EECS/BioE/ME C106A/206A

Final Project Guidelines

Fall 2021

Overview & Requirements

Your final projects must include **sensing**, **planning**, and **actuation**, which means you must be performing a real robotic task, on real hardware, using real sensors. Beyond requiring these three elements, the project is completely open-ended. We have provided some sample project ideas in this document. Broadly speaking, we will divide projects into three tracks: classic, research, and industry/design.

Classic projects are just that! Most projects in this class are just for fun, utilizing the class hardware (or making your own!) to implement something fun or cool. Most of the projects listed as references on the website are classic projects. If you do something similar to a previous project, we expect you to be able to build off it and do something bigger and better! It is insufficient to simply replicate.

Research projects are projects done in conjunction with graduate students in research labs. This is a great opportunity to get involved in robotics research at Berkeley! Be advised that these projects still require all components. We've talked to several grad students in different labs and have provided opportunities below.

Industry/design projects are a little more embedded than other tracks. In this style of project, you'll work with an industry partner and engage with their work. Often, this will involve identifying a problem, engaging with the community who faces this problem, prototype a solution, iterate on the solution, and provide a report to your partner on what your suggested next steps are. Do not be fooled into thinking that this might be an easier project, especially in terms of time commitment! Good design requires rigorous testing and community engagement.

To spice things up and keep you engaged, we will be recognizing Showcase Winners and Honorable Mentions for each track. You'll be recognized on the course website and will win prizes! ~~Did someone say C106A swag?~~

Dates, Deadlines, & Grading Breakdown

Please note: failure to submit a final project will result in an automatic Failing grade for the entire course.

Mini-Proposal	10/08	5%
Final Proposal & Parts List	10/29	10%
Final Products		
Presentation	12/9, 12/10	20%
Demo	12/9, 12/10	20%
Report (website)	12/17	25%
Video	12/17	20%

Grading Scheme

Overall, we will be evaluating your project on its complexity, polish, the participation of all team members, and on the following characteristics:

- **Design**: How original or ingenious is your design?
- **Implementation**: Does your implementation work? How reliable is it?
- **Scope**: Does your project contain sensing, planning, and actuation?

- **Rigor**: Do you properly test/evaluate your project? Are your assumptions reasonable?

These characteristics will be evaluated on the following scale:

Mark	**Description**	**Equiv. Score** (undergraduate)	**Equiv. Score** (graduate)
5	Exceeds expectations	95-100%	90-100%
4	Fully meets expectations	90-95%	80-90%
3	Adequately meets expectations	80-90%	70-80%
2	Barely meets expectations	70-80%	60-70%
1	Does not meet expectations	0-70%	0-60%

We expect most projects to score around 3-4 in each category, but we are not opposed to giving everyone a 5 if all projects are great. **Note that you do not need all 5s to make an A on the project.**

Projects will vary in complexity, and in general, the more complex or risky the project, the less polished we expect it to be. In other words, if your project is very complex, then we don't expect it to work perfectly or reliably. If your project is relatively simple, however, we'll expect it to work reliably and consistently, as you'll have more time to devote to getting it working well. A project that is simple but well done (i.e., very reliable) may receive the same grade as a high-risk project that is functional.

Late Work Policy

In general, **no late project work will be accepted**. If you feel that you will be unable to make any of the deadlines listed above, let us know **before** the deadline explaining your situation and we will revisit this policy at our discretion.

Groups

Project groups should consist of **4-5 people**. If you would like to form a group that is larger or smaller, please talk to us **before** submitting your mini-proposal. Note that expectations will scale with the number of project group members: we will expect more polish, complexity, and reliability from larger teams. We will also of course expect that all members equally contribute to each team. Peer evaluations will be submitted alongside the final report.

If you're having trouble finding a team even after the team-building mixer, feel free to start a thread on Piazza!

Multi-Class Projects

If you are in another project course, you are welcome to complete a single project for both classes, provided the scope of the project is extended appropriately (i.e., you should not simply turn in the same project for both classes — the portion of the project that you turn in for EE106A should stand on its own). You may work with team members who are only enrolled in the other class, as long as you complete all the project requirements of EE106A as listed here. We may ask to see the report you submit to any other class to ensure that the amount of work completed is sufficient to cover both assignments.

Similarly, if you are building off your own existing research and projects, we will ask you to specify which components were done before starting the final project and what was done for the scope of this project.

Mini-Proposal (due 10/08)

A preliminary mini-proposal is due **10/08** at **11:59p** and should be submitted to Gradescope. This document should be about one page and contain the following:

- name and contact information of each team member (full name, SID, email address);

- (brief) qualifications of each group member (department, previous experience, etc.); and
- project idea(s) and a brief description thereof.

In the subsequent week, we will read over your mini-proposals, and the week of 10/18, we will meet with each group individually to discuss your ideas in lieu of regular lab section (information forthcoming).

Final Proposal & Parts List (due 10/29)

Incorporating your project meeting feedback, you will complete a finalized proposal, due **10/29** at **11:59p** to Gradescope. A LaTeX template for this proposal has been provided on the website; you are not obligated to use the template, but all listed components should be present and complete.

An important part of this final proposal is the **parts list**, or **bill of materials**. Each group will be allocated approximately $50 to spend on parts for their project. You are not obligated to use these funds, and all purchased components must be returned to the lab on completion of the project. **If you plan on requesting materials, it's critical that they appear clearly and completely in your final project proposal as well as submitted via a Google form, as that gives us plenty of time to order them for you in time for subsequent project deadlines.**

Showcase: Final Demo / Presentation (12/9, 12/10)

For our end-of-year Showcase, final project demonstrations will occur in the lab space on **12/9** and **12/10** (the Thursday and Friday of RRR week), time TBD. We expect that **all team members are present** for the demos. Final project demonstrations will occur in blocks with multiple groups, and we expect you to be present for the full block to see what others have been working on and give feedback. If you have a conflict, let us know ASAP and we will do our best to accommodate you as we develop the final schedule. Exact expectations will be posted to the website.

Though exact details have yet to be finalized, you can expect to have a 13 minute slot. 10 of those minutes will be used to present your project, and the remaining 3 minutes will be used for QA. We highly encourage you to watch as many groups as possible!

Final Project Report (due 12/17)

Final project reports are due **12/17** at **11:59p** (the Friday of finals week), and will take the form of a website. It will also include link(s) to the video(s) of your functional system that make up 20% of your final grade. Exact expectations will be posted to the website.

Additionally, 5% of your grade will be dedicated towards your analysis of where your project fits into the larger picture. What potential social, political, and economic impacts could your project make? Who benefits? Who loses out? Are there any environmental impacts? These are all important questions to ask yourself whenever you work in design and engineering. Nothing exists in a bubble!

Teamwork / Peer Grading

To help ensure fair project grades, final scores will be modified based on peer evaluation. Each student will fill out a form evaluating both their own and teammates' performances. Exact instructions will be posted to the course website.

Example Projects & Ideas

A list of past projects has been posted to the website. The teaching staff has collated a number of research projects for groups to attempt. If you're interested in getting involved in undergrad robotics research or start involvement with another lab, this is a great way to get your foot in the door. We've also provided a couple more general ideas.

Past Projects

- Fall 2015
- Fall 2017
- Fall 2018
- Fall 2019
- Fall 2020

General Ideas

- Make robot art! And enter it here (if they ever hold another competition)
- Have Baxter play a board game! Chess and Checkers are overdone, but something a bit more complicated would be very cool. (Former TAs are partial to this)
- Collaboration between multiple robots. Have two Baxters collectively pick up an object or implement some searching algorithms on Turtlebots.
- Track the surface of an object using position control using vision and/or force feedback.
- Make a Turtlebot carry your stuff! Have it follow you around using image tracking. (Is this–a DIY Amazon Astro?)
- Measure an object's hardness, compliance, or coefficient of friction.
- Have Baxter copy a human's motions. IMU or Kinect based tracking is overdone and a bit too easy, so don't do that. There was a lot of work done circa 2005-2010 on estimating human 3D kinematics from their 2D poses, so combining this with a modern 2D pose tracker like OpenPose could be a cool project. You could also try building your own skeleton tracker or using a novel sensor.
- Track the surface of an object using position control and determine its curvature, using both vision and kinematic tools to control the manipulator.

Research Projects

If you're interested in a research project, express interest to Stella, Jay, and Josephine and state your interest in your mini-proposal so we can get you in touch with the sponsor. However, please also provide a backup project, since most of these projects can only support one group, and we want to ensure a good fit between you and your sponsor.

Here are some of the research projects:

- ROAR (Robotic Open Autonomous Racing)
  Sponsor: Ritika Shrivastava, Dr. Allen Yang
  ROAR stands for Robot Open Autonomous Racing and is Berkeley's first AI race car competition. With most of the semester being in person, students can use 1:8 ratio radio controlled cars to race on tracks in various environments (icy & sandy). Use Carla to simulate various racing environments and train a controller that can accomplish several tasks. Goals for this project include: getting a fast time for the competition, training a controller and sensing element for racing with the cars. Additional tasks include: following traffic signals, Multicar interaction, real world mapping with Realsense and autonomous driving. This project has a physical aspect if you are located in Berkeley.

- DEC-LOS-RRRT: Decentralized Path Planning for Multi-robot Systems with Line-of-sight Constrained Communication
  Sponsor: Victoria Tuck, Sastry Group
  The goal is to make a full drone demo of the algorithm from (this paper). From Victoria: "I made a 2D implementation in simulation, and an undergrad I worked with in the spring extended it to 3D. It assumes single integrator dynamics, so I think some buffers and things would need to be added for it to work with drones. It's pretty computationally heavy, so changes would need to be made to make it more real-time compatible, or a plan that's run offline would need to be implemented online. Both of these I think would require synchronization between the drones or some sort of sensing or communication between them. Or this could possibly all be replaced with the MoCap system, but I haven't worked with that, so I don't know how it works.

  I'm working on an extension of this that has less strict assumptions on dynamics. While I don't believe a drone implementation would require this (whereas a car implementation would...I think...maybe not), it could possibly be a less conservative version."

- Using UAVs to Position Rebar
  Sponsor: Prasanth Kotaru, Hybrid Robotics Lab (Industrial Project with startup SkyMul)
  Rebar is an important part of construction. This project will involve using two drones to pickup rods of rebar and placing them in a prespecified pattern. Automating rebar placement will save a lot of manual labor and automate the onsite construction. The project goals:

  - Design a gripper / electromagnet to pickup a small rod rebar
  - Plan motions and update flight controller to get two quadrotors to synchronize grabbing a rebar and flying with it
  - Create motion plans to place rebar in a given pattern

  Required skills:

  - Good at programming
  - Good at electro-mechanical design

- Locomotion/Manipulation on a Ball
  Sponsor: Bike Zhang, Hybrid Robotics Lab
  The goal is to get a quadruped robot to experimentally balance on a ball. Additional details:

  - Stretch goals: Walking / Bounding / galloping on the ball
  - Project will involve using cameras and IMUs to estimate not only the pose of the robot but also the ball.

  Required skills:

  - Good at programming

  Existing work can be found here and here.

- Racing with Mini Cars
  Sponsor: Jun Zeng (a former 106 GSI!), Hybrid Robotics Lab
  Anki Overdrive was a product from the startup Anki that recently closed. This product provides a customizable race track that can be organized in various shapes. The track has embedded magnets that the car reads to localize itself on the track. The goal of this project is to use an API to develop a custom autonomous racing planner / controller that can work with the the overdrive tracks and cars. Project goals:

  - Use the API to communicate with the cars to read sensor data and send driving commands.
  - Develop a planner / controller to be able to race on the track - minimize lap time.

- Stretch goal: develop a planner / controller that is able to make the controlled car race and avoid collisions with other cars on the track.

Required skills:

- Good at programming

Existing work can be found here and here.

- Robotic Guide Dog: Navigation Across Floors
Sponsor: Zhongyu Li, Hybrid Robotics Lab
Robotic Guide Dog (a quadruped robot) leads a blind-folded person to navigate across floors by operating the elevator on behalf of the person being led.

  Required skills:

  - ROS

  Existing work can be found here (The lead authors were originally recruited from 106A course project last year, and this paper is in the finalist of best service robot paper of ICRA 2021). Elevator button detection has been done here.

- Construction Site Inspection using Quadrupeds
Sponsor: Ayush Agrawal, Hybrid Robotics Lab
Legged robots are well suited for inspecting construction sites, particularly due their different mobility modes and ability to traverse across diverse terrain. A typical scenario in construction sites is to navigate across terrains with discrete gaps and footholds, such as across a field of rebar or over a flight of stairs. This poses several safety-critical constraints and challenges for integrated control, planning and perception. Project goals:

  - Develop planning and control algorithms for quadrupedal robots to autonomously navigate a construction site, particularly across terrain with discrete footholds.

  Required skills:

  - Model Predictive Control/Trajectory Optimization/State Estimation [EKF]
  - Programming/ROS
  - Bonus: Experience with visual sensors such as depth cameras/LiDAR

  Existing work can be found here.

- Energy Efficient Walking Gaits: ESC Approach
Sponsor: Jun Zeng (a former 106 GSI!), Hybrid Robotics Lab
Project goals:

  - Implement energy efficient walking gaits to enhance walking endurance for quadruped robots using esc (extreme seeking controller) approach

  Required skills:

  - Coding (ROS in cpp)
  - Hardware skills to estimate quadruped energy consumption.

  Existing work can be found here about energy efficient flight and here about energy efficient flight (endurance + range) and formal analysis.

- Manipulation of Non-Rigid Objects / Manipulation of Rigid Objects with a Flexible Vacuum Gripper
Sponsor: Ellis Ratner, Donggun Lee (106A GSIs!), BAIR
Project goals:

- **Multi-link model of non-rigid object OR rigid object grasped by a (flexible) vacuum gripper.** Here the goal is to form an approximate model of a non-rigid object grasped by a robot manipulator (using a parallel-jaw gripper), by representing it as a chain of rigid links and (revolute) joints, as shown in Fig. 2 (a). In general, non-rigid objects require an infinite degree of freedom (DOF) model, but this is not computationally tractable in practice. So, we'll form a finite-DOF model. However, each DOF of this simplified model is not actuated (unlike our robot, which has an actuator at each DOF).
- **Planning with contact for an under-actuated model.** Once we have a model of the type described previously, we note that none of the DOFs are actuated. So if we want to change the configuration of the object, we can use contact with the surrounding environment. As the example in Fig. 2 (b) shows, if we wish to flatten out the grasped non-rigid object, we'll have to make use of a contact force from some surface.

Key Components

- **Perception:** use a RGBD camera to estimate the configuration of the non-rigid object being grasped (and possibly use the point cloud to fit the approximate model)
- **Planning / control:** this might get complicated, but ideally plan and execute a motion to flatten out a non-rigid object being grasped. I have some ideas on how to do this without explicitly planning through contact, and instead having a more "hand-crafted" solution, which might be better scoped for a project.

- Autonomous Parts Assembly
  Sponsor: Ellis Ratner, Donggun Lee (106A GSIs!), BAIR
  Design and implement a system that enables a robot manipulator (6/7 DOF) to assemble a component consisting of 2 (or more) rigid parts, such as the example in Fig. 1. The robot will have a parallel-jaw gripper as its end effector to grasp and manipulate the parts. The robot will also have an RGBD camera (e.g., RealSense) for perceiving and estimating the poses of the parts. Key Components
  - **Perception:** use the CAD model of the parts, along with the RGBD camera to estimate the pose of the parts (could also be abstracted by using fiducial markers, e.g., AR tags)
  - **Planning** plan a path from the start configuration of the robot to a goal pose, e.g., a "pre-grasp" pose, while satisfying kinematic constraints; depending on the complexity of the problem, this can be achieved using interpolation, or some planning algorithm such as RRT/A*
  - **Trajectory smoothing and control:** have the robot smoothly follow the path generated by planning
  - **Grasping:** find a good grasp point for the parts

Additional details from Hybrid Robotics are here, and additional details from BAIR projects are here.

Industry Projects

Similarly to research projects, if you're interested in one of the following, express interest to Stella, Jay, and Josephine and state your interest in your mini-proposal so we can get you in touch with the sponsor. However, please also provide a backup project, since most of these projects can only support one group, and we want to ensure a good fit between you and your sponsor.

- Improving Self-driving Cars
  Sponsor: Amay Saxena (former 106A GSIs!), Tesla Autopilot
  Interested in autonomous vehicles? Tesla can provide a dataset for you to play around with to focus on an area of need that you identify. The hardware component for this project may be waived, but other expectations will go higher.

- Automating wheelchairs
  Sponsor: Pranav Kumar, Ben Gasser, Permobil
  Permobil makes advanced wheelchairs that are more robust to unique environments and situations. They've sponsored 106A projects before that included semi-autonomous driving on sidewalks/ramps and auto-docking at tables. They'll help you find needs that you can address for real-world impact!

- Exploring robotics with NVIDIA Isaac
  Sponsor: Neha Hudait, NVIDIA
  The NVIDIA Isaac Software Development Kit (SDK) brings intelligence to robots. The platform comes stacked with comprehensive tools, application frameworks, GPU-enabled algorithms, reference designs, and pre-trained capabilities to accelerate development workflows for robotics applications. You can create a developer account on NVIDIA's developer program platform to download Isaac and other SDKs to use to create various simulations.

Available Hardware

We have some hardware that you may use, depending on your proposal.

- Baxter (3x)
- Sawyer (2x)
- Turtlebot (6x)
- Ridgeback (1x). The ridgeback has a LIDAR and Cartesian control.
- Realsense 3D Cameras (many). We have several types, including ones with integrated IMUs and SLAM.
- Kinect 3D camera (2x). Some packages work better with Kinect than Realsense.
- Logitech C922 Cameras. (6x) High resolution wide-view webcams. 1080p at 30fps or 720 at 60fps.
- Research Turtlebots. (3x) We have some fancier Turtlebots with onboard NVidia Jetson Nanos and Realsenses.
- The following are either a) things we're pretty sure we have but need to find, or b) equipment that will be only made available on a case-by-case basis.
  - Crazyflie Drones. (6x) The Sastry group has a set of Crazyflie drones that can be made available for projects we deem good enough. We also have some larger drones, though we'd need you to have pretty extensive experience before we'd consider letting you use them.
  - Motion Capture Room. The Sastry group has a motion capture room you can use for HRI projects.
  - Haptic Device (1x). The Sastry group has a 6-DOF haptic feedback joystick. You could possibly use this for impedance control or some other human feedback project.
  - Dynamixel Servos (many). Dynamixel servos are like RC hobby servos, but give you much more sensor information. They're great for control projects.
  - Microsoft Lifecams. (4x) Middle-of-the-road webcam. 720p at 30fps.

Many teams have bought supplementary equipment that is still left in the lab! Before you consider purchasing or if you're just in need of some inspiration, take a look at what we have available at this link.