:50, E192
ME192 Section 2 (Lab, by Dr. Hee Man Bae) 44341 M 13:30-16:15, E192
Lab Instructor, Dr. Bae's Office Hours: M 10:00-11:50 AM (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:* 1st Edition by Winncy Du
Optional: *Introduction to Robotics: Mechanics and Control*, 3rd Edition, John J. Craig, Prentice Hall, 2005. ISBN 0-201-54361-3
Robotics Lab Manual: 1st Edition by Hee Man Bae

Grading Scheme

Homework	10%
Midterm Exam	18%
Final Exam	17%
Lab Experiments & Reports	20 %
Term Project	20 %
Lab Quiz and Programming	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.

Tentative Seminar Schedule

WEEK #	**TOPICS**
Week #1 08/21	Course syllabus, pre-requisites, permit codes; course overview and structure Ch.1 Robotics History, Types, and Applications
Week #2 08/26, 08/28	Ch.2 Robotics Terminologies, Configurations, and Workspace Ch.3 Homogenous Transformation Matrix and Robot Link/Human Arm Descriptions
Week #3 09/04	Ch.4a Coordinate Transformation Ch.4b Denavit-Hartenberg Convention to Assign Frames to Links
Week #4 09/9, 09/11	Ch.5a Manipulator/Human Limb Forward Kinematics
Week #5 09/16, 09/18	Ch. 5b: Implementation of Forward Kinematics through Matlab Ch.6a Inverse Kinematics: Closed-form Solution
Week #6 09/23, 09/25	Term Project Information & Guideline (by Dr. Bae) Ch.6b Inverse Kinematics: Piper's Solution
Week #7 09/30, 10/02	Inverse Kinematics Exercise on An Articulated Robot
Week #8 10/07, 10/9	Review for Exam #1 **Midterm Exam (Ch.1-4)**
Week #9 10/13, 10/15	Ch.7 Velocity "Propagation" from Link to Link Ch.8 Cartesian Transformation of Velocities and Static Forces
Week #10 10/20, 10/22	Ch. 9 Jacobians and Singularities Ch.10a Manipulator Dynamics: Newton's and Euler's Equations
Week #11 10/28, 10/30	Ch.10b Iterative Newton-Euler Formulation Ch.10c Lagrangian Formulation
Week #12 11/04, 11/06	Ch.11 Forming Manipulator/Limb Dynamics in Cartesian Space
Week #13 11/13	Derivation of a Robot Dynamic Equation Using Iterative Newton-Euler Method
Week #14 11/18	Ch.12a Trajectory Generation: Cubic Polynomials Cubic Trajectory Description Using MATLAB
Week #15 11/25	Ch.12b Trajectory Generation: Linear Function with Parabolic Blends Linear Function with Parabolic Blends Using MATLAB II
Week #16 12/02, 12/04	Course project presentation, demonstration, and evaluation
Week #17 12/9	Course Review
Final Exam Date: 12:15-14:30, Wednesday, December 11, E192	

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. Each lab has a three week duration.

- 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 determing the camera position offset from the gripper or the robot base.

Lab Demonstrations (*as time permits*)

- Advanced robot types such as collaborative robots and mobile robots.
- Conveyor tracking with extended robot vision application.
- Tool changer and vacuum generator for end effectors.

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 team projects needs to be conceived by the 7th or 8th week of the term.

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.

Class Conduct, Rules, and Expectations

Pertaining to Lectures

Attendance: Attendance in all lectures/labs is expected.

Homework: Homework will be assigned on Wednesday. It will be collected at the beginning of the class on the following Monday.

Pertaining to the Lab

Teamwork: The lab exercises are done in teams of three students. There may be a few teams with one less or one more student. 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 (3) - 20% weight on the course grade
- 3 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 - 20% weight
- 5 week duration following 2-3 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 Schedule

Wk	***Dates***	***Subject***	***Contents***
1	8/26	Lab 1-1	Download ACE & Excel model. Power up procedure. Manual Control Pendant.
2	9/9	Lab 1-2	Joint framing, Link twist/offset. Joint rotation. Use Excel kinematics model.
3	9/16	Lab 1-3	Manipulate robot using V+ monitor command. FTP program file transfer.
4	9/23	Lab 2-1	V+ program control - Pick & place routine with position indexing.
5	9/30	Lab 2-2 Quiz 1	Set up transformation equation in V+ for Gripper offset Quiz on robot manipulation, program commands.
6	10/7	Lab 2-3	Pick & place with Gripper offset
7	10/14	Lab 3-1	Lecture - Robot vision process. Geometric test for shape recognition.
8	10/21	Lab 3-2	Transformation equation for Camera offset
9	10/28	Lab 3-3 Quiz 2	Vision guided pick & place Quiz on gripper offset, vision processing and camera offset.
10	11/4	Proj. wk 1	Submit team proposal & consult with the instructor.
11	11/18	Proj. wk 2	Demonstration – Collaborative robot and Mobile robot
12	11/25	Proj. wk 3	Submit a progress report & consult with the instructor.
13	12/2	Proj. wk 4	Team presentation & final report submission.
14	12/9	Review	Lab review and make up demonstration for those who missed a lab session.

Lab Exercises – General Description

Lab 1 – Robot joint frames & Arm manipulation

Contents – Robot configurations, identification of joint type & link parameters (link length, link twist, and link offset), rotational vs. linear motion. Use of Excel model for robot kinematics and location transformation. ACE software download to student PC.

Instructor Demo – Arm manipulation with teach pendant, E-stop, jam recovery, monitor commands for location definition and joint motion. Safe pick & place routine.

Exercise – Manipulate the robot arm with teach pendant in both joint and Cartesian motion. Find the gripper angle in terms of the robot base given the joint angles and the arm link twists. Move the joints by the set values and compare the gripper position change with the Excel model. Extract a homogeneous transformation matrix from a location vector. Get familiar with location definition and motion commands

Lab 2 – Robot pick & place motion and V^+ program commands

Contents – V^+ program commands, SEE and ACE editors, Adept's on-line language/user/reference manuals. Location definition in Cartesian and joint frames. Relationship between relative positioning and transformation equation.

Instructor Demo – Arm manipulation with teach pendant, E-stop, jam recovery, monitor commands for location. ACE simulation for tracking and picking randomly placed object on conveyor belt based on inverse Jacobian solution.

Exercise – Define locations and set up coded transformation equation. Write a command sequence for pickup & drop-off operation. Use loops for repeat motion and position indexing. Learn data file read-write commands,

Lab 3 - Robot Vision

Contents – Robot vision processing sequence and common terminology used. Analog to digital conversion of pixel image and the algorithm used in 8-digit quantization. Threshold for binary conversion. Image filters. Area of Interest. Morphology operation (erosion and dilation). Object perimeter (edge) extraction.

Instructor Demo - Pallet bar code read using edge detection tool and 4-digit quantization. Extraction of the perimeters of color images via linear scanning (as an alternative to extraction based on morphology operation).

Exercise – Learn Adept vision commands and image attributes. Perform a geometric test for object identification. Learn the technique used in mapping the camera frame to the robot frame. Set up an inverse transformation equation to find the camera offset.