SILICON VALLEY ROBOTICS

TOGETHER WITH AMT

ARE YOU INTERESTED IN ROBOTICS?

Guide to Robotics Research and Education

IN THE GREATER BAY AREA OF CALIFORNIA

2022/2023 EDITION

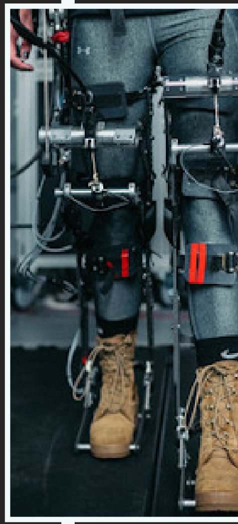
TABLE OF CONTENTS

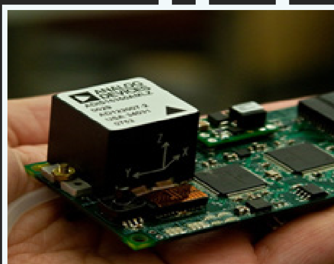
01 Introduction
02 About Us

04 Why Study Robotics

09 Map of Colleges/List by Regions
10 San Francisco Region Colleges
17 San Jose Region Colleges
28 North Cal Region Colleges
30 Greater Bay Region Colleges

36 Community College/STEM Education
37 The Advanced Robotics for Manufacturing (ARM Institute)
38 Mechlabs
39 Women in Robotics
40 Black in Robotics





SVR INTRODUCTION

In the last decade we have seen more robotics innovation commercializing than in the entire history of robotics.

Furthermore, the greater Silicon Valley and San Francisco Bay Area is at the center of this 'Cambrian Explosion in Robotics' as Dr Gill Pratt, Director of Robotics at Toyota Research Institute described it. In fact, two of the very first robots were developed right here.

In 1969 at Stanford, Vic Sheinman designed the first electric robot arm able to be computer controlled. After successful pilots and interest from General Motors, Unimation acquired the concept and released the PUMA or Programmable Universal Machine for Assembly. Unimation was eventually acquired by Staubli, and the PUMA became one of the most successful industrial robots of all time.

Shakey was the first mobile robot able to perceive and reason. Also called the world's first electronic person by Time Magazine in 1972. Shakey was developed at SRI International from 1966 to 1972 and pioneered many advances in computer vision and path planning and control systems that are still in use today.

These companies have been at the heart of Silicon Valley Robotics, the regional robotics ecosystem/association, but we have also seen enormous growth in new robotics companies and startups in the last decade.

And all of them are hiring.

This volume serves as a guide to students who are interested in studying the field of robotics in any way. Robotics jobs range from service technician, electrical or mechanical engineer, control systems and computer science, to interaction or experience designer, human factors and industrial design.

All these skills are in great demand in robotics companies around the world, and people with experience in robotics are in great demand everywhere. Robotics is a complex multidisciplinary field, which provides opportunities for you to develop problem solving skills and a holistic approach.

The robotics industry also requires people with skill sets in growing businesses, not just robotics, but product and project management, human resources, sales, marketing, operations.

Get involved in robotics - the industry of the 21st century.

Andra Keay

Director of Silicon Valley Robotics

VP of Global Robotics for the Association of Manufacturing Technologies

Founder of Women in Robotics

About Silicon Valley Robotics

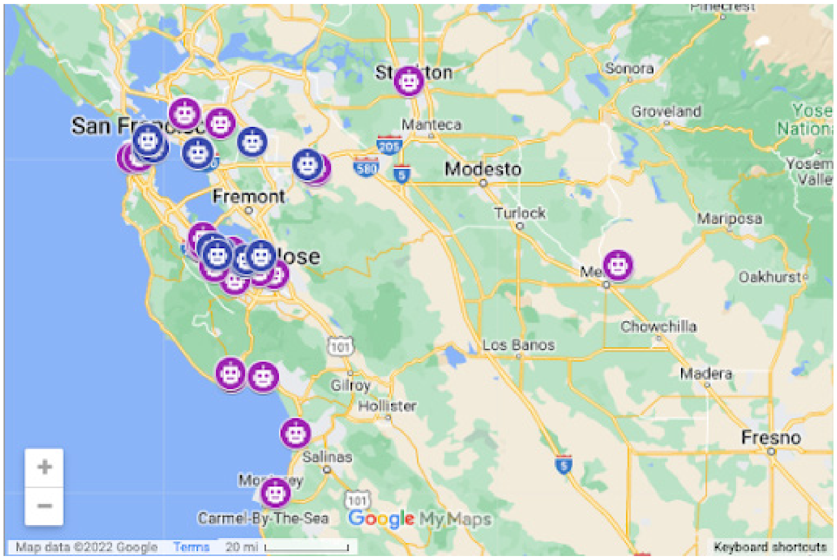
Silicon Valley Robotics is the largest cluster of robotics and AI technology innovation and investment in the world. SVR is a non-profit organization representing the robotics cluster of northern California. Started by the robotics and AI industry to support the emerging new robotics and AI industry, including agricultural, medical, social, retail, logistical, transport and space robotics networks.

Silicon Valley Robotics is ground zero of the robotics revolution, helping startups get investment and grow into category-creating industry leaders. SVR industry cluster encompasses almost 50% of global investment in robotics, more than 50 robotics research labs, and more than 500 robotics startups from the seed stage to billion-dollar new unicorns. Silicon Valley Robotics is more than an industry cluster, it is a super-connector/accelerator.

The mission of SVR is to support the innovation and commercialization of robotics technologies. More information can be found at: https://svrobo.org/

Silicon Valley Robotics MAP of Robotics Research Labs in Greater Bay Region

Silicon Valley Robotics started a map of public robotics labs providing education and conducting research. We found at least 50 in the greater Bay Area, as there may be several labs within any university. We have also started collecting information on commercial robotics r&d labs.



This is an ongoing project. If you'd like to be included on the map or in the next Guide to Robotics Research and Education please email us at researchguide@svrobo.org.

About the Author: Karen Tapia

This report was created by Karen Tapia, who participated in the CITRIS Workforce Innovation Program (WIP) and was partnered with Silicon Valley Robotics for an internship. Karen Tapia is a senior UC Berkeley Mechanical Engineering student whose interests lie in product development and research.

During her internship, she was tasked with creating this report/catalog that would serve as a guide to anyone who was interested in the robotics field. The project was very eye-opening as it gave an insight into the creative and innovative minds of the Professors around the Greater Bay Area. Being able to learn about the technology and research being developed in the different labs and projects was the best part of this project.

Personally, this project made me more inclined to not only learn more about robotics but also take a greater part in working with robots. I will be taking advantage of the robotics courses at UC Berkeley in Fall and will take a robotics course to continue my engagement in the field. ORCID Number: 0000-0002-7726-0260

The CITRIS Workforce Innovation Program

The CITRIS Workforce Innovation Program helps UC students pursue world-changing research and accelerate their careers.

The program offers select University of California students the opportunity to inform their career decisions through eight-week internships, where they'll build in-demand skills through on-the-job experience. Participants will receive training in leadership and project management, and will be supported throughout the internship program by dedicated CITRIS staff, as well as the community of peers in their cohort.

CITRIS and the Banatao Institute invite undergraduates from all majors at UC Berkeley, UC Davis, UC Merced and UC Santa Cruz to apply for placements in one of five areas of emerging IT innovation important to the state of California: aviation, climate resilience, digital health, robotics and semiconductors.

Students who represent the rich diversity of the University of California, including women, people from underrepresented backgrounds, Pell Grant recipients, undocumented students and first-generation students, are encouraged to apply.

CITRIS AND THE BANATAO INSTITUTE

Why Study Robotics?

Key Facts about the Robotics Industry and Research

The National Center for Science and Engineering Statistics (NCSES) of the National Science Foundation (NSF) provides State Profiles of data on personal, finances, and state rankings in the sector of Science and Engineering (S&E).

Important data from the NSF Science and Engineering State Profiles in California

- Rank #1: Gross domestic product 2020 (3,007,188 $millions)
- Rank #1: Total R&D performance 2019 (193,095 $millions)

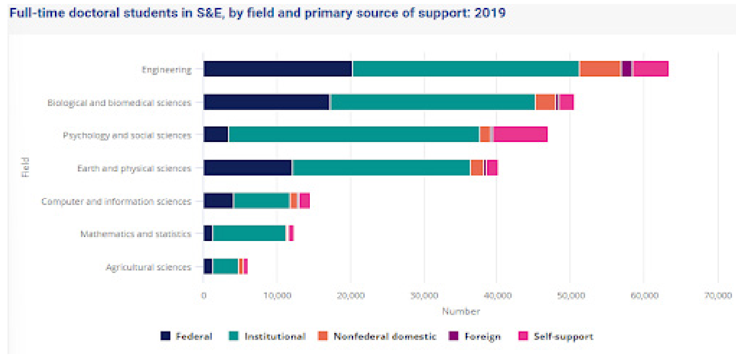
R&D in 2019 for the US was estimated at $656 billion

- Rank #1: Business R&D performance 2019 (171,961 $millions)

According to the NCSES NSF the number of degrees in S&E fields across all degree levels as of 2019 is 1,087,000. U.S. STEM workforce which is defined as workers who use S&E skills in their job is comprised of 36 million people which constitutes 23% of the total U.S. workforce. Bachelor's degrees account for nearly 70% of all S&E degrees awarded.

In 2019 S&E fields accounted for 65% of doctorates conferred by U.S universities. In 2018 the number of S&E doctoral degrees awarded by the US was 41,071, which is ranked first in comparison to other countries.

- Full-time Doctoral Students in S&E by field as of 2019
- Rank #1: Higher education R&D performance 2020 (10,522 $millions)
- Rank #1: Academic research space 2019 (24,784 thousand sq ft)
- Rank #1 in all these areas compared to other states



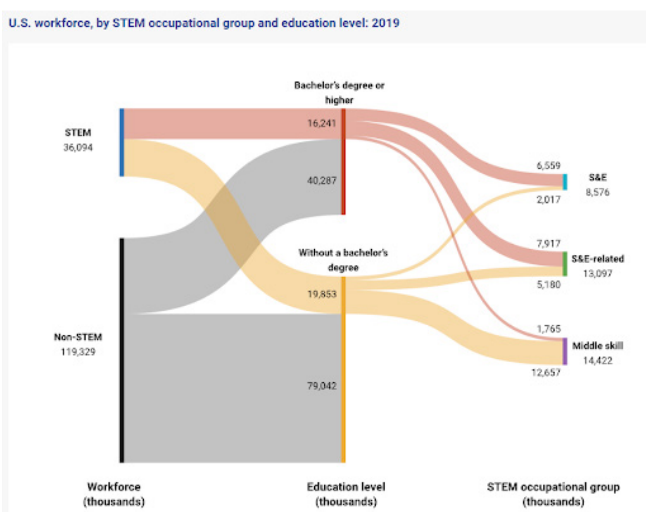
Field	Federal	Institutional	Nonfederal domestic	Foreign	Self-support
Engineering	20,250	30,982	5,685	1,494	4,983
Biological and biomedical sciences	17,290	27,880	2,835	376	2,095
Psychology and social sciences	3,478	34,085	1,504	292	7,563
Earth and physical sciences	12,092	24,296	1,815	341	1,586
Computer and information sciences	4,063	7,777	961	238	1,546
Mathematics and statistics	1,306	9,911	243	102	760
Agricultural sciences	1,381	3,429	605	80	675

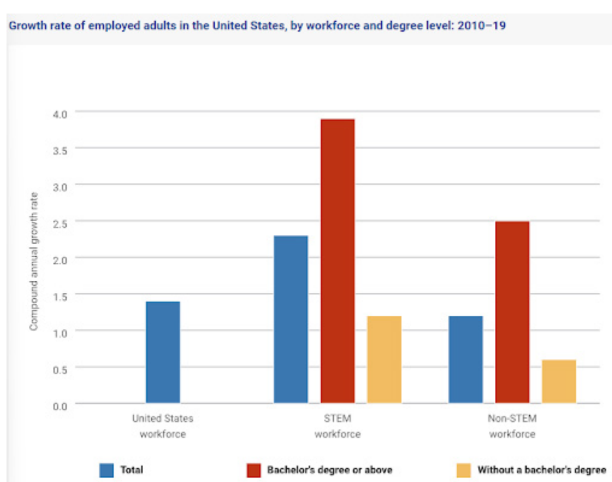
The chart shows the number of full-time doctoral students by field in 2019.
Photo courtesy of NCSES NSF.

Demographic Composition: According to NSCES NSF

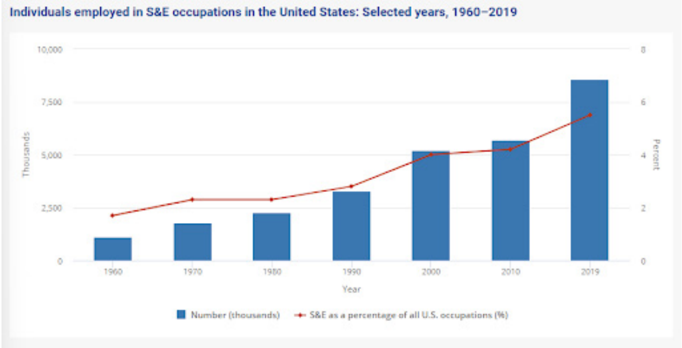
STEM Workforce Facts

- There are approximately 36 million STEM workers, representing 23% of the total U.S. workforce in 2019.
- Within the STEM workforce, 55% of workers do not have a bachelor's degree and 45% of workers have a bachelor's degree.
- In 2019 STEM workers had a higher median salary (55,000$) than non-STEM workers (33,000$).
- The median salary in S&E (regardless of education level or field) was 88,720$.
- Among STEM workers 89% with a bachelor's degree or higher, and most (89%) are employed in S&E or S&E-related occupations.
- Those with a bachelor's degree or higher within the STEM workforce experienced the greatest employment growth (3.9%) during 2010-2019.





The long-run dynamics of workers in STEM occupations from 1960-2019 have more than tripled from 1.7% in 1960 to 5.5% in 2019, according to the U.S. Census Bureau data.



STEM Pathways: Degree Attainment, Training, and Occupations

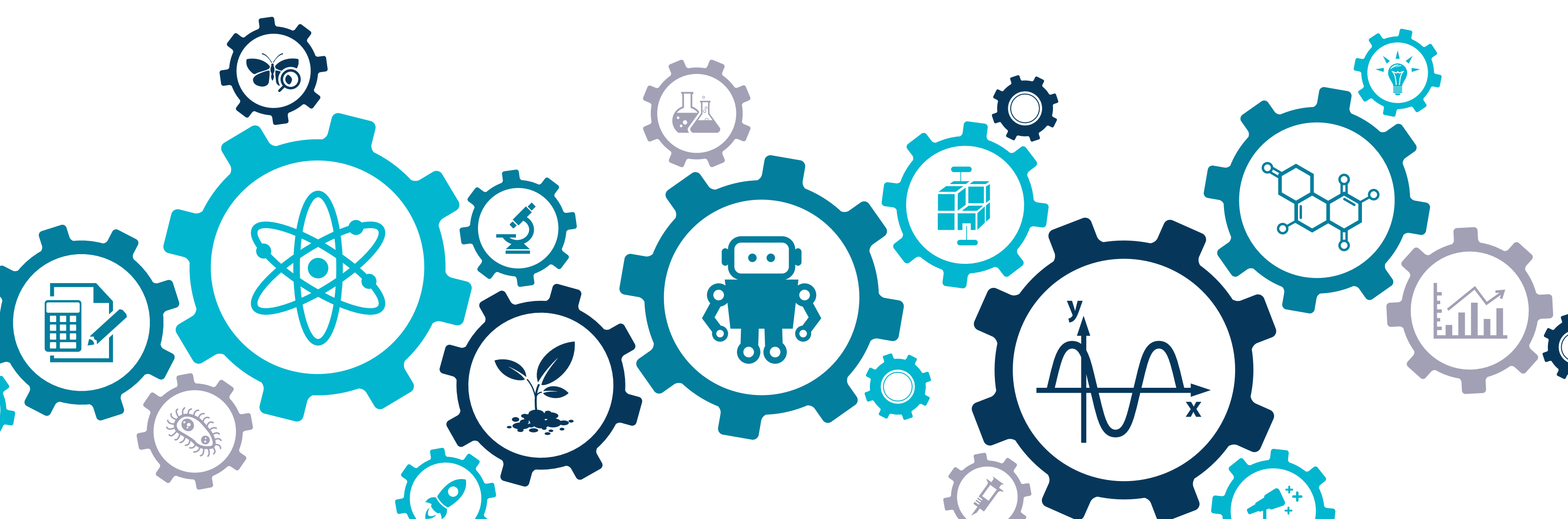
Education and training are fundamental ways to enter the STEM workforce. A variety of pathways are available such as technical education at secondary levels, postsecondary education 2 and 4-year degree programs, or certifications.

A 4-year degree is the main pathway for STEM workers. Within STEM, most workers in S&E occupations (76%) and S&E-related occupations (60%) hold a bachelor's degree or higher.

Among STEM workers 43% with a bachelor's degree or higher held a certification or license compared to 28% without a bachelor's degree.

Among the STEM workforce, workers in S&E-related occupations held certifications and licenses at the highest proportions, both those with (69%) and without a bachelor's degree (53%).

Workers with their highest degree in computer and mathematical sciences (56%) and engineering (40%) fields work the most in occupation in their major fields of study.



STEM Pathways: Degree Attainment, Training, and Occupations

Women make up about one-third (12 million workers) of the STEM workforce in 2019. Representing 44% of those with a bachelor's degree or higher and 26% of those without a bachelor's degree.

Within STEM, women comprised 44% of workers with a bachelor's degree (7 million workers) and 26% of those without a bachelor's degree (5 million workers).

In 2019, women accounted for 48% of life scientists and 65% of social scientists but only 35% of physical scientists and 26% of computer and mathematical scientists. Representation of women is the lowest in engineering (16%).

Women holding their highest degree in S&E increased from 31% in 1993 to 40% in 2019.

According to an Article by the Maryville University called Women in STEM, the growing challenges women and girls face in the field are getting more awareness. This means that Universities and tech industries can increase their efforts to encourage women to continue their pursuit in the STEM field. Some examples are training and workshops that attempt to counter the gender bias in STEM. Awareness of the contributions of women in STEM history is increasing. Mentorship and employee resource groups have increased, to help women combat the isolation that many women feel in the first years of their STEM careers.

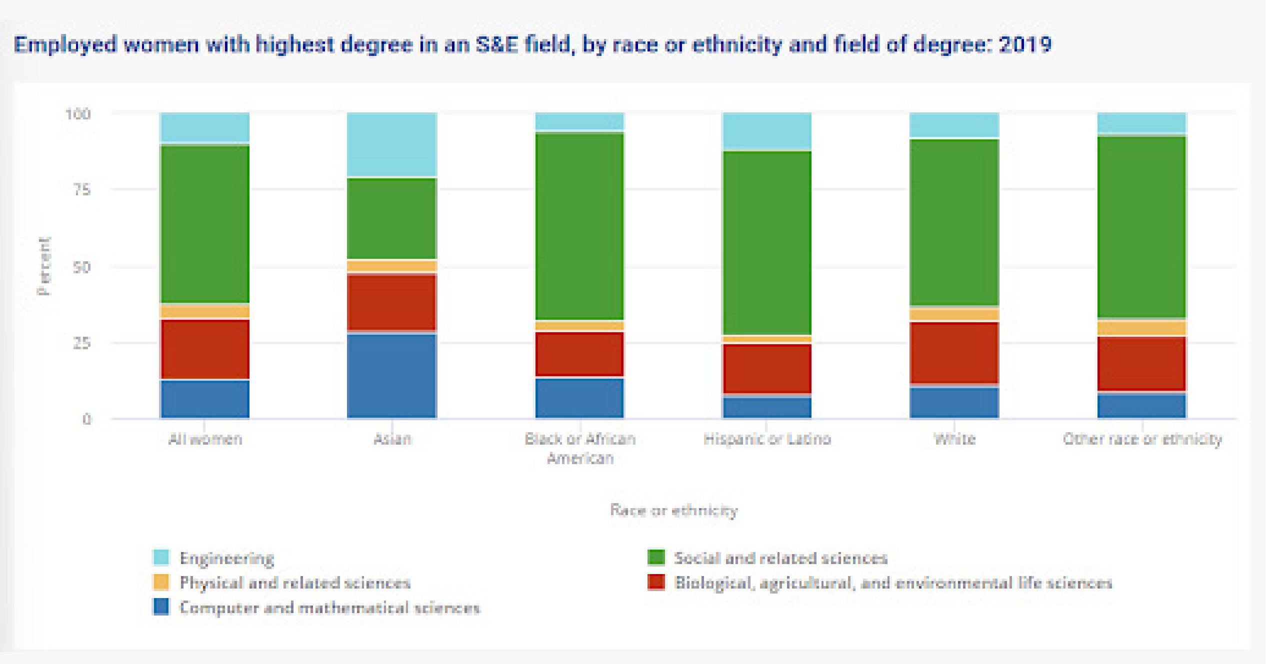
In terms of future job opportunities, with the growing need for Tech, this means more STEM opportunities for women. The U.S. Bureau of Labor Statistics (BLS) estimates that between 2016 to 2026, the employment of computer and information researchers will increase by 19%. The BLS also estimates that 140,000 new engineering jobs will be created between 2016 to 2026.

A study written by Laura Sherbin, in the Harvard Business Review, attempts to identify the strategies women use to overcome workplace barriers in STEM. She found that 52% of "highly qualified" women in STEM left their positions due to a "culture" they found challenging. The six approaches researchers found that contributed to women having successful careers were: exude confidence, claim credit when deserved, cultivate peer networks, serve as a mentor for other women in STEM, be your true self, and take pride in your successes, particularly in how they solve real-world problems. By women practicing these approaches, they can hopefully have a more successful career in STEM.

Representation of Race or Ethnicity in STEM

According to the U.S. Census Bureau, American Community Survey 2019, Asians and Whites represent a greater share of STEM workers (9% and 65%).

- Hispanic or Latino workers make up 18% of the U.S. workforce but represent 14% of STEM workers.
- Black or African American workers make up 12% of the U.S. workforce but represent only 9% of STEM workers.
- In the STEM workforce with a bachelor's degree or higher, Hispanic or Latino workers represent 8% of the workforce, and Black or African American workers represent 7%.
- Hispanics or Latinos working in S&E occupations grew from 3% in 1995 to 8% in 2019. Holding their highest degree in S&E fields grew from 3% to 9%.
- In the same period, Black or African American workers in S&E occupations grew from 3% to 5%, and holding their highest degree in S&E fields grew from 5% to 7%.



University Research Labs and Courses

Robotics research is essential to developing the technologies of today and tomorrow. The Bay Area and its surrounding regions are a hub for innovative projects and research. This guide will help serve as a tool that will showcase a variety of different research labs from different Universities in the Bay Area and its surrounding regions. The Directors of these labs have provided a statement explaining their research, projects, and hopes for the future. If you wish to find more information on these research projects please feel free to visit the website of the Directors. The guide also provides examples of robotics courses at the undergraduate and graduate levels, for each University. Hopefully, this can give a better insight into what an education in the pathway of Robotics looks like and possible learning opportunities.

List of Universities by Region

Robotics research is essential to developing the technologies of today and tomorrow. The Bay Area and its surrounding regions are a hub for innovative projects and research. This guide will help serve as a tool that will showcase a variety of different research labs from different Universities in the Bay Area and its surrounding regions. The Directors of these labs have provided a statement explaining their research, projects, and hopes for the future. If you wish to find more information on these research projects please feel free to visit the website of the Directors. The guide also provides examples of robotics courses at the undergraduate and graduate levels, for each University. Hopefully, this can give a better insight into what an education in the pathway of Robotics looks like and possible learning opportunities.

San Francisco Region
- San Francisco State
- Pacific
- UC Berkeley
- San Jose
- Stanford
- Santa Clara

San Jose/Silicon Valley Region
- San Jose State
- Santa Clara
- Stanford

North Cal Region
- San Francisco State
- Stockton
- UC Berkeley
- UC Davis

Greater Bay Area
- UC Merced
- UC Santa Cruz

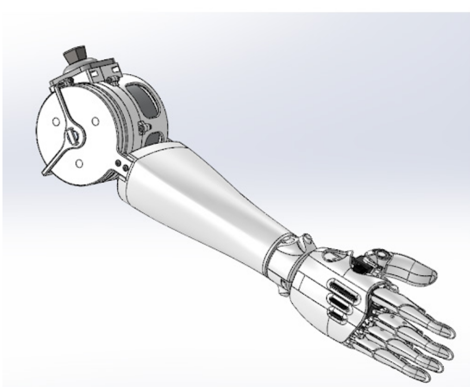
San Francisco State University Control for Assistive and REhabilitation Robotics (CARE) Lab

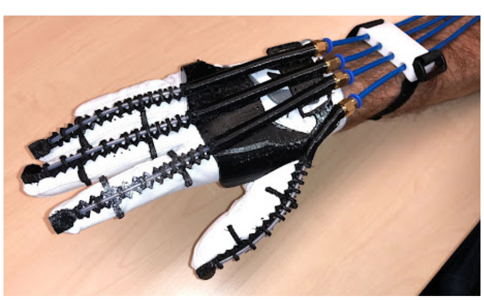
Directed by Dr. David Quintero

The CARE Lab (Controls for Assistive and REhabilitation) Robotics Laboratory is on a mission to develop low-cost, wearable robotic devices for people with limited mobility. The evidence-based research conducted in the lab entails designing robotic prostheses to provide the biomechanical movement of amputees' missing limb or robotic exoskeletons for people with paralysis that needs human movement assistance. Beyond design, we develop novel control strategies that systematically determines a human motion intent with a limited set of wearable sensing. Our work has collaboration with various engineering disciplines and medical clinicians from design concept to human subject experimental practice. We are an active robotics research lab with having 15+ diverse research students working on a variety of design and controls challenges within wearable robotics. At SFSU, we pride ourselves being a Hispanic-Serving Institution where over 50 undergraduates and graduate students (64% are from underrepresented minority groups) that have been supervised in this particular robotics field. In addition, we invest in modernizing robotics and mechatronics education curriculum to better prepare the next generation workforce entering silicon valley robot companies.

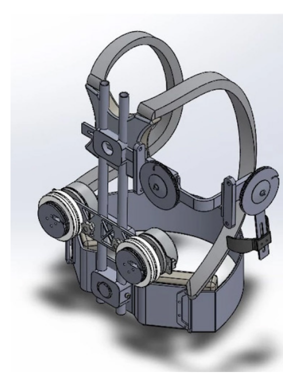
A new engineering building at SFSU is currently in development that will house modernized robotics research and teaching laboratories for academic and industry collaborations. Below is the vision we are trying to create for those new labs. https://cose.sfsu.edu/. More information can be found at CARE Lab. Contact Email: gdavid@sfsu.edu.

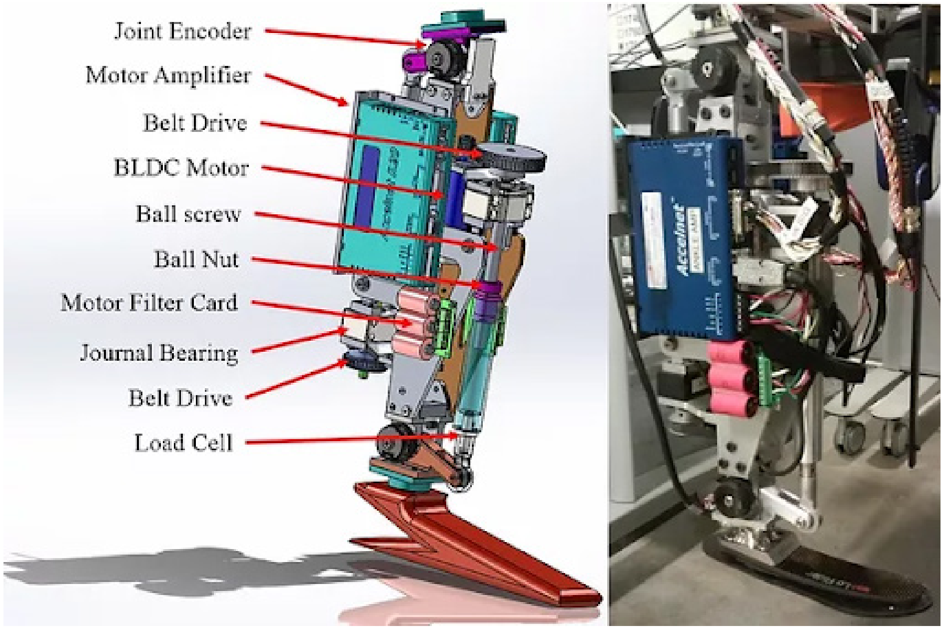
Transhumeral Powered Prothesis,
Hand Powered ExoGlove





Full Upper-Body Prothesis, Elbow Exoskeleton,
Two-Degree-of-Freedom Shoulder Exoskeleton





Design and Manufacturing of a Powered Knee-Ankle Prothesis
All images are courtesy of SFSU CARE Lab

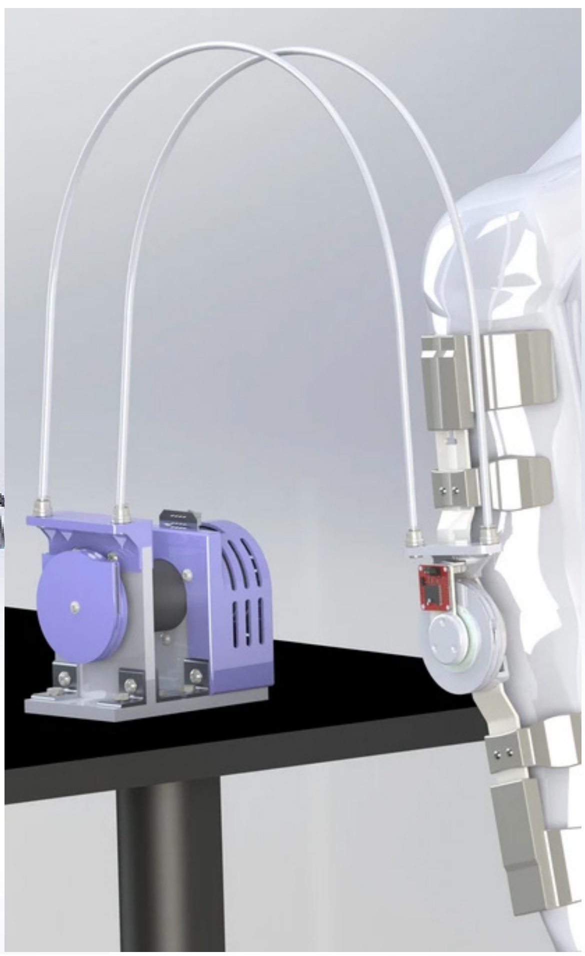
Courses from SFSU

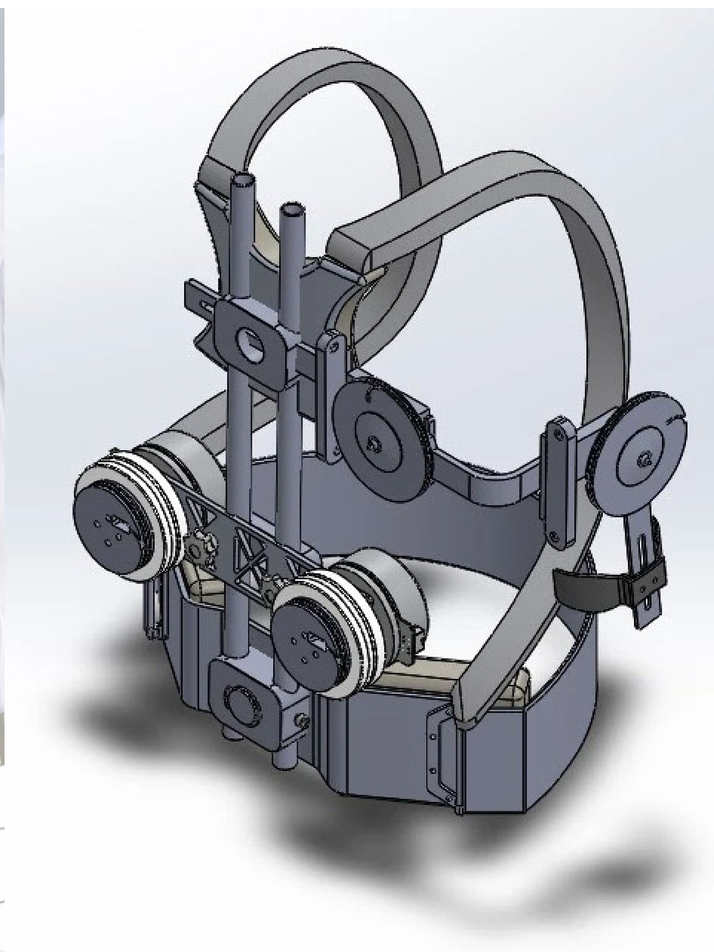
Undergraduate Level Courses

- ENGR 121 Gateway to Computer Engineering – Hands-on introduction to embedded computer systems. Basic laboratory instrumentation, electronic circuit assembly, measurement, and testing. Introduction to hardware and software of robots.
- ENGR 415 Mechatronics – Basics of a multidisciplinary field that combines electronics, mechanical design and simulation, and control systems. Simulation and design of systems with sensors, controllers, and actuators. System elements, including common sensors, actuators, and various electronic controllers.
- ENGR 447 Control Systems – Analysis and design of continuous and discrete control systems. Systems modeling and stability. System compensation using root-locus and frequency domain techniques. Z-transforms, discrete transfer functions, and state-space representation. Control of digital systems using state-space methods.
- ENGR 470 Biomechanics – Understanding and characterizing the mechanical behavior of biological tissues and systems. Emphasis on the fundamentals of biomechanics including force analysis, mechanics of deformable bodies, stress analysis, and viscoelasticity.
- ENGR 478 Design with Microprocessors – Assembly language programming. System bus. Interfacing with memory and I/O devices. Serial and parallel communications. Timer and counter functions. Polling and interrupt. A-D conversion. Fuzzy logic.
- ENGR 498 Advanced Design with Microcontrollers – Advanced topics on design with modern microcontrollers including advanced microcontroller architecture, system bus and interfacing with memory and I/O devices, advanced serial interfaces, direct memory access, pulse width modulation, memory and power management, and introduction to real-time operating systems. Develop microcontroller-based real-time embedded systems.

Graduate Level Courses

- ENGR 845 Neural-Machine Interfaces: Design and Applications – Introduction to the concepts, designs, and challenges of neural-machine interfaces (muscle-machine interfaces, brain-computer interfaces, etc.) and their applications (e.g., neuroprosthetics, gesture-controlled devices) from an engineering perspective. Design real-time neural-machine interfaces and applications by combining principles of neural signal processing, machine learning, and real-time computer system design.
- ENGR 868 Advanced Control Systems – Advanced feedback control and simulation techniques. Sensor filtering and estimation. State space control and modern control topics. Real-time control and implementation in embedded systems.
- ENGR 869 Robotics – Kinematics and kinetics of robotic manipulators including serial manipulators, parallel manipulators and legged robots.
- ENGR 870 Robot Control – Control system design and analysis within the field of robotics through solving engineering control challenges in robot manipulation. Examine feedback control, robot modeling and system identification, motion planning, impedance and force control, feedback linearization, and passivity-based control. Hands-on application of robot control and motion planning. Discussion of practical robot areas including autonomous robots, haptics, collaborative and underactuated robots.





University of the Pacific, Stockton


Dr. Elizabeth Basha

University of the Pacific School of Engineering and Computer Science has a wide variety of robotics opportunities. Our research areas cover environmental monitoring with multi-agent systems for agriculture and ecological understanding, automated manufacturing, and biomedical devices. There is one dedicated robotics class taught every semester (alternating undergraduate and graduate) that covers the full robotics system from mechanical to electrical to programming.

For more information, please contact Dr. Elizabeth Basha, Professor of Electrical and Computer Engineering and key robotics researcher. More information can be found at https://engineering.pacific.edu/engineering/directory/basha-elizabeth. Contact Email: ebasha@pacific.edu

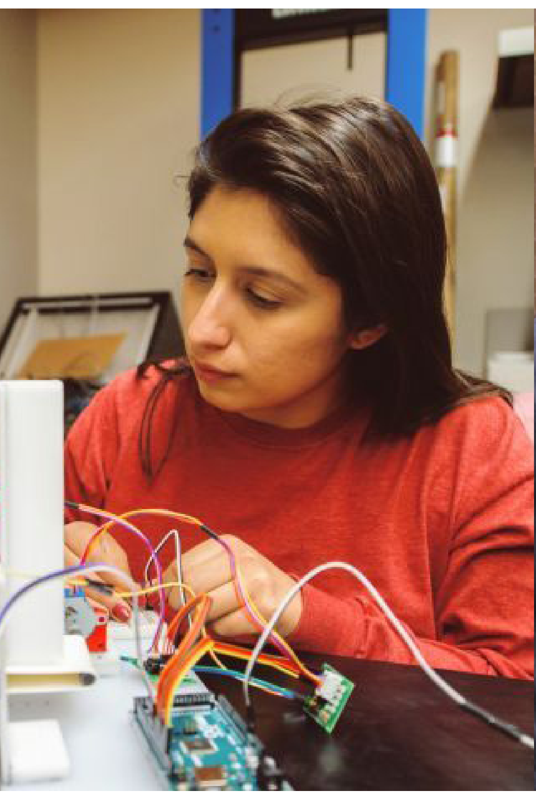
Courses from UofP

Undergraduate Level Courses

- MECH 104 Introduction to Mechatronics – A broad understanding of the main components of mechatronic systems; Understanding of the general principles involved in computer controlled machinery, including sensing, actuation and control; Practical knowledge of the development of simple embedded computer programs; Understanding of the practical application of mechatronic systems in applications such as manufacturing, automobile systems and robotics.
- BENG 124 Biomechanics – This course discusses concepts of engineering mechanics including stress, strain, deformation, and analysis of structures with application to biomechanical phenomena over a range of biological length scales. Engineering mechanics concepts are used to evaluate forces and moments acting on human joints, forces in musculoskeletal tissue, material properties of biological tissues, and disease state conditions.
- ECPE 155 Autonomous Robotics – This course is an overview of the design of autonomous robotics. Students study architectures for robot organization and control, configurations of fixed and mobile robots, sensors and actuators. Students also study the design of algorithms and knowledge representations.
- ECPE 161 Automatic Control Systems – Students study component and system transfer functions, open and closed loop response; stability criteria; applications to engineering systems. This course include a laboratory.
- BENG 175 Human/Brain Machine Interface – Human/Brain Machine interface (HMI/BMI) is a direct communication pathway between human signals such as heart activity, electro dermal activity, and brain with an external device. Bioelectrical activity can be employed directly to provide information or predict the human alertness, stress level, health or control external devices such as an external keyboard and robotic arm. This topic includes the physiology of generation of human vital signals, designing interface device, and developing offline and real-time computational algorithms for controlling external devices.

Graduate Level Courses

- BENG 202 Biosensor – This course provides a comprehensive introduction to the basic features of biosensors. Discussion topics include types of most common biological agents and the ways in which they can be interfaced with a variety of transducers to create a biosensor for biomedical applications. The focus is on optical biosensors and systems (e.g. fluorescence spectroscopy, microscopy).
- MECH 204 Advanced Mechatronics – Students study the design of mechatronic systems that integrate mechanical, electrical, and control systems engineering. Laboratories form the core of the course. They cover topics such as mechanism design, motors and sensors, interfacing and programming microprocessors, mechanical prototyping, and creativity in the design process.
- ECPE 255 Robotics – This course explores high-level issues of autonomous robotics. The course will focus on theory, design, and implementation of making intelligent and autonomous robots. The course will examine these topics from the perspective of individual robots, swarm robots, and multi-agent robots. Students will learn both theory and practice through simulations and work on robot platforms.
- COMP 257 Advanced Algorithms – This course will cover the fundamentals of algorithm design. We will discuss some basic paradigms for reasoning about algorithms and their asymptotic complexity and survey many of the techniques that apply broadly in the design of efficient algorithms.



University of California, Berkeley

Directed by Alice M. Agogino

BEST (Berkeley [Energy and Sustainability Technologies/Expert Systems Technologies/Emergent Space Tensegrities]) Lab

The BEST (Berkeley [Energy and Sustainability Technologies/ Expert Systems Technologies/ Emergent Space Tensegrities]) Lab is located in 230 Hesse Hall on the UC Berkeley campus. The BEST lab conducts research at the intersection of cutting-edge frontiers in design research, computational design, sustainability, gender equity, human-machine cognition, supervisory control, soft robotics, artificial intelligence, sensor fusion, and design research.

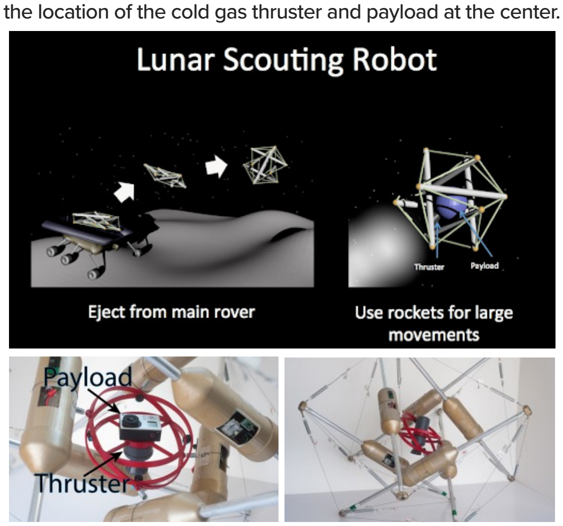
The BEST Lab is under the direction of Alice M. Agogino, the Roscoe and Elizabeth Hughes Professor, Emeritus, of Mechanical Engineering. Alice Agogino has served in a number of administrative positions including Chair of the UC Berkeley Division of the Academic Senate, Associate Dean of Engineering and Director of the Instructional Technology Program. She is a member of the National Academy of Engineering (NAE) and has served on a number of committees of the National Academies. Agogino currently serves as Chair of the Graduate Group in Development Engineering housed in the Blum Center for Developing Economies. Agogino has authored over 300 peer-reviewed publications and has won numerous teaching, mentoring, best paper and research awards. She has supervised 196 MS projects/theses, 62 doctoral dissertations and numerous undergraduate researchers.

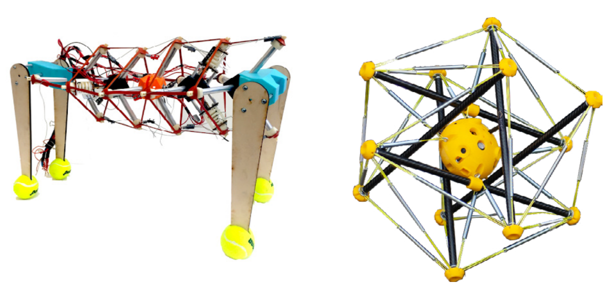
Squishy Robotics is a spin-off the BEST Lab's research on sensor robots for space exploration with a new mission today: Save Planet Earth! Our product platform roadmap begins with our HazMat robots for improved situational awareness in hazardous environments. Our sensor robots can be rapidly deployed by aerial vehicles. We have tested them at drops of 300 meters. They can survive the landing and can continue to submit critical data without the need for humans to drive to the area and hand-place sensors. Our sensor robots are impact resistant and can be deployed in fleets. They provide 360-degree vision and can carry customizable gas detection sensors.

The BEST Lab, working with Squishy Robotics is also developing an early wildfire and methane detection robot. We are performing R&D to create aerial/ ground hybrid robots, with Prof. Mark Mueller, also from UC Berkeley.

More information can be found at https://best.berkeley.edu/. Contact Email: agogino@berkeley.edu

The Berkeley rapidly-prototyped tensegry robot (Version 3) illustrates the location of the cold gas thruster and payload at the center.





Laika the quadruped robot with a tensegrity spine, Squishy Robotics a spin-off of BEST Lab research on tensegrity robots for space exploration. All images are courtesy of UCB BEST Lab.

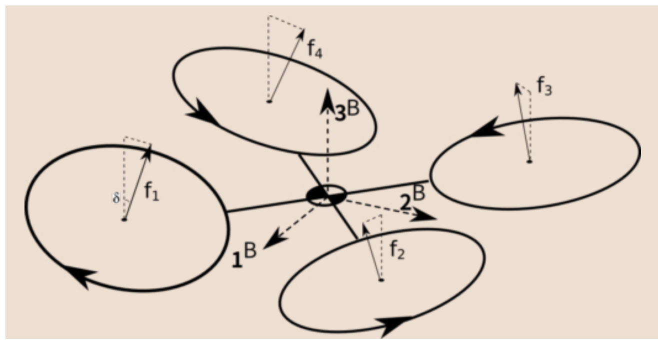
Directed by Dr. Mark Mueller

High Performance Robotics (HiPeR) Lab

At the High Performance Robotics Lab, we focus on low-level research on fundamental robotics capabilities, especially for Unmanned Aerial Systems. Areas of particular focus are safety, localization, and design. We aim to enhance the systems' capabilities by advanced algorithms, mechanical design, and control strategies.

We have a strong focus on experimental validation of ideas, and therefore we expend substantial energy in ensuring that algorithms etc. can be implemented on a real system, and run in real time. We also like making videos of our results — find our YouTube channel here.

More information can be found at https://hiperlab.berkeley.edu
Contact Email: mwm@berkeley.edu



UAV with tilted propellers away from common thrust direction which helps improve total power consumption.
All images are courtesy of UCB HiPeR Lab.

Directed by Dr. Ken Goldberg

AUTOLab

UC Berkeley's AUTOLab, directed by Professor Ken Goldberg, is a leading center for research in robotics and automation sciences. The lab supports 30 postdocs, PhD students, and undergrads pursuing projects in Robust Robot Grasping and Manipulation for Warehouses, Homes, and Robot-Assisted Surgery. We focus on methods at the intersection of analytic theory (eg, geometric and statistical models, motion planning) and deep learning.

AUTOLAB

Courses from UC, Berkeley

Undergraduate Level Courses

- BIO ENG 102 Biomechanics: Analysis and Design – This course introduces, develops and applies the methods of continuum mechanics to biomechanical phenomena abundant in biology and medicine. It is intended for upper level undergraduate students who have been exposed to vectors, differential equations, and undergraduate course(s) in physics and certain aspects of modern biology.
- BIO ENG C119 Orthopedic Biomechanics – Statics, dynamics, optimization theory, composite beam theory, beam-on-elastic foundation theory, Hertz contact theory, and materials behavior. Forces and moments acting on human joints; composition and mechanical behavior of orthopedic biomaterials; design/analysis of artificial joint, spine, and fracture fixation prostheses; musculoskeletal tissues including bone, cartilage, tendon, ligament, and muscle; osteoporosis and fracture-risk predication of bones; and bone adaptation.
- MEC ENG 131/236C Vehicle Dynamics and Control – Physical understanding of automotive vehicle dynamics including simple lateral, longitudinal and ride quality models. An overview of active safety systems will be introduced including the basic concepts and terminology, the state-of-the-art development, and basic principles of systems such as ABS, traction control, dynamic stability control, and roll stability control. Passive, semi-active and active suspension systems will be analyzed. Concepts of autonomous vehicle technology including drive-by-wire and steer-by-wire systems, adaptive cruise control and lane keeping systems. Design of software control systems for an actual 1/10 scale race vehicle.
- MEC ENG 136/236 Introduction to Control of Unmanned Aerial Vehicles – This course introduces students to the control of unmanned aerial vehicles (UAVs). The course will cover modeling and dynamics of aerial vehicles, and common control strategies. Laboratory exercises allow students to apply knowledge on a real system, by programming a microcontroller to control a UAV.
- MEC ENG 139/239 Robotic Locomotion – This course provides students with a basic understanding of robotic locomotion and the use of kinematics, dynamics, control algorithms, embedded microcomputers and mechanical components in designing artificial legs such as prosthetics, orthotics and exoskeletons.

Graduate Level Courses

- EECS C106A/C206A – This course is an introduction to the field of robotics. It covers the fundamentals of kinematics, dynamics, control of robot manipulators, robotic vision, sensing, forward & inverse kinematics of serial chain manipulators, the manipulator Jacobian, force relations, dynamics, & control. We will present techniques for geometric motion planning & obstacle avoidance. Open problems in trajectory generation with dynamic constraints will also be discussed. The course also presents the use of the same analytical techniques as manipulation for the analysis of images & computer vision. Low level vision, structure from motion, & an introduction to vision & learning will be covered.
- EECS C106B/EECS C206B Robotic Manipulation and Interaction – The course is a sequel to EECS/BIOE/MEC106A/EECSC206A, which covers the mathematical fundamentals of robotics including kinematics, dynamics and control as well as an introduction to path planning, obstacle avoidance, and computer vision. This course will present several areas of robotics and active vision, at a deeper level and informed by current research. Concepts will include the review at an advanced level of robot control, the kinematics, dynamics and control of multi-fingered hands, grasping and manipulation of objects, mobile robots: including non-holonomic motion planning and control, path planning, Simultaneous Localization And Mapping (SLAM), and active vision.
- MEC ENG C210 Advanced Orthopedic Biomechanics – Students will learn the application of engineering concepts including statics, dynamics, optimization theory, composite beam theory, beam-on-elastic foundation

theory, Hertz contact theory, and materials behavior. Topics will include forces and moments acting on human joints; composition and mechanical behavior of orthopedic biomaterials; design/analysis of artificial joint, spine, and fracture fixation prostheses; musculoskeletal tissues including bone, cartilage, tendon, ligament, and muscle; osteoporosis and fracture-risk predication of bones; and bone adaptation. Students will be challenged in a MATLAB-based project to integrate the course material in an attempt to gain insight into contemporary design/analysis/problems.

- MEC ENG 231A Experimental Advanced Control Design I – Experience-based learning in the design of SISO and MIMO feedback controllers for linear systems. The student will master skills needed to apply linear control design and analysis tools to classical and modern control problems. In particular, the participant will be exposed to and develop expertise in two key control design technologies: frequency-domain control synthesis and time-domain optimization-based approach.
- MEC ENG 231B Experimental Advanced Control Design II – Experience-based learning in the design, analysis, and verification of automatic control systems. The course emphasizes the use of computer-aided design techniques through case studies and design tasks. The student will master skills needed to apply advanced model-based control analysis, design, and estimation to a variety of industrial applications. The role of these specific design methodologies within the larger endeavor of control design is also addressed.
- MEC ENG 270 Advanced Augmentation of Human Dexterity – This course provides hands-on experience in designing prostheses and assistive technologies using user-centered design. Students will develop a fundamental understanding of the state-of-the-art, design processes and product realization. Teams will prototype a novel solution to a disabilities-related challenge, focusing on upper-limb mobility or dexterity. Lessons will cover biomechanics of human manipulation, tactile sensing and haptics, actuation and mechanism robustness, and control interfaces. Readings will be selected from texts and academic journals available through the UCB online library system and course notes. Guest speakers will be invited to address cutting edge breakthroughs relevant to assistive technology and design.
- COMPSCI 287 Advanced Robotics – Advanced topics related to current research in algorithms and artificial intelligence for robotics. Planning, control, and estimation for realistic robot systems, taking into account: dynamic constraints, control and sensing uncertainty, and non-holonomic motion constraints.
- COMPSCI 287H Algorithmic Human-Robot Interaction – As robot autonomy advances, it becomes more and more important to develop algorithms that are not solely functional, but also mindful of the end-user. How should the robot move differently when it's moving in the presence of a human? How should it learn from user feedback? How should it assist the user in accomplishing day to day tasks? These are the questions we will investigate in this course. We will contrast existing algorithms in robotics with studies in human-robot interaction, discussing how to tackle interaction challenges in an algorithmic way, with the goal of enabling generalization across robots and tasks. We will also sharpen research skills: giving good talks, experimental design, statistical analysis, literature surveys.

San Jose State University

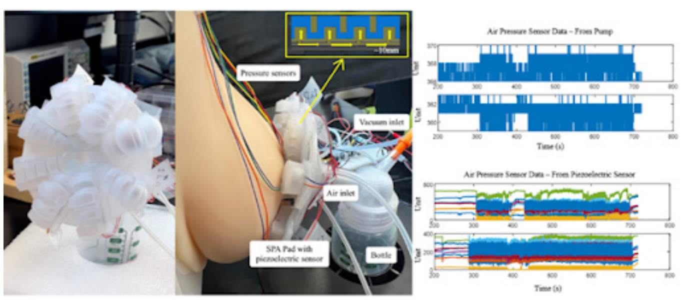
Directed by Dr. Lin Jiang

Biomechanics and Robotics (BioRob) Lab

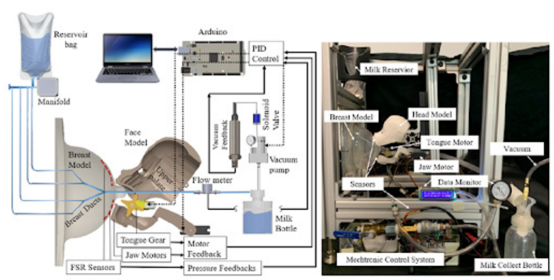
The BioRob lab at the Department of Mechanical Engineering, San Jose State University, focuses on the development and application of biomechatronic robots, with a special emphasis on maternal and child healthcare and treatment. We investigate a range of robotic system and their control - from wearables to surgical robots- for use in teleoperation, virtual/augmented reality, physical therapy and engineering education. We study a broad class of subjects such as smart materials, mechanical design, biofluid transport, tactile sensing, and haptic control to the design and development of exoskeleton wearables, bio-inspired actuators, rehabilitative robotic and surgical robots. The outcome of our research contributes to the understanding of human biomechanics, and further enhance the integration of biomechatronic robotics in medical device, diagnosis, therapy, and treatment.

More information about our work can be found at https://sites.google.com/sjsu.edu/biorob/home

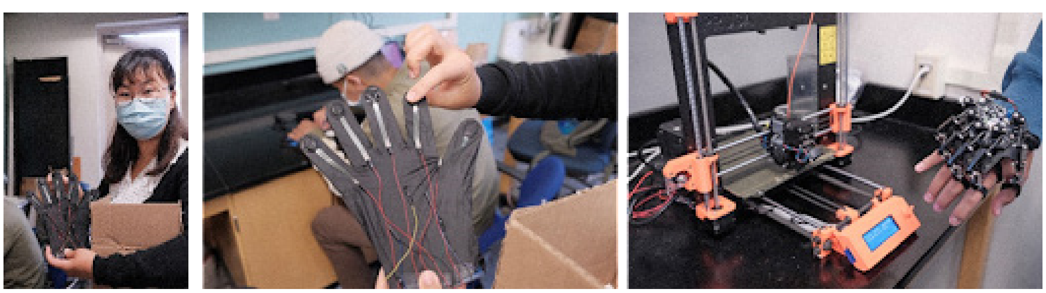
Contact Email: lin.jiang@sjsu.edu



In smart material and soft robotics, we develop low-cost soft actuation to mimic infant oral suckling dynamics during breastfeeding and integrate with AI controlled breast pump to facilitate comfort and efficient milk extraction.



In bio-inspired simulators, we aim to develop bench-top apparatus for flow experiments with bio-inspired soft actuators, user defined interface, and intelligent control systems to investigate the fluid-structure interaction in human biomechanics. All images are courtesy of SJSU BioRob



In tactile sensing and haptic control, we design, model and fabricate soft exoskeletons and wearable electronics. Among them is a wearable master-slave glove, which can communicate with haptic feedback wirelessly through ESP32. We are interested in using them for manipulation, teleoperation, and remote surgical training tasks.

Courses from SJSU

Undergraduate Level Courses

- ME 106 Fundamentals of Mechatronics Engineering – Foundational concepts in mechatronics including analog and digital electronics, sensors, actuators, microprocessors and microprocessor interfacing to electromechanical systems. Hands-on laboratory.
- TECH 115 Automation and Control – Theory and application of automation elements including analog and digital sensors, controllers, indicators, actuators. Control modes for proportional, derivative, and integral control systems. Hands-on integration practices among PLC, robots, automatic identification devices, computers, and other industrial equipment.
- CMPE 150 System Architecture and Electronic Design for Robotics – Design and architecture for generating autonomous and human-reliant robots, algorithm development for object perception, electronic design and system integration for cognitive and sensory capabilities of robots, mechanisms for actuation and mobility, fault diagnosis and self-calibration.
- CMPE 185 Autonomous Mobile Robots – Basic concepts and algorithms for mobile robots that act autonomously in complex environments. Emphasis on mobile robot locomotion and kinematics, environment perception, probabilistic map-based localization and mapping, motion planning, and programming in Robot Operating System (ROS).
- ME 187 Automatic Control Systems Design – Analysis of dynamic systems in time and frequency domain. Design of automatic control systems. Analog and digital control systems design. Computer aided control system design and performance evaluation.
- ME 192 Robotics and Manufacturing Systems – Scientific and engineering principles of robotics in the area of mechanical manipulation, dynamics, sensing, actuation, control, computer vision and manufacturing automation application. Motor, motion control, digital control devices application and integration.

Graduate Level Courses

- ME 281 - Advanced Control System Design – Establishment of design criteria. Digital control system design is based on conventional and modern approaches. Intelligent control system design. Digital control system hardware and software. Case studies. Microprocessor implementation of control systems.
- ME 284 - Sensor Technology and Principles – Sensors and principles, including mechanical and magnetic sensors, optical sensors, chemical sensors, and bio sensors; Sensor circuitry, signal characterization, and processing; Sensor design, fabrication, and applications.
- ME 286 Autonomous and Connected Vehicles – Application of fundamentals of robotics, computer vision, and mechanical engineering in a vehicle-to-vehicle and vehicle-to-infrastructure connected environment for safe driving and reducing traffic congestion. Defining levels of autonomy in relation to driver-assist and self-driving technologies.
- CMPE 249 Intelligent Autonomous Systems – Introduction to autonomous systems and intelligent solutions for self-driving cars, advanced topics in multi-modal sensing, sensor fusion, AI computing, mapping, deep learning, object detection, perception, localization, prediction, path planning, control, reinforcement learning, and Robotic Operating System (ROS).

Santa Clara University

Directed by Dr. Chris Kitts

Robotic Systems Lab (RSL)

The Robotic Systems Laboratory is a field robotics lab with about 100 students, both graduate, and undergraduate. We specialize in developing and applying robotic systems and control technology for systems that operate on/in land, sea, air and space. Systems are developed and then operated by students/staff/faculty to serve the needs of external collaborators, partners and sponsors. Examples of this work includes the development of advanced marine robots for several government agencies, autonomous rovers for a variety of field agriculture tasks, drones for a range of observational/mapping/inspection applications, and satellite mission control technology used to operate numerous NASA and industry spacecraft.

Research is conducted with undergraduate, Masters and doctoral students, primarily in the areas of multi-robot control techniques, advanced anomaly management, and human-robot collaborative manipulation.

One of the distinguishing features of the program is hands-on "operational" opportunities in which students learn to professionally operate/deploy real-world robotic systems in order to provide services to industry/government partners. Examples of this work includes 15+ years of conducting satellite mission control services for NASA and industry partners, using multiple student-developed robots (underwater vehicles, surface vessels, drones) to map and explore Lake Tahoe with the US Geological Survey and other agencies, and so on.

More information can be found at https://www.scu.edu/engineering/labs--research/labs/robotic-systems-lab/
Contact Email: ckitts@scu.edu

Collaborative Multirobot Systems, Marine Robot, Spacecraft Control
All images are courtesy of SCU Robotics Systems Lab

Courses from SCU

The School of Engineering offers a wide range of opportunities for students interested in robotics. Undergraduate students complete degrees in conventional disciplines such as mechanical/electrical/computer engineering, but may join the robotics lab through affiliated courses, internships, and senior capstone projects. Masters students typically participate through courses and work performed either through an interdisciplinary MS in Robotics and Automation (MSRA) or through the mechatronic systems engineering depth area within the MS in Mechanical

Engineering program. MS-level project experience is conducted either through thesis research or a capstone design project. The MSRA program has specialty areas with industry partnerships in topics such as advanced manufacturing, aerospace robotics, marine systems, bio-mechatronics, etc. Doctoral students participate through research and development work supporting their dissertation project.

Undergraduate Level Courses

- MECH 143: Mechatronics – Students will be introduced to the behavior, design, and integration of electromechanical components and systems. The course will review appropriate electronic components/ circuitry, mechanism configurations, and programming constructs.
- ENGR 20: Topics in Robotics – Gain exposure to sensing, actuation, and control techniques and components in the process of developing a robotic system or subsystem.
- ENGR 180 Marine Operations / ENGR 181 Advanced Marine Operations – Hands-on course introducing the design and operation of SCU's marine robots, to include an ocean deployment of a tethered underwater robot.
- ELEN 131: Introduction to Robotics – Overview of robotics: control, artificial intelligence, and computer vision. Components and structure of robots. Kinematics and dynamics of robot manipulators. Servo-control design, PID control. Trajectory planning, obstacle avoidance. Sensing and vision. Robot intelligence and task planning.

Graduate Level Courses

- ELEN 337/MECH 337 Robotics I – Overview of robotics: control, AI, and computer vision. Components and structure of robots. Homogeneous transformation. Forward kinematics of robot arms. Denavit-Hartenberg representation. Inverse kinematics. Task planning, path planning, and trajectory planning in the motion control problem of robots.
- ELEN 338 Robotics II/ MECH 338 Robotics II – Joint-based control. Linear control of manipulators. PID control and set-point tracking.
- ELEN 339 Robotics III/ MECH 339 – Intelligent control of robots. Neural networks and fuzzy logic in robotic control. Selected topics of current research in robotics.
- MECH 207, 208, 209 / ELEN 207, 208, 209 Advanced Mechatronics I, II, III – Design, implementation and control of mechatronic systems, with in-depth hands-on development activities. Sensors, actuators, controllers, Design and implementation of linear and state machine controllers, both implemented in hardware and software.
- ELEN 331 Autonomous Driving Systems (and Lab) – Students will gain hands-on experience in the major modules of the system including localization, sensor fusion, perception, detection, segmentation, scene understanding, tracking, prediction, path planning, control, routing, and decision-making.
- MECH 292 Special Topics in Mechatronic Systems Engineering – A variety of special topics courses have been and continue to be offered, with topics such as marine systems, UAV design, multi-robot systems, robotic vision systems, etc.
- MECH 311 Modeling and Control of Telerobotic Systems – Case studies of telerobotic devices and mission control architectures. Analysis and control techniques relevant to the remote operation of devices, vehicles, and facilities.

Stanford University

Directed by Dr. Monroe Kennedy III

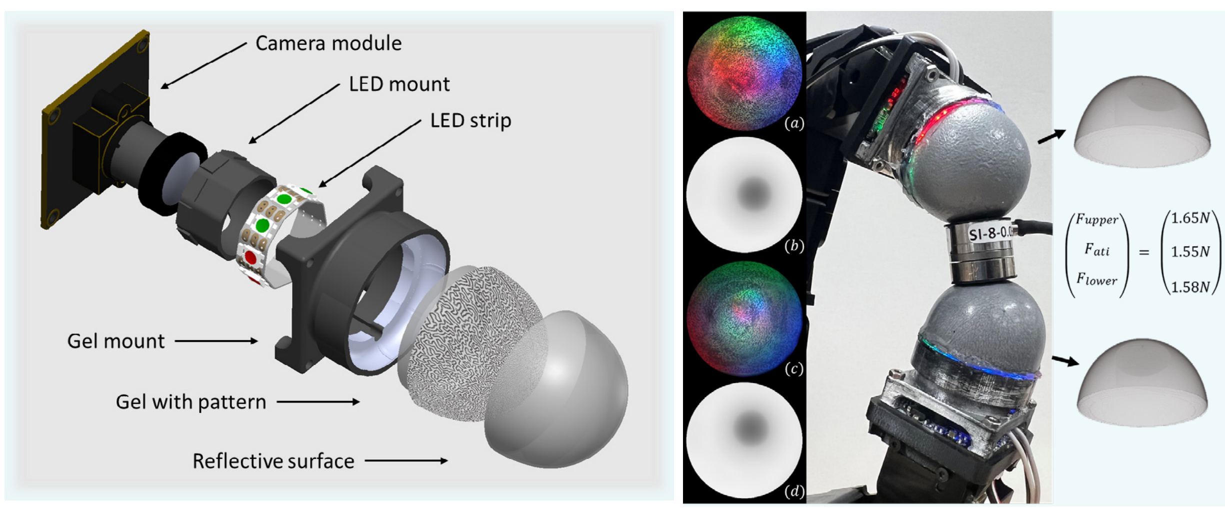
Assistive Robotics and Manipulation Lab (ARMLab)

We are an experimental robotics lab with about 10 students both graduate and undergraduate. Our work is focused on technology that enables collaborative robotic applications where robots work closely alongside and for human counterparts. We have many research projects that span this domain. To increase a collaborative humanoid robot dexterity and manipulation capability, our lab has projects focused on robotic finger design and modeling.

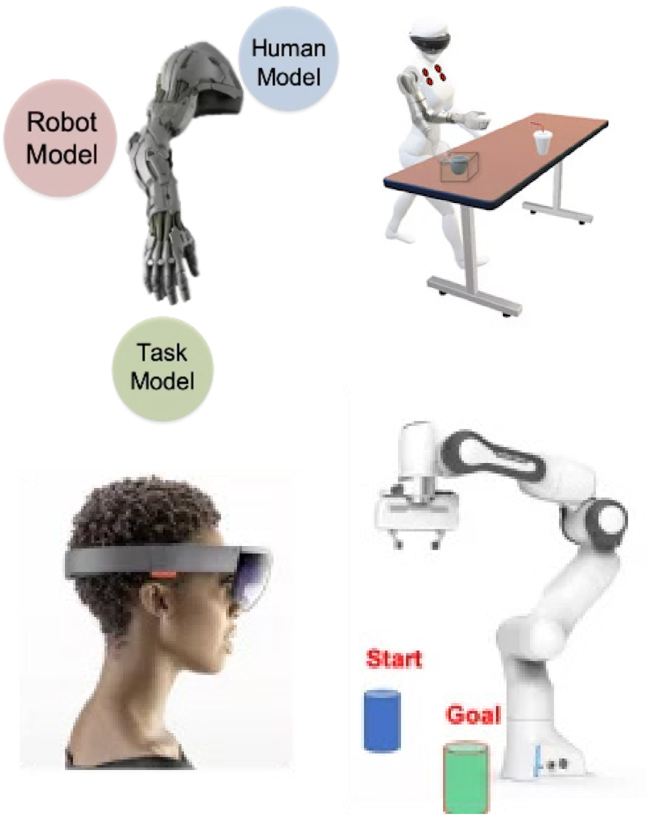
To decrease the amount of time it takes a human to teach a robot a new task, our group has projects dedicated to increasing the efficiency of learning from demonstration in physical tasks and leverages mixed reality to improve communication between the human and robot. For applications with robotic assistants, we are working on improving capabilities of powered, upper-limb prosthesis leveraging robotic autonomy to better estimate and act on human wearer intention to increase agency and manipulation capability of the human. The common theme in our research are developing robots that are capable of working closely with people to complete complex tasks, and advanced modeling techniques of the task and human are required for successful teammate behavior of the robot.

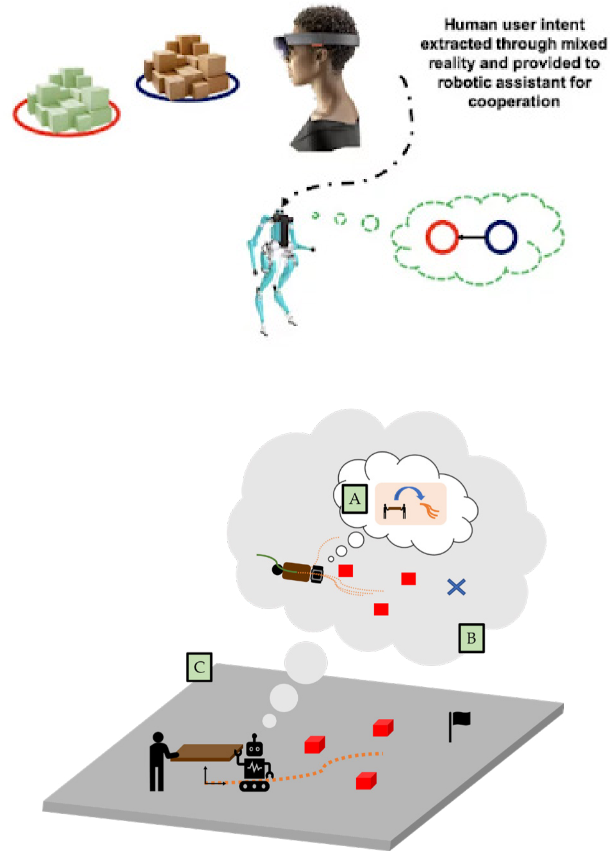
More Information can be found at: https://arm.stanford.edu/ **Contact Email:** monroek@stanford.edu

Improving Robotic Assistant Dexterity:
2nd generation robotic tactile fingertip



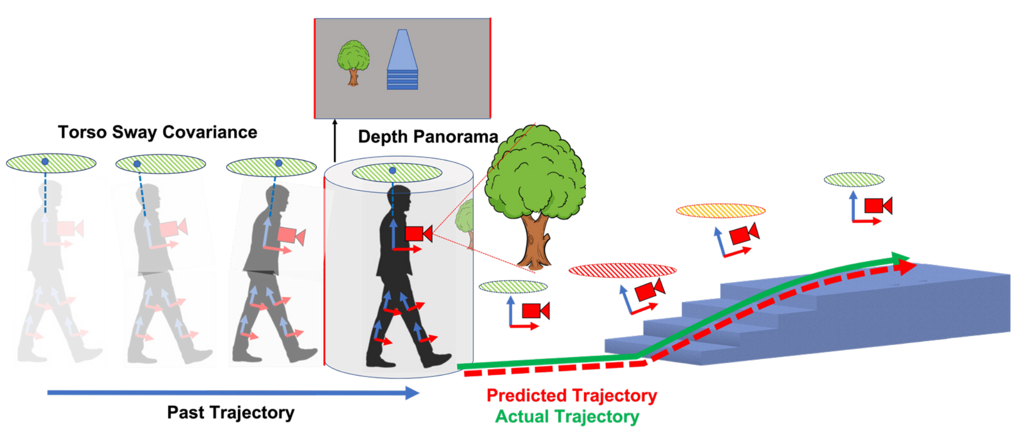
Intelligent Prosthetic Arm (IPARM)

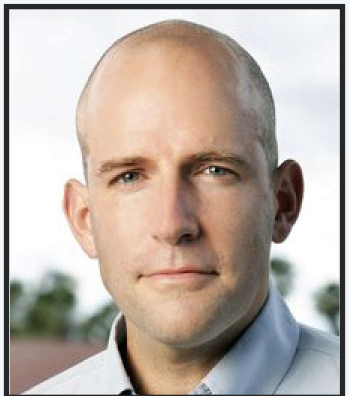




Collaborative Robotic Assistant: Efficient Learning from Demonstration, Human-Robot Cooperative Transport

Picture 9: SmartBelt: Human Motion Prediction and Fall Prevention from Wearable Sensor. All images are courtesy of Stanford ARMLab





Directed by Dr. Steven H. Collins

Biomechatronics Lab

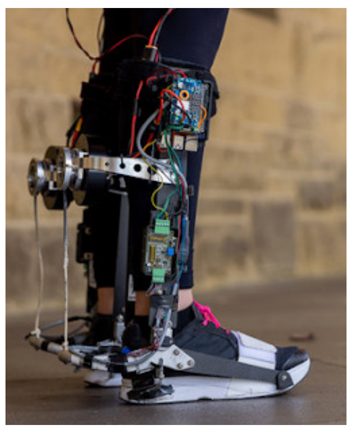
We develop wearable robots to improve efficiency, speed and balance while walking and running, especially for people with disability. Our primary focus is to speed and systematize the design process itself by developing versatile prosthesis and exoskeleton emulators and algorithms for human-in-the-loop optimization. We perform basic scientific research on related topics, for example the role of ankle push-off in balance and the effects of arm swinging on energy economy.

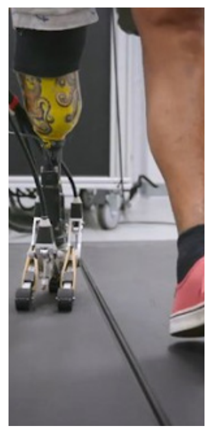
We develop efficient autonomous devices, such as energy-efficient walking robots, ultra-low-power electroadhesive clutches, and unpowered exoskeletons that reduce the energy cost of walking. We work with spin-out companies to translate our results into products. You can learn more by visiting our Publications Page, which links to manuscripts, videos, designs, data, and other materials from our research. For a high-level perspective on our lab, please see the Laboratory Overview Video.

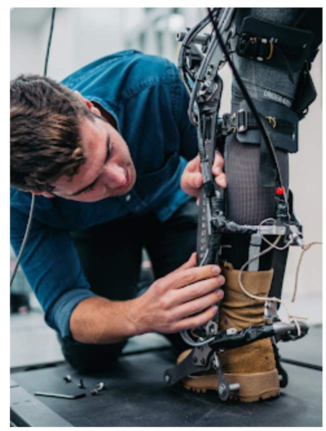
More Information can be found at https://biomechatronics.stanford.edu/

Contact Email: stevecollins@stanford.edu

Prothesis and exoskeleton robots that help improve efficiency, speed, and balance. All images are courtesy of Stanford Biomechatronics Lab







Directed by Dr. Allison Okamura

Collaborative Haptics and Robotics in Medicine (CHARM) Lab

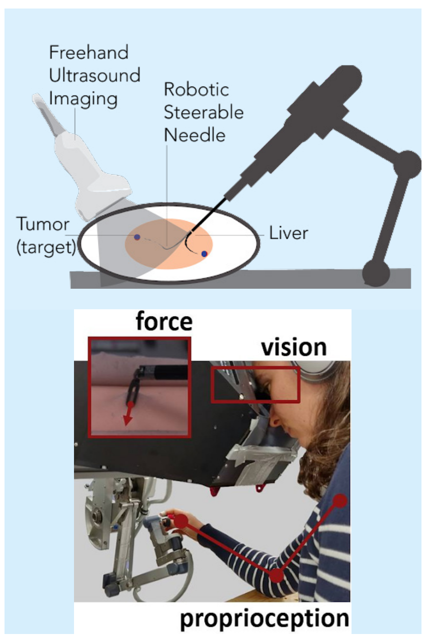
The Collaborative Haptics and Robotics in Medicine (CHARM) Lab led by Prof. Allison Okamura is focused on haptics, medical and rehabilitative robotics, and soft robotics. We currently have about 20 PhD students and postdocs in the lab. We design and study haptic and robotic systems using both analytical and experimental approaches. Our work has been funded by the NSF, NIH, DoD, DoE, and leading partners in industry.

We develop a range of haptic devices across a wide scale - from large-area wearables to fingertip devices - for use in education, teleoperation, navigation, and virtual/mixed/augmented reality.

In medicine and rehabilitative robotics, we develop low-cost devices to assist in stroke rehabilitation and work to improve minimally invasive surgery through work on the da Vinci surgical system. In soft robotics, we design, model, and fabricate a variety of actuators and systems. Among them is the 'vine' robot, which can navigate its environment through growth. We have deployed these robots in the field and are interested in using them for manipulation, inspection, and search-and-rescue tasks.

More information about our work can be found at http://charm.stanford.edu/
Contact Email: aokamura@stanford.edu

Design and Control of Haptic Systems for Virtual Environments and Teleoperation, Wearable Haptic Interfaces and Perception



Robot-Assisted Percutaneous Interventions, Human Motor Performance and Adaptation in Robot-Assisted Surgery

Soft Robotics, Biomechanics and Rehabilitation Robotics All images are courtesy of Stanford CHARM Lab

Courses from Stanford University

Undergraduate Level Courses

- CS225A Experimental Robotics – Hands-on laboratory course experience in robotic manipulation. Topics include robot kinematics, dynamics, control, compliance, sensor-based collision avoidance, and human-robot interfaces. The second half of the class is devoted to final projects using various robotic platforms to build and demonstrate new robot task capabilities.
- AA277 Multi-Robot Control and Distributed Optimization – Survey of current research topics in multi-robot systems including multi-agent consensus, formation control, coverage control, and sensor deployment, collision avoidance, cooperative mapping, and distributed Bayesian filtering.
- CS223A Introduction to Robotics – Robotics foundations in modeling, design, planning, and control. The class covers relevant results from geometry, kinematics, statics, dynamics, motion planning, and control, providing the basic methodologies and tools in robotics research and applications.
- CS237A/AA174A Principles of Robot Autonomy – Basic principles for endowing mobile autonomous robots with perception, planning, and decision-making capabilities. Algorithmic approaches for robot perception, localization, and simultaneous localization and mapping; control of non-linear systems, learning-based control, and robot motion planning.
- CS274B/AA174B Principles of Robot Autonomy II – This course teaches advanced principles for endowing mobile autonomous robots with capabilities to autonomously learn new skills and to physically interact with the environment and with humans. It also provides an overview of different robot system architectures.

Graduate Level Courses

- ME326 Collaborative Robotics – This course focuses on how robots can be effective teammates with other robots and human partners. Concepts and tools will be reviewed for characterizing task objectives, robot perception and control, teammate behavioral modeling, inter-agent communication, and team consensus.
- CS327A Advanced Robotic Manipulation – Advanced control methodologies and novel design techniques for complex human-like robotic and bio-mechanical systems. The class covers the fundamentals of operational space dynamics and control, elastic planning, and human motion synthesis.
- CS336 Robot Perception and Decision-Making – This course focuses on studying how a robot can make decisions based on raw, high-dimensional sensory data that represents only partial, noisy observations of the environment.
- CS326 Topics in Advanced Robotic Manipulation – This course provides a survey of the most important and influential concepts in autonomous robotic manipulation. The course cover approaches toward motion planning and control using visual and tactile perception as well as machine learning.

University of California, Davis


Directed by Dr. Stavros G. Vougioukas

Dr. Stavros G. Vougioukas Research Lab

My lab's research lies in the general area of mechanization, agricultural robotics, and automation for specialty crop production. We focus on developing methodologies and technologies that can be used to improve the efficiency and working conditions of human workers or replace labor in some tasks. Additionally, we work on 'core' robotic technologies, such as sensor-based safe, accurate, and robust autonomous navigation in orchards.

In the Robotic Harvesting project, our research investigates the use of robotic harvesters with many arms to increase harvesting speed. In particular, we explore alternative mechanical designs and the efficient and load-balancing distribution of work among arms to achieve high picking speeds.

We are also currently building model-based design tools to enable researchers and developers to investigate the interrelationships among orchard layout, tree canopy geometry and spatial fruit distribution, harvester design, and worker activities. Such tools can accelerate the development of next-generation orchard mechanization and automation systems.

Another project is the Human-Robot collaboration and multi-robot coordination. Robots cannot currently replace human perception and dexterity in many agricultural operations (e.g., harvesting, pruning). One alternative is to design advanced autonomous machines that work together with agricultural workers to improve labor efficiency and human factors. An essential challenge in this area is to develop mechanistic models of agricultural worker activities that robots can use to collaborate with them safely and efficiently. Another challenging issue is how autonomous agricultural vehicles can coordinate and collaborate to improve field and orchard logistics while guaranteeing human and equipment safety.

More information can be found at https://faculty.engineering.ucdavis.edu/vougioukas/research/
Contact Email: svougioukas@ucdavis.edu

Courses from UC, Davis

Undergraduate Level Courses

- EAE 130A Aircraft Performance & Design – Major aircraft design experience with multiple realistic constraints including aerodynamics, performance analysis, weight estimation, stability and control, and appropriate engineering standards.
- EAE 143A Space Vehicle Design – Governing equations and operational practices of robotic and human space travel. Principles of Systems Engineering are introduced and are used as a basis for a team project in spacecraft reverse-engineering and design.
- EEC 189H/289H Special Topics in Electrical Engineering & Computer Science: Robotics – Special topics in Robotics.
- EEC 195A Autonomous Vehicle Design Project – Design and construct an autonomous race car. Work in groups to design, build and test speed control circuits, track sensing circuits, and a steering control loop.

Graduate Level Courses

- MAE 225 Spatial Kinematics & Robotics – Spatial kinematics, screw theory, spatial mechanisms analysis and synthesis, robot kinematics and dynamics, robot workspace, path planning, robot programming, real-time architecture and software implementation.
- MAE 252 Information Processing for Autonomous Robotics – Computational principles for sensing, reasoning, and navigation for autonomous robots.
- EEC 255 Robotic Systems – Introduction to robotic systems. Mechanical manipulators, kinematics, manipulator positioning and path planning. Dynamics of manipulators. Robot motion programming and control algorithm design.
- MAE 258 Hybrid Electric Vehicle System Theory & Design – Advanced vehicle design for fuel economy, performance, and low emissions, considering regulations, societal demands and manufacturability. Analysis and verification of computer design and control of vehicle systems in real vehicle tests. Advanced engine concepts.
- MAE 275 Guidance & Control of Unmanned Aerial Systems – Introduction to Unmanned Aerial Systems (UAS). Challenges in guiding and controlling limited-payload small and miniature aircraft systems. Coordinate frames, kinematics and dynamics, linear design models, autopilot design, sensor models, state estimation, design model for guidance, straight-line and orbit following, and path planning.
- EEC 295 Systems, Control & Robotics Seminar – Course Description: Seminars on current research in systems and control by faculty and visiting experts. Technical presentations and lectures on current topics in robotics research and robotics technology.

University of California, Merced

Directed by Dr. Ricardo de Castro

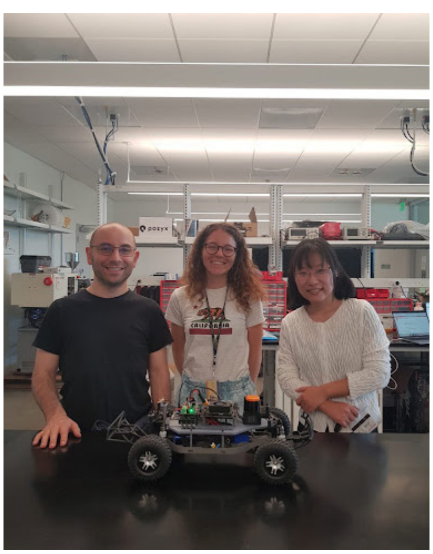
Dr. Ricardo de Castro's Research Lab

My research focuses on electric and robotic vehicles. I am interested in combining power conversion with advanced control and optimization methods as a means of achieving high energy efficiency, durability and reliability of energy storage systems. Vehicle automation is another area of my research, with particular emphasis on safe motion planning and resilient control. The lab has 3 graduate and 3 undergraduate students, plus 1 visiting PhD student. I maintain a strong connection with the German Aerospace Center (DLR), and collaborate with them in the development of motion control algorithms for their robotic vehicles.

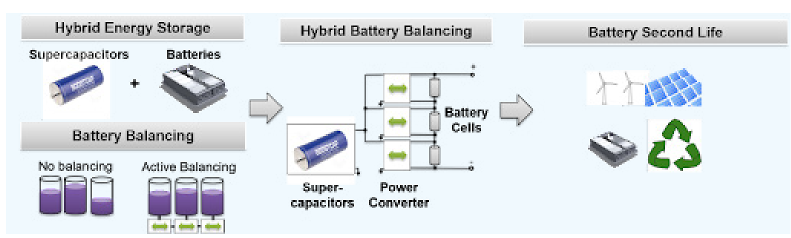
In terms of research projects, I have been investigating a new class of battery balancing systems, called hybrid battery balancing, capable of simultaneously equalizing battery capacity and temperature while enabling hybridization with additional storage systems, such as super-capacitors. My research departs from the current research paradigm, which regards battery equalization and hybridization as two independent functions performed by two separated power converters. In contrast, my concept integrates these two functions into a single system, paving the way for a lower cost of power conversion in hybrid energy storage units.

Electric mobility introduces profound modifications, not only to the vehicle's energy storage, but also to the powertrain. Unlike vehicles with internal combustion engines, electric vehicles can be propelled by compact in-wheel electric motors, enabling a fast, accurate and energy efficient control of the torque applied to the wheels. I have leveraged these emerging actuators to enhance control of automated vehicles and estimation of road surface grip. Additionally, my contributions seek to seamlessly incorporate user preferences— such as journey time, comfort and energy—in the design and safe execution of maneuvers.

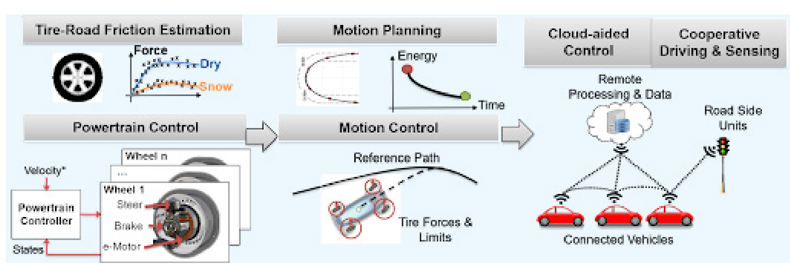
More information about our work can be found at https://castro.ucmerced.edu/
Contact Email: rpintodecastro@ucmerced.edu



Dr. Ricardo de Castro accompanied by students, showcasing his research.



Energy Storage Systems - Hybrid Battery Balancing



Automated Vehicles – All images are courtesy of UCM Dr. Ricardo Castro's Research Lab

Courses from UC, Merced

Undergraduate Level Courses

- COGS 125 Introduction to Artificial Intelligence – Overview of the main concepts and methods underlying the construction and analysis of intelligent systems, including agent architectures, problem-solving, heuristic search, knowledge representation, reasoning, planning, communication, perception, robotics, and machine learning.
- COGS 128 Cognitive Engineering – Provides an introduction to cognitive engineering, with an emphasis on cognitive science. Topics include human-computer interaction, human-robot interaction, speech recognition systems, animated characters, and virtual reality systems.
- CSE 171 Game Programming – Covers the main algorithms and techniques used in the implementation of interactive 3D graphics, such as in Computer Games, Robotics Simulators, and Virtual Reality.
- AE 173 Design of Unmanned Aerial Vehicles – Conceptual and preliminary design of autonomous aerial vehicles (UAVs). Review of low Reynolds number fixed and rotary wing aerodynamics, with a focus on the wing and rotor design. Vehicle dynamics and control, flight path planning and optimization, control system design.
- CSE180 Introduction to Robotics – Covers the basics of robotics focusing on the algorithmic side, rather than technology. Introduces basic computational techniques concerning spatial modeling, planning, and sensor processing. The course has a strong hands-on component.

Graduate Level Courses

- EECS 270 Robot Algorithms – In-depth study of algorithmic techniques to solve fundamental robotic problems, with a particular emphasis on probabilistic aspects. Sensor fusion, mission planning, and other selected topics are covered as well.
- EECS 281 Advanced Topics in Robotics – Contemporary issues in mobile robotics. Topics include but are not limited to: cooperative mobile robotics, mathematical models for complex tasks (e.g. manipulation), humanoid robotics, human-robot interfaces, robot hardware and middleware.
- EECS 283 Advanced Topics in Internet of Things and Sensing Systems – Research in intelligent systems is multi-disciplinary and its foundation can be found from fields such as estimation, communication, and control. Other areas such as artificial intelligence, machine learning, networking, robotics, security, and signal processing are also highly related. This class will review the most current results in intelligent systems and help students prepare for research in intelligent systems.
- EECS 285 Advanced Topics in Motion Planning – Covers advanced algorithms in the motion planning research domain and reviews selected topics in applications to robotics, computer animation, cognitive science and/or bioinformatics.
- ME 290 Robotic Vehicles – The goal of this course would be to provide foundations that allow the students to understand how to design, implement and test robotic vehicles. We will review the modeling, motion planning, control, actuation, and sensing for these robots and then evolve into more advanced concepts, e.g., cooperative motion control and formation, locomotion of mobile robots in slippery and irregular surfaces, and learning-based control algorithms. Applications of mobile robots in transportation, agriculture and industry would also be considered.

University of California, Santa Cruz

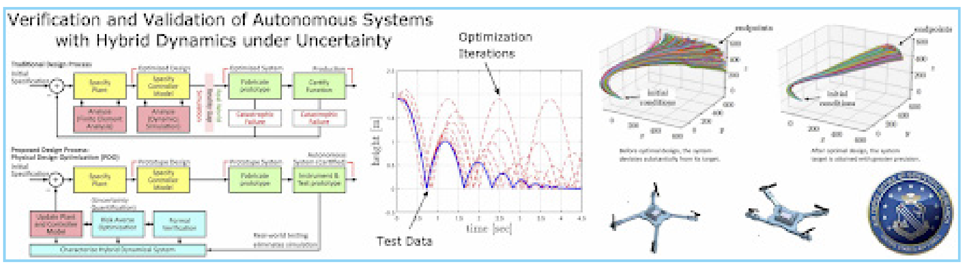
Directed by Dr. Ricardo Sanfelice

Hybrid Systems Laboratory (HSL)

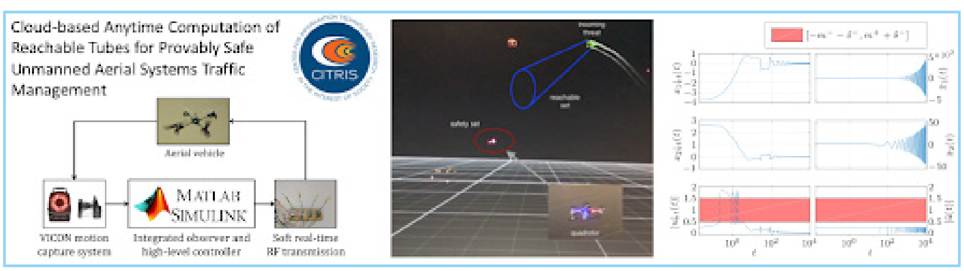
The Hybrid Systems Laboratory (HSL) at the Department of Electrical and Computer Engineering, University of California at Santa Cruz, focuses on the analysis of hybrid dynamical systems and the design of hybrid feedback control algorithms. The research approach is mainly theoretical with numerical validation via simulations (though experimental validations of findings at an on-site testbed are performed at times). Particular emphasis is given to dynamical systems with nonlinear hybrid dynamics, cyber-physical systems, and feedback systems with decision-making strategies emerging in the areas of robotics, aerospace, power systems, and biology.

More information can be found at https://hybrid.soe.ucsc.edu/projects

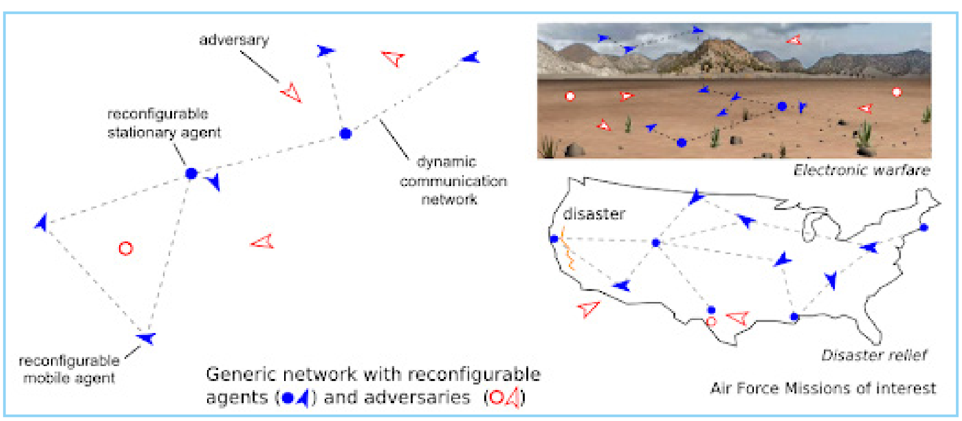
Contact Email: ricardo@ucsc.edu



Verification and validation of Autonomous Systems with Hybrid Dynamics under Uncertainty



CITRIS: Cloud-Based Anytime Computation of Reachable Tubes for Provably Safe Unmanned Aerial Systems Traffic Management



AFOSR YIP: Robust Feedback Control of Reconfiguration Multi-agent Systems in Uncertain Adversarial Environments – All images are courtesy of UCSC HSL

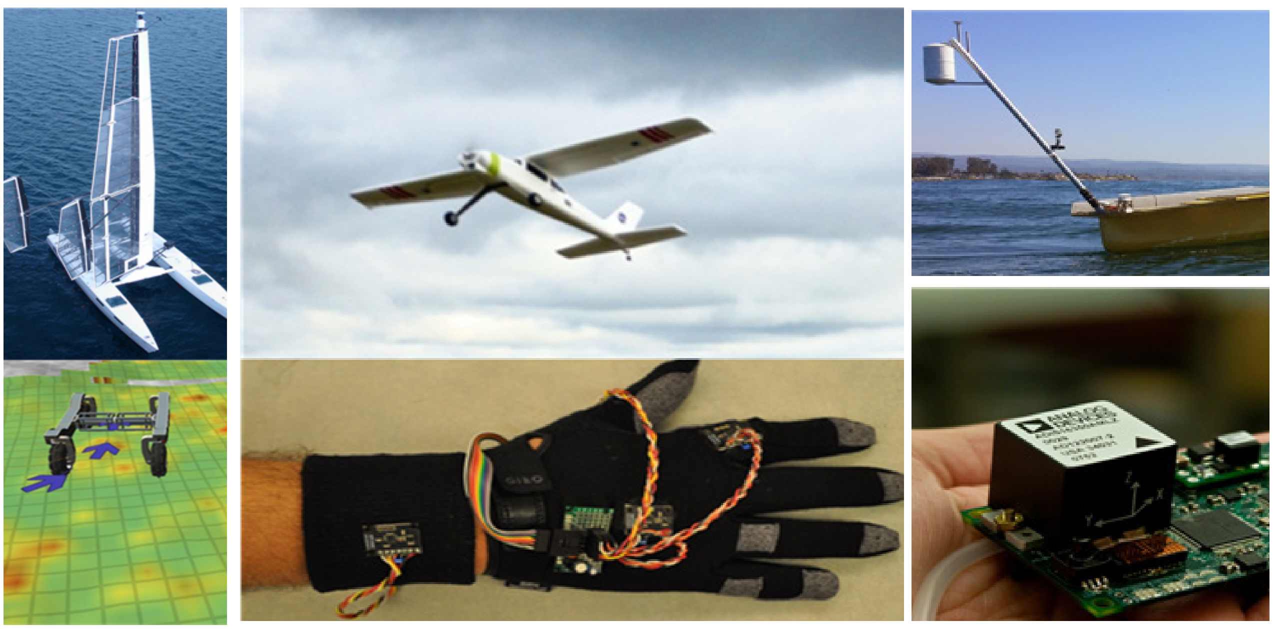
Directed by Dr. Gabriel Elkaim

Autonomous Systems Lab

The Autonomous Systems Lab (ASL) was founded by Professor Gabriel Elkaim when he joined the University of California at Santa Cruz in 2003. It is one of several labs that work on control theory at UCSC. The ASL specializes in guidance, navigation, and control, path-planning, computer vision, and sensor fusion within the scope of autonomous systems.

We aim to reduce the cost of autonomous systems through open-source development of both complete autonomous systems as well as their required on board sensors. The overarching theme of the ASL research has been to radically reduce cost (and hence increase the ubiquity) of Robotics and Autonomous Systems by adding increased sophistication and processing power (cheap) and reducing the quality and quantity of sensors (expensive); in essence, we are driven to reduce the dollar-to-data ratio.

More information can be found at: www.elkaim.com **Contact email:** elkaim@ucsc.edu



- Energy scavenging autonomous oceanographic surface vessels
- Fast, efficient algorithms for path planning and obstacle avoidance in unknown environments
- SLUGS rapidly reconfigurable autopilot for UAV research
- Smart tracking collars for wildlife energetics and tracking
- Tremor sensing and diagnostics and attenuation using actuated weighted ring
- UAVs for interior and exterior structure inspection
- All images are courtesy of UCSC ASL

Courses from UC, Santa Cruz

Undergraduate Level Courses

- ECE 8 Robot Automation: Intelligence through Feedback Control – Introduction to dynamical systems, feedback control, and robotics. Fundamental concepts in dynamical systems, modeling, stability analysis, robustness to uncertainty, feedback as it occurs naturally, and the design of feedback-control laws to engineer desirable static and dynamic response.
- ECE 10 Fundamentals of Robot Kinematics and Dynamics – Covers the theory and application of mathematical models to analyze the kinematics and dynamics of robot mechanisms or their components using vector algebra, differential equations, and computer simulations; also covers robot vehicle kinematics, robot arm kinematics, and robot dynamics with computational examples and problems.
- ECE 118/218 Introduction to Mechatronics – Technologies involved in mechatronics (intelligent electro-mechanical systems) and techniques necessary to integrate these technologies into mechatronic systems. Topics include electronics (A/D, D/A converters, op amps, filters, power devices), software program design (event-driven programming, state machine-based design), DC and stepper motors, basic sensing, and basic mechanical design (machine elements and mechanical CAD). Combines lab component of structured assignments with a large and open-ended team project.
- Mechatronics! - YouTube
- ECE 121 Introduction to Microcontrollers – Focus is on the design and use of microcontroller-based embedded systems, specifically addressing issues of low-level functionality, direct manipulation of input/output using various specialized peripheral sets, and multiple communications protocols. Covers timers, Input Capture, Output Compare, ADC, PWM, interrupts, bus and memory organization, DMA, SPI, I2C, device driver programming, serial packet communication, and clocking.
- ECE 141 Feedback Control Systems – Analysis and design of continuous linear feedback control systems. Essential principles and advantages of feedback. Design by root locus, frequency response, and state space methods and comparisons of these techniques.
- ECE 163/263 Small Scale UAV modeling and control – Technologies involved in the modeling and simulation of small-scale unmanned aerial vehicles (UAVs) with an emphasis on control applications, from low-level flight stabilization to higher level path planning and vision-based control. Topics include coordinate frames, aerodynamics, equations of motion, full non-linear simulation, linearized dynamics models and trim states, force and moment balances for steady flight, flight controls by successive loop closure, state space control, path planning and guidance, sensors and estimation.
- ECE 167 Sensors and Sensor Systems – Introduces fundamental issues in sensing of temperature, motion, sound, light, position, etc. Sensors are integrated into a digital system using filtering, amplification, and analog-to-digital conversion. Advanced topics may include noise, temperature, and other sources of variability.
- ECE 176 Energy Conservation and Control
- AC/DC electric-machine drives for speed/position control. Integrated discussion of electric machines, power electronics, and control systems. Computer simulations. Applications in electric transportation, hybrid-car technology, robotics, process control, and energy conservation.
- EAE 143A Space Vehicle Design – Governing equations and operational practices of robotic and human space travel. Principles of Systems Engineering are introduced and are used as a basis for a team project in spacecraft reverse-engineering and design.

Graduate Level Courses

- ECE 215 Models of Robotic Manipulation – Theory and application of mathematical models to analyze, design, and program serial kinematic chains (robot arms). Covers models of arbitrary articulated robotic or biological arms and their application to realistic arms and tasks, including the homogeneous coordinate model of positioning tasks; the forward and inverse kinematic models; the Jacobian matrix; trajectory generation;and dynamic models.
- ECE 216 Bio-Inspired Locomotion – Presents the principles of biological locomotion and application to robotics problems. Students learn about effective movements in the biological world (slithering, walking, climbing, and flying); extract their underlying principles; and apply them creatively to robotics design.
- CMPM 237 Advanced Topics in Human-Robot Interaction – Study of current topics in human-robot interaction design and research. Topics vary, but are expected to include how people think, act, and behave around robotic agents; telepresence and teleoperated robotics; applications of human-robot systems; collaborative robotics; and social robotics.
- ECE 240 Linear Dynamical Systems – Introduction to applied linear algebra and linear dynamical systems with applications to circuits, signal processing, communications, and control systems. Topics include the following: Least-squares approximations of over-determined equations and least-norm solutions of underdetermined equations. Symmetric matrices, matrix norm and singular value decomposition.
- ECE 241 Introduction to Control Systems – Graduate-level introduction to control of continuous linear systems using classical feedback techniques. Design of feedback controllers for command-following error, disturbance rejection, stability, and dynamic response specifications. Root locus and frequency response design techniques
- ECE 242 Applied Feedback Control Systems – This course explores state space control, discrete time control, and two case studies in control design. Students design and implement feedback controllers on an inverted pendulum experiment.
- ECE 246 Hybrid Dynamical Systems – Examines the modeling and analysis of hybrid dynamical systems, including the modeling of hybrid systems, the concept of solutions, Zeno behavior, equilibrium sets, stability, convergence, Lyapunov-based conditions, robustness, and simulation.

Community College STEM Education

Community Colleges offer students the opportunity to enter the workforce directly with an associate's degree, obtain non-degree credentials such as certifications, or transfer to a four-year university.
According to the NCSES NSF among students who completed high school in 2018 and enrolled in college two-fifths enrolled in community colleges.

In 2019 the US awarded 104,000 associate's degrees in S&E fields and 123,000 in S&E technologies.
S&E technologies degrees include technician degree programs in engineering, health sciences, and other S&E fields.
There are 28 community colleges in the Bay Area that offer a range of STEM-focused opportunities that vary from technical certifications to associate degrees.


Dr. Mark Martin

Statement from Dr. Mark Martin, Bay Area Regional Director for Advanced Manufacturing Workforce Development for the California Community Colleges.
Dr. Martin has more than 25 years of experience in manufacturing and engineering, including product development, manufacturing and design research, teaching, and workforce development.

The US is a major industrial economy, manufacturing over $2.3 trillion worth of goods annually, second only to China. In addition, we are the leaders in engineering and design. The SF/Oakland Bay Area is a critical part of this leadership - both in the engineering and manufacturing sectors - and having skilled trades employees is very important to these sectors. These skilled trades include machinists, welders, CAD designers, as well as quality control, industrial maintenance, electronics technicians, and others. Having enough of these skilled workers is vital in ensuring that Bay Area companies continue to design and make cutting-edge products.

And who trains these skilled tradespeople for manufacturing? In the Bay Area, this is done through the community colleges, as well as unions, some high schools, and adult education programs. In the community colleges, there are a number of programs that have one to two-year certificates that are inexpensive (under $2000) and that prepare people for living-wage jobs paying from $50k - $100k.

If you are interested, you can find more information at: https://bayareamanufacturingcareers.com/programs-by-career.html **Contact Email:** mark.martin@design4x.com

The ARM Institute

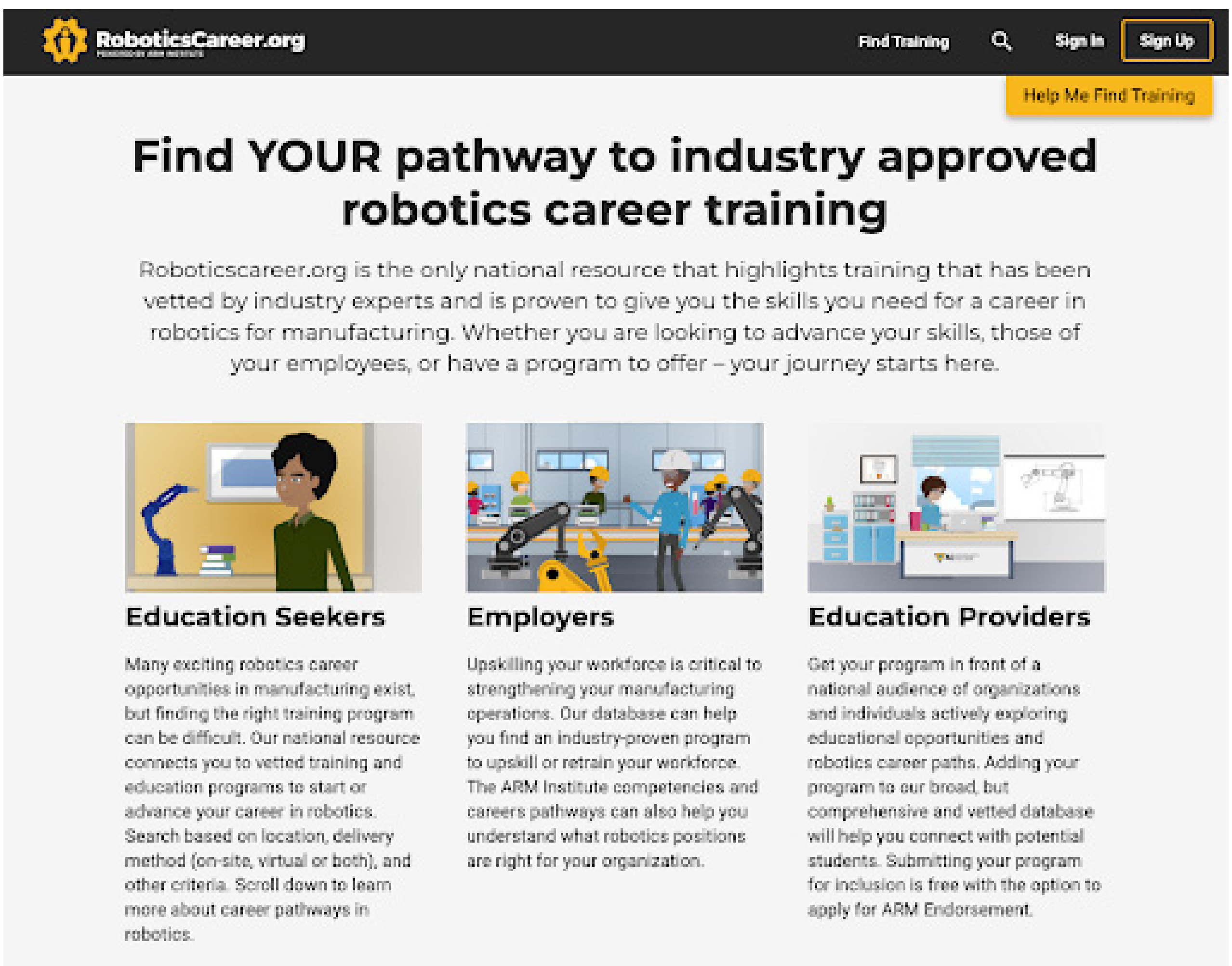
The Advanced Robotics for Manufacturing (ARM) Institute provides links to robotics courses, with a focus on the manufacturing industry, at Community Colleges across the USA.

Robotics jobs pay well, are challenging and rewarding, and provide a career that's spent on the leading edge of advancing technology. Better still, your child or student doesn't need a 4-year college degree to be a part of it.

An entry level position as a robotics technician generally requires a 2-year degree or a trade school certification in a related field. But that's it. No need to spend another extra couple years and tens of thousands of dollars- on a degree.

Plus, the average salary for a robotics technician starts in the $50k-$60k range, and only goes up from there. And with the ever-growing popularity and demand for robotics in a variety of industries, especially in manufacturing, now is the perfect time to start a career in robotics.

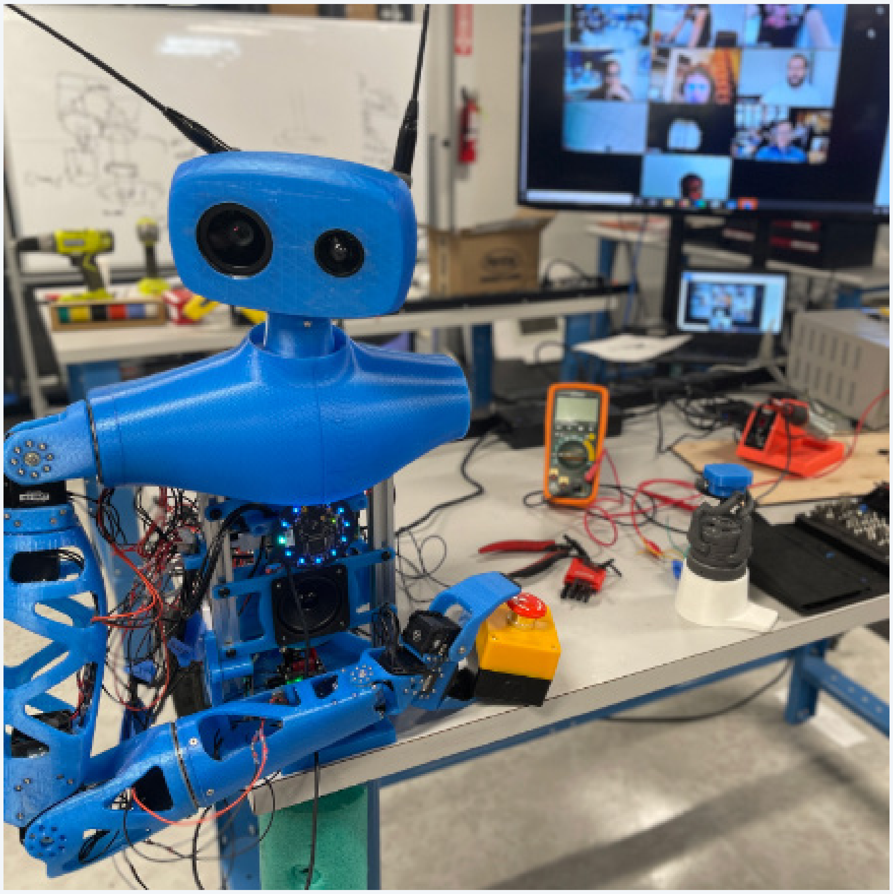
The Advanced Robotics for Manufacturing (ARM) Institute is funded by the Department of Defense and catalyzes innovations in robotic technology and workforce development to strengthen U.S. manufacturing. The ARM Institute created Roboticscareers.org to connect workers and employers with vetted training opportunities, increase awareness of the career pathways for robotics in manufacturing and endorse the most relevant and effective training programs.



Mechlabs

Another non-degree pathway into robotics is by hands-on learning. Mechlabs is a new program in Oakland that focuses on collaborative building of open source robots as the pathway to learning a wide range of robotics and AI skills.

"Our belief is that truly learning mechatronics and robotics is more efficient through the process of building Humans are naturally hands-on learners, and the mechlabs learning path beats to the core of this drum. Textbooks and curriculum are out of date almost before they are published. Lectures are boring and inefficient. We build robots to learn to build robots."



Reachy, an open source robot from Pollen Robotics, was built during one of the Mechlabs programs. In another program, incoming students at SJSU built DIY Robocars, trained the machine learning algorithms and had a car race.

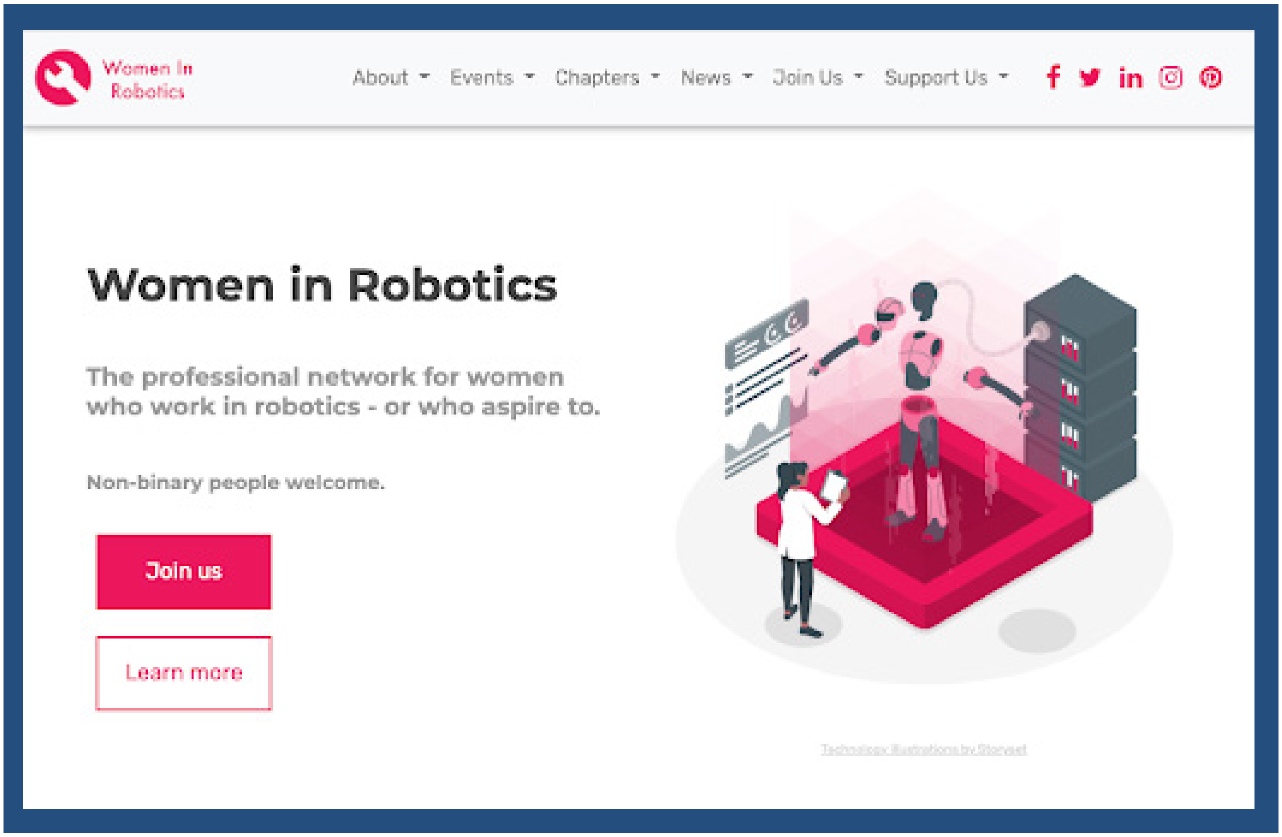
Women in Robotics

Women in Robotics is an organization for women and non-binary people working in robotics or who are interested in working in robotics. You can join an online community as well as local chapters in locations from the SF Bay Area and Boulder/Denver, Boston, Pittsburgh and San Antonio, all the way to Delhi, Bristol and Brisbane.

Women in Robotics was founded firstly, to counteract the isolation or feeling of not belonging that still has an impact on many in robotics. Diversity in robotics is improving rapidly but historically, lack of diversity has been a significant issue.

Secondly, Women in Robotics wants to promote the stories of women who have succeeded in robotics, many of whom were trailblazers, pioneering algorithms, patenting innovations and creating companies of significance in robotics. It's too easy for the contribution of women to be overlooked, just like in Hidden Figures, because no one was telling their story.

Every year, Women in Robotics publishes a "50 women in robotics you need to know about" list to showcase how women contribute to robotics in many different and critical areas.



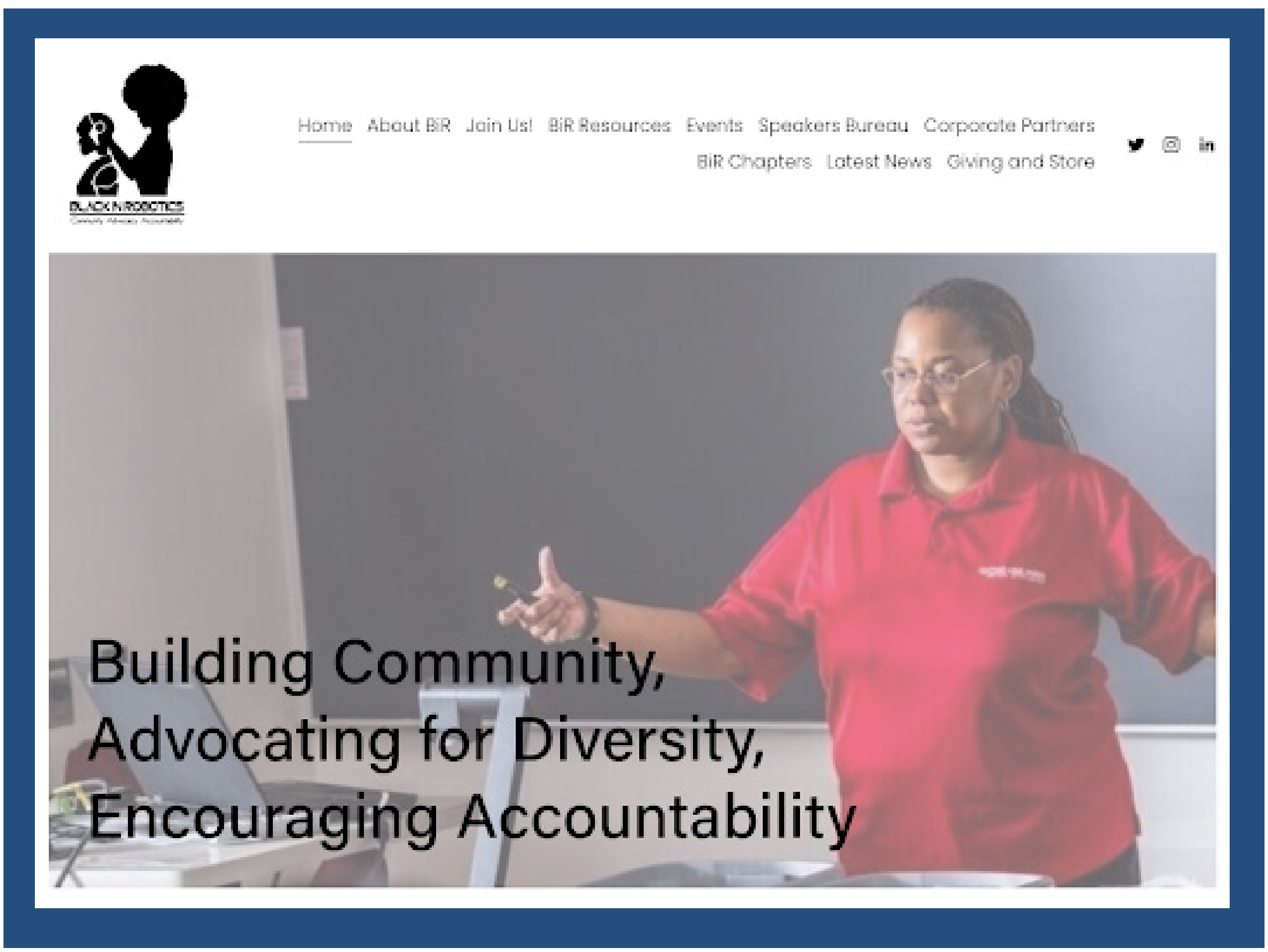
Black in Robotics

Similarly, the Black in Robotics organization has been formed to support the increasing diversity in robotics. The mission of Black in Robotics is:

- To bring together Black researchers, industry professionals and students in robotics to mutually support one another to help navigate academic, corporate and entrepreneurial paths to success.
- To advocate for more diversity, inclusion and equity within the organizations that we live and work in.
- To ensure a seat at the table during the development, test and deployment of robotic systems that affect our communities.
- To amplify our collective voices for calls for social justice.

There are chapters in Boston and the Bay Area, and Black in Robotics is working with universities and major robotics companies to create pathways for people of color into internships, university programs and research conferences. Black in Robotics has a Speakers Bureau, a Resume Book, a Student Travel Grant program, and a Reading List where you can see examples of Black Faculty and Researchers and their work.

IEEE Spectrum published an article on Supporting Black Scholars in Robotics which provides insights into addressing the lack of diversity in robotics academically.



In 2023, we will update this robotics research guide and provide more information about commercial or private robotics research labs, for example NASA, SRI International and the National Laboratories.

Please contact us if you'd like to update entries or add information about your robotics courses. You can email us at researchguide@svrobo.org.

Guide to Robotics Research and Education

IN THE GREATER BAY AREA OF CALIFORNIA

2022/2023 EDITION