MECA 470 – Robotics Engineering

Mechanical Engineering and Mechatronic Engineering,
and Advanced Manufacturing

California State University, Chico

Welcome to Robotics Engineering!

Section 1, Foundations of Robot Motion (Chapters 2 and 3): Robot configuration spaces (C-spaces) and representation of spatial motions and forces.

Section 2, Robot Kinematics (Chapters 4-6): Forward kinematics (e.g., calculating the position and orientation of a robot's end-effector based on the joint positions), velocity kinematics and statics relating joint velocities and forces/torques to end-effector velocities and forces, inverse kinematics (e.g., calculating joint positions that achieve a desired end-effector configuration), and kinematics of robots with closed chains.

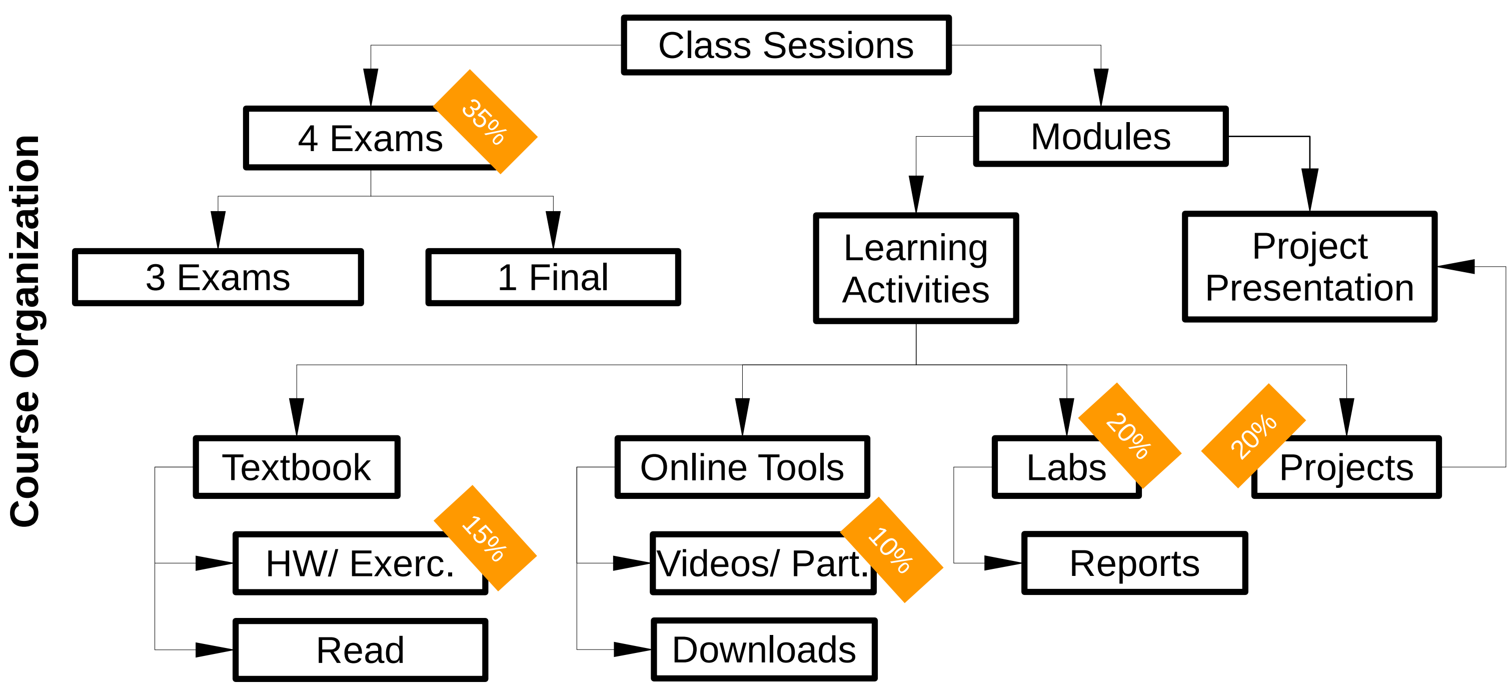
Section 3, Robot Motion Planning and Control (Chapters 10 and 11): Motion planning in the presence of obstacles and feedback control for trajectory tracking, force control, and hybrid motion-force control.

Section 4, Robot Manipulation and Wheeled Mobile Robots (Chapters 12 and 13): Advanced topics such as analysis and planning for robot manipulation, and modeling, motion planning, and control for wheeled mobile robots and mobile manipulators (wheeled robots equipped with robot arms).

This specialization is a deep and rigorous presentation of fundamental material, serving as a strong foundation for more advanced study in robotics, much like a university course sequence. It is not meant as a shallow robotics sampler for students with only a casual interest in robotics.

Textbook:
Modern Robotics, Kevin Lynch 2nd , 9781107156302, (Free Pre-print Digital Version Acceptable)
A Gentle Introduction to ROS, Jason M. O'Kane, 9781492143239 (Free Digital Version Acceptable)

Software and Hardware: We will use software tools heavily for the exercises, labs, and projects. With that, we will use Robot Operating System, RoboDK, and CoppeliaSim. For ROS, we will use AWS Robomaker -and you can also use VM. Please see more details of the software section in the Blackboard. We do not have a specific hardware requirement for this class. However, there are ROS compatible easy to use hardware solutions which we will list in the hardware section. The project of this class does NOT require any hardware and you will NOT receive credit for completing anything on hardware.



Student **My Answers**

FAQ/ Office Hours

1) I have a question on the assignment.

2) I have something to talk about (grad school, industry, any other problems).

3) I have software installation and running problems.

4) We didn't learn anything yet or we didn't cover this in the class.
Why do we start the projects early?

1) Did you look into the example problems?
- **Yes** → Good. Where did you look? There are the same problems. Let me explain over the examples.
- **No** → Please check the references.

1) Did you start to solve it?
- **Yes** → I can tell whether you are in the right direction or not. But I do NOT solve the problems for you.
- **No** → I don't provide solution for any Assignments until the completion of their grading. I solve the exercises.

2) Let's talk about it.

3) You should look into the provided documentation. I do not install any software for you except the documentation that I shared.

4) Projects are for enabling the concepts of learning-by-doing. There would be cases in your project which is Not yet covered -or won't be covered- in this class. However, the project will help you to understand those via tutorials. That said, for individual topics I can provide similar examples.

Weightings, Grading, and Rubric:

Weightings

15%	Homework x 6	Upload to Provided Link	Make sure you completed them before the test.
	Exercises x 8	Samples will be provided	Make sure you completed them before the test.
15%	Exams x 3	In class exams	Make sure understand HW and exercises
10%	Participation		
20%	Project x 1	W1 - Select a topic → W2 - Setup a group → Get an approval → Start to work on and complete the milestones	
20%	Exam x 4		
20%	Labs x 10	Same team	

Excluding 5-10 % extra credits

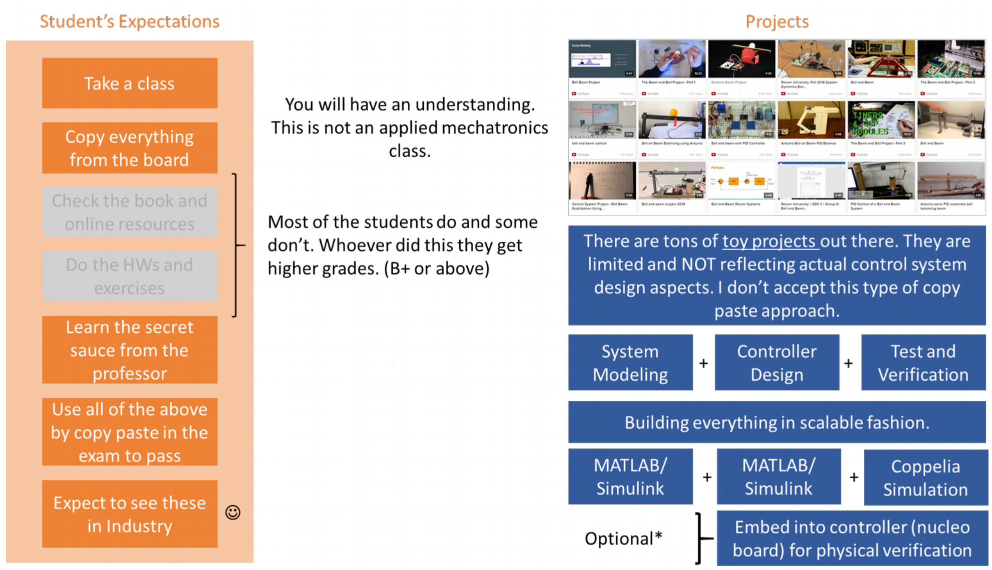
Total

A	A-	B+	B	B-	C+	C	C-	D-	D	F
-	-	-	-	-	-	-	-	-	-	-

Sample Rubric

	Unsatisfactory	Satisfactory	Beyond Expectations
Participation	• No participation, • Incomplete in class quizzes	Full participation, Completed in class quizzes	Criteria in Satisfactory+ Bringing good ideas related to topic
Assignments	• Incomplete and unorganized answers	Complete and concise answers	Criteria in Satisfactory + bringing exemplary problems with solutions
Project	• Failure in teamwork • No direct contribution to the project	A team player with can do attitude Fulfilled her/ his part	Criteria in Satisfactory + leading the team's effort with great contrib.
Labs	• Incomplete and unorganized lab reports	A team player with can do attitude Complete and concise answers	Criteria in Satisfactory + completion of optional parts of labs.
Exams	• Incomplete, not readable and unorganized solutions	Complete and concise answers	Criteria in Satisfactory + bringing exemplary solutions to verify

Map of Success (see Intro Presentation)



See Blackboard for the details

Learning Methods

Learning Method 1 – Textbook Reading Assignment Individual weekly reading assignments of two textbook chapters per week (estimated study time 3 hrs) as listed in the Module Description (shown as a reference below). Please don't dive into the book as a reading assignment. You should try to build a connection with the exercises and context.

Learning Method 2 – Online Lectures (Synchronous and Asynchronous) Each Module includes an on-line lecture (estimated watch time 2 hrs) related to the lecture topic. Students are required to watch the lectures and follow the instruction related to homework assignments.

Learning Method 3 – Online Lab Tutorials Lab tutorials and analysis tools instruction are provided with short videos. (estimated 1 hr lab). Students will follow the instruction on the video regarding the lab or project assignment and the analysis tools. The analysis tools are relatively easy to learn and apply and may serve as a good toolkit for future engineering work

Learning Method 4 - **Project Teams** - Students will form into teams of maximum 4 students per team on the first day of the course. Project team members are expected to plan, work and solve problems together on project, followed up by individual work per project manager Action Items (AI) assignments. Students must attend assigned meeting schedule for group work.

Assignments

Homework/ Exercises – The homeworks will be posted on Blackboard and you need to upload your response in the specified format to the Shared folder with you for this class. You will receive the graded homework in the same folder and will get the chance to see it. Late assignments will be accepted with a penalty (e.g., after a week of the delay the total grade will be 0).

Lab Assignments – There will be several lab assignments that requires you to team up with a person (lab buddy). Your assignment will be graded together. My expectation from you to work together as a group with your lab mate. If there is a problem in terms of contribution you MUST report me as soon as possible. So that we can You can check the lab template which has sections such as 1- Title 2- Lab Objective, 3- Names of submitting student or students in the submitting group, 4- Report Date, 5- Results, 6- Comments

Projects – There are selected projects in the projects folder. You must form the project group by the second week as part of Milestone 1. <u>There is no reason not to start the project with an excuse such 'We didn't learn the topic.' Please read the project section for the details of the semester project.</u>

Details of the Modules

Section 1: Foundations of Robot Motion

Week 1: Aug 24 – Aug 29		Complete Below Tasks By:	08/30/20
	Watch:	Khan's Linear Algebra Videos (Online Resources > Mathematical Foundations)	
	Read:	Chapter 1 - Preview (Chapters 2-3-4-5-6-9-10-12-13)	
	Assignment:	Due date September 6	
	Lab:	Installation of the software packages and Python Programming	
Week 2: Aug 31 – Sep 4		Complete Below Tasks By:	09/06/20
	Watch:	Dr. Lynch Chapter 2 Videos	
	Watch:	Dr. Corke 2D and 3D Videos	
	Read:	Chapter 2.1 – 2.5	
	Assignment:	N/A	
	Lab:	RoboDK – types of robots, degrees of freedom, reference frames	
Week 3: Sep 7 – Sep 11		Complete Below Tasks By:	09/13/20
	Watch:	Dr. Corke 3D Videos	
	Watch:	Dr. Lynch Chapter 3 Videos	
	Read:	Chapter 3.1 – 3.2	
	Assignment:	Due date September 20	
	Lab:	CoppeliaSim – Types of robots, degrees of freedom, reference frames	
Week 4: Sep 14 – Sep 18		Complete Below Tasks By:	09/20/20
	Watch:	Dr. Corke 3D Videos	
	Watch:	Dr. Lynch Chapter 3 Videos	
	Read:	Chapter 3.2 – 3.4	
	Assignment:	N/A	
	Lab:	Application of linear algebra by using python on RoboDK and CoppeliaSim	

<u>Learning Outcomes</u>

- Understanding of the concept in the robotics engineering such as software architecture, hardware architecture
- Explain the number of degrees of freedom of a rigid body.
- Derive the number of degrees of freedom of a mechanism by summing the freedoms of the bodies and subtracting the independent constraints.
- Understand the freedoms and constraints provided by common robot joints.
- Apply Gruebler's formula to determine the number of degrees of freedom of a Mechanism.

Details of the Modules

Section 2: Robot Kinematics

Learning Outcomes

- Express the joint axes of open-chain robots as screw axes in a frame {s} at the base of the robot or a frame {b} at the end-effector of the robot when the robot is at its home configuration (all joint variables zero).
- Evaluate the product-of-exponentials (PoE) formula, in the space frame {s} or end-effector frame {b}, to find the end-effector configuration in SE(3) given the vector of joint variables.
- Calculate the configuration-dependent Jacobian of an open-chain robot, relating the joint velocities to the twist of the end-effector, where the twist is expressed in either the robot's base frame {s} or the end-effector frame {b}.
- Use the Jacobian to calculate the joint forces and torques required to statically resist a given wrench applied to the end-effector.
- Test for singular configurations of the robot where the rank of the Jacobian drops below its maximal rank, reducing the dimension of the space of instantaneous twists available to the end-effector.
- Visualize the configuration-dependent ability of the end-effector to move in different directions as a manipulability ellipsoid, and measure how isotropic this ellipsoid is using a scalar manipulability measure.
- Understand the relationship between the manipulability ellipsoid and the force ellipsoid, which measures the ability of the end-effector to apply forces or moments in different directions.

Details of the Modules

Section 3: Robot Motion Planning

Learning Outcomes

- Understand different types of motion planning problems and properties of motion planners.
- Apply the concept of C-space obstacles in the analysis of motion planning.
- Represent free C-space as a graph or a tree.
- Implement the A* optimal graph search algorithm.
- Understand how a road-map representation of the free C-space allows the design of a path planner that is guaranteed to find a path when one exists (a "complete" planner).
- Develop a grid-based representation of free C-space allowing path planning by graph search.
- Implement a rapidly-exploring random tree (RRT) motion planner.
- Implement a probabilistic roadmap (PRM) motion planner.
- Understand how virtual potential fields can be used for real-time motion control among obstacles.

Details of the Modules

Section 4: Manipulation and Wheeled Robotics

Learning Outcomes

- Identify the contact normal direction at a point contact.
- Classify a contact as rolling, sliding, or breaking.
- Express rolling, sliding, and breaking contacts as constraints on the relative twists between rigid bodies.
- Represent a set of twists satisfying specified contact constraints as a polyhedral convex set or a polyhedral convex cone.
- Classify the contact situation between a rigid body and external contacts as a contact mode.
- Represent twists and twist cones for planar bodies using centers of rotation.
- Apply graphical and mathematical tests for full kinematic constraint, also known as form closure.
- Apply the definitions of linear span, positive span, and convex span to a set of vectors.
- Apply the Coulomb law of dry friction, visualize the forces that can be applied through a frictional contact as a friction cone, and represent friction cones as cones in wrench space.
- Represent planar wrench cones using moment labels.
- Apply graphical and mathematical tests determining whether a set of contacts on a body can generate all feasible wrenches, i.e., force closure.
- Apply contact kinematic analysis, contact force analysis, and either force balance or rigid-body dynamics to solve mechanics problems involving rigid bodies in frictional contact.

Dropping and Adding: You are responsible for understanding the policies and procedures about add/drops, academic renewal, etc., found in the CSU Chico University Catalog. You should be aware of the new deadlines and penalties for adding and dropping classes.

University Policies and Campus Resources

Academic Integrity

Students are expected to be familiar with the University's Academic Integrity Policy. Your own commitment to learning, as evidenced by your enrollment at California State University, Chico, and the University's Academic Integrity Policy requires you to be honest in all your academic course work. Faculty members are required to report all infractions to the Office of Student Judicial Affairs (Office of Student Conduct, Rights & Responsibilities) . The policy on academic integrity and other resources related to student conduct can be found on the Student Judicial Affairs (Office of Student Conduct, Rights & Responsibilities) web site.

Student Services

Student services are designed to assist students in the development of their full academic potential and to motivate them to become self- directed learners. Students can find support for services such as skills assessment, individual or group tutorials, subject advising, learning assistance, summer academic preparation and basic skills development. Student services information can be found on the current students page of the CSU Chico web site.

Americans with Disabilities Act

If you need course adaptations or accommodations because of a disability or chronic illness, or if you need to make special arrangements in case the building must be evacuated, please make an appointment with me as soon as possible, or see me during office hours. Please also contact Accessibility Resource Center (ARC) as they are the designated department responsible for approving and coordinating reasonable accommodations and services for students with disabilities. ARC will help you understand your rights and responsibilities under the Americans with Disabilities Act and provide you further assistance with requesting and arranging accommodations

Accessibility Resource Center

530-898-5959, Student Services Center 170, arcdept@csuchico.edu

Student Learning Center

The mission of the Student Learning Center (SLC) is to provide services that will assist CSU, Chico students to become independent learners. The SLC prepares and supports students in their college course work by offering a variety of programs and resources to meet student needs. The SLC facilitates the academic transition and retention of students from high schools and community colleges by providing study strategy information, content subject tutoring, and supplemental instruction. The University Writing Center has been combined with the Student Learning Center. You can also visit the Student Learning Center web site.

Netiquette

Please comply with the policies in Chico State's **"Computing Use and Netiquette."**