EECS C106B/206B Project Proposal and Guidelines

April 8, 2024

1 Overall Project Guidelines

The overall goal of this final project is to give you the opportunity to tackle a research problem of your own choosing and gain experience writing a full-length academic paper. We want you to pick a problem at approximately the scale of a conference paper and perform a preliminary analysis. If your initial experiments end up working (which we don't necessarily expect to happen), you should be far enough along that you could submit to a conference after a couple more months of work.

The usual requirements for this project are quite open-ended:

- The project must be a research project (not an implementation/engineering project like most 106A projects)
- The project must relate to robotics in some way
- You must do at least some work on hardware

Your project should be some convex combination of

- A theoretical contribution: Extend the mathematical theory of robotics in some way, shape, or form. Prof. Sastry's lab does a lot of this sort of work.
- An experimental contribution: Devise or implement an algorithm or sensor and test or characterize it in the real world (or simulation if appropriate). Prof. Bajcsy's lab does a lot of this sort of work.
- A design contribution: Design, analyze, and perhaps prototype a novel robotic system. [1] Prof. Fearing's lab does a lot of this sort of work.
- A literature review: Collect, organize, and summarize recent papers in the field. All good research includes some amount of literature review, and literature reviews are important to find in the current body of work (new problems to solve) as well as to educate researchers new to the field.

Examples of all four types of papers (and many combinations of those types) can be found in the list of paper presentations. These are a starting point to think about new problems in the field.

In the sections below we discuss some aspects of the project in greater detail. We are deliberately vague in defining the project requirements because we don't want to constrain you from doing interesting research. However, we expect you to put a significant amount of work into this project (well over 50 hours per person) and produce something that you are truly proud of. This is not a project you can start at the last minute.

Project groups should be composed of 4 students. This is the ideal size for a good research project; it's good to have more than one person so you can catch each others' mistakes, but research projects are rarely dividable into many independent tasks and thus aren't suitable for large groups. Exceptions can be made on an ad hoc basis for projects that require a different number of people in the group.

[1] Some papers of this type instead detail the design of novel software (tools, simulators, solvers, etc) for researchers to use. Examples include Trac-IK, IPOPT, MoveIT, OMPL, Tensorflow, etc. We *strongly discourage* you from trying to design novel software. It's not easy to make high-performance software and takes a long time, and you usually need to invent a new algorithm before you make the software package

We strongly encourage you to pursue a project that is related to some of the material we've covered in class. This way, you will have some preliminary groundwork already covered before you dive into your project. At least one team member should ideally meet with a TA to discuss your project ideas before submitting your proposal. We will approve projects not related to the coursework on a case-by-case basis.

2 Final Project Deliverables

The deliverables for your final project will be

Deliverable	**Percent of Grade**	**Due Date**
Project Proposal	5%	4/19*
Final Presentation	30%	5/2, 5/3 (Dead Week)
Final Report	40%	5/10 (Finals Week)

*The project proposal is due on a rolling basis - we encourage you to submit at your earliest convenience.

A brief description of each deliverable is listed here. More information will be forthcoming.

Proposal See below.

Final Presentation We will have Showcase in the same style we had it for EECS C106A. Each group will be expected to attend the entirety of their Showcase Block. Each group will give a 20 minute final presentation followed by 5 min of Q/A on their work during RRR Week. This presentation should include videos of any hardware demos, simulations, etc. At the end of the Showcase block, we will break for refreshments and a poster symposium.

Final Report Each group will write a full-length research paper on their work. The minimum paper length is 4+n pages (4 pages not including the bibliography), barring ad-hoc exceptions. Papers shouldn't exceed 6+n pages (the limit at most conferences). In addition to this, each report should contain links to videos to supplement your paper and to market your work.

Please Note! Failure to deliver on any of these components without any prior accommodation or notice will result in a forfeiture of those points. Ex: failure to show up to your scheduled showcase block without notifying before the block starts will results in a 0 for the 30% allocated to the final presentation.

3 Project Proposal

Project proposals will be due on Friday 4/19 at 11:59pm on Gradescope. Before submitting your proposal, you are welcome to meet with a TA to discuss your idea and make sure that it meets our expectations. You can go to any TA's office hours or schedule an appointment. Your proposal should include:

- **About You**. Include your names, years, majors, relevant courses/research experience, and a one-to-two sentence description about your research interests (or the aspects of robotics that interest you).
- **Research Question**. What problem are you trying to solve? What contribution are you trying to add to the field? This should be phrased as a question – if you already know the answer it's not interesting research.
- **Motivation**. Why is the project of interest? Are there motivating applications?
- **Proposed Methodology**. How do you plan to approach the problem? What literature will you be surveying, or how will you undertake your research project? What assumptions will you be making?

- **Related Work**. Include at least three[2] references to papers on your topic. Summarize them in a couple lines and justify why you picked them. You don't need to have performed a full second pass on them yet, but you should have gone deeper than a first pass. Note that you may need to first-pass more than three papers in order to find three papers to start with, so please remember your your literature review skills and be efficient with your time. Some tips:
  - S Keshav's How to Read a Paper is a great resource.
  - Remember that your very first read of any paper should just encompass the abstract, section titles, and figures. Your next read should include the introduction and conclusion. Don't read the proofs until after you've determined that the paper is worthwhile.
  - If you find a (high quality) recent paper, look at its references to find seminal older work. Similarly, if you find a useful older paper, you can use google scholar to search through the papers that cite it.
  - Keep the academic family tree in mind. If you find a researcher doing relevant work, it's likely that their advisor or students do similar things.
- **Experimental Plan**. If you'll be performing experimental or design work, elaborate on the methodology section above. What hardware or simulator do you plan to use? Provide a system diagram to characterize the inputs and outputs to your system. Describe any software modules you will need and provide references to third party software (e.g. ROS packages) you plan to use. Describe what experiments you plan to run. The purpose of this section is to give the course staff more information so we can help you out.

4 Final Presentation

Demos are scheduled 5/2 and 5/3 in Cory 105. You'll have a total of 20 minutes to talk about your project and show off any results. You should plan to spend around 15 minutes on your presentation, including a couple of minutes to demo any results, and 5 minutes on questions/transition time. Feel free to organize your presentation any way you'd like, but you should probably include the following components:

- What problem are you examining and why is it important?
- What is your solution? What was your initial goal?
- What have you learned? How does it affect any future work you would do?

Remember that a presentation is a very different medium from a paper, so you shouldn't be organizing your talk like you would a paper. What are your most interesting results/insights? What is the minimum amount of background information you need to present to adequately discuss these insights? You'll likely need to discuss math, but you shouldn't get bogged down in equations or algebra. Try to develop effective visuals to streamline your talk. Consider integrating gestures or a whiteboard. We encourage you to invite other folks, including friends and mentors, to the showcase to show off your work!

5 Final Paper

The main deliverable for your project is a conference-style research paper detailing your current progress. While we don't expect your product to be worthy of publication, writing a conference-style paper is still a very useful academic exercise, and will likely prove useful should you decide to continue work on your projects after the course. By writing this paper, you'll get practice crystallizing your ideas into a readable document. And often the act of writing things down will reveal holes in your research that you'll need to fill.

Please write your report in the IEEE conference format, which we've been using through the semester. Your submission should be at least 4 pages plus references (4+N), and at most 6 pages

[2] Potentially you might find fewer than three papers that are actually useful for your project (if your field is very new or esoteric, for example). If this is the case, feel free to include fewer papers and justify why you did so.

plus references (6+N). These are hard limits and include figures. You must include a title and an abstract, but the rest of the paper's organization remains up to you. However, the following template is generally good to go by:

1. Abstract
   (a) This is a short summary of your work, which highlights what is most important. Keep this less than 100 words.
2. Introduction/Motivation
   (a) Describe the motivation and how this relates to what you've learned in class.
   (b) Briefly summarize your approach.
   (c) Potentially cite a few papers related to your research.
3. Related Work
   (a) Organize the related work by which subpart of your project it corresponds to.
   (b) You should include some citations here, with a sentence or two description for each work if appropriate. The number of citations you'll need is highly dependent on your project, but *you should have at least 5 citations* in your overall paper. If you're doing a highly theoretical project, it's possible you'll only need 5 citations. If you're doing a more thorough literature review-esque project, you could need as many as 50 citations. Use your judgement and reference an appropriate number of papers.
4. Methods
   (a) What success criteria did your approach aim to solve? (e.g. formally, what was the goal).
   (b) Include a high level overview of your approach, breaking it into components.
   (c) Describe the equations and / or models you used.
   (d) Describe each component of your approach in detail.
5. Results
   (a) Explain your experimental setup. What were your hypotheses? What hardware did you use? What data sets did you use? What were the independent variables (inputs) and dependent variables (measurable outputs)?
   (b) Provide a qualitative summary of your results
   (c) Provide a quantitative analysis of your results. You will almost definitely want to use one or more figures or tables to describe your results.
   (d) Discuss your results and their implications.
6. Conclusion/Discussion
   (a) Recap the key ideas and results
   (b) Reflect on difficulties you encountered
   (c) What future work is there to do in this area?

We've deliberately left many of the requirements open-ended, but we expect your paper to be concise, readable, and informative. Pay special attention to figures – a good figure can be a very efficient source of information, but a poor figure is a waste of space.

Writing a good paper is very hard work. Contrary to expectations, you generally want to start with the middle of the paper (the methods and results), then write the conclusion, then the intro/related work, and finally the abstract. The introduction is usually the most difficult part to write, so some grad students will start there after writing their outline, but for this project we recommend starting with the middle.

5.1 Videos

Please attach videos to your final project report! These are important to showcase functionality, especially beyond what you were able to demo at the showcase. If you have the time, you could put them on a 106A-style website, although that's completely optional.

6 Potential Topics

Here we list a couple potential topics for projects. However, the projects to do not have to be limited to these areas, as long as they relate to robotics as a field. Example projects from previous years can be found on the website.

You are free to use your own research (masters project, work for a lab, etc) as long as you're clear about what work you did previously and what you're using to satisfy this project.

6.1 Grasping

1. Grasping or segmentation of objects in clutter:

   One of the major goals in grasping is the ability to pick up objects in cluttered spaces (like product bins in Amazon warehouses). What current solutions exist? How might you redefine grasp metrics or grasping algorithms to work well in clutter?

   A similar problem is the difficulty of segmenting or identifying distinct objects in cluttered environments (like a box of odds and ends at a garage sale), as they may be partially occluded or difficult to distinguish from nearby objects. One way to deal with this is by using a robot to push, grasp, separate, or otherwise manipulate the objects into positions in which they can be identified. This is an example of *Active Perception* a field which Prof Bajcsy started in the 80's, or the integration of perception and control to learn new information about a robot's environment.

2. Part-based grasp analysis:

   One hypothesis about how humans quickly grasp objects is by identifying affordances, or parts that are easy to grasp, such as handles, cylindrical, or spherical parts. What solutions already exist?

   A possible direction to take this is to segment 3D models and analyze grasp quality for each segment. What's the proper way to segment a model? If you have two objects with similarly shaped affordances, how can you transfer grasps between the objects?

6.2 Soft Robotics

1. Soft robot design and sensor integration:

   Researchers and hobbyists have been designing soft robotic actuators for a number of years, but relatively little work has been done in soft robotic sensing and control. Often these systems are evaluated qualitatively or via external cameras, but in order to deploy soft robots in the real world, we need reliable on-board sensing.

   How have roboticists designed soft robots, and how have they integrated sensing, if they have at all? Design a multi-DOF soft robot manipulator and specify the actuators you'd need to properly observe its state. If you have access to materials, you can try prototyping.

2. Soft robot grasp metrics:

   Soft robotic grippers are used to pick up delicate items like fruits, etc because they can wrap around the object and conform to its profile. They can better control the forces they apply and are robust to small errors in grasp pose. However, no one (that Valmik knows of) has designed grasp metrics for soft robots or mechanical models for how the grasps work.

   What are the current approaches being tried, if any? Try to develop a model for how a soft finger would grasp an object. One thing you can try is to imagine that the finger is composed of N rigid links in an open chain that share the same torque input (where N is on the order of 100). How do the model predictions change with N? How do you account for multiple fingers or strangely-shaped objects? You could try testing your model with the soft fingers in the lab.

3. Dynamics of hyper-redundant manipulators:

   Because soft robots deform smoothly, they can be expressed as an infinite chain of rigid joints, each with infinitely small length. A lot of work has been done on the analysis of hyper-redundant robot manipulators: those manipulators with arbitrarily many rigid joints, and this analysis could be very helpful in modeling soft robots.

   This is an area into which Valmik has been planning on looking for his research, but he hasn't done so yet, so this would be just a literature review unless you find a gap in the work or have an idea for an extension.

6.3 Autonomous Vehicles

1. Decentralized motion planning for swarms:

   Professor Sastry read this article and is a bit suspicious of its claims. Provably correct decentralized control for groups of mobile robots is a major research problem and Professor Sastry is curious about how far this group has come. An interesting project could be designing a decentralized motion planning strategy to control a number of mobile robots (and hopefully prove things about it). You could potentially extend Wang and Rubenstein's work, or go in a different direction.

   Other professors whose work you could look into are Hadas Kress-Gazit at Cornell, and perhaps Magnus Egerstedt at UC Irvine. This project would likely benefit from the use of the Robotarium.

2. Active Safety in Vehicles:

   There's been a lot of interest recently in *active safety* in vehicles, where the vehicle will take over from the human driver in order to prevent collisions. Examples include automatic lane keeping and autonomous emergency braking. There are a couple projects you could do in this area:

   - Identify a traffic scenario and try to design an active safety controller to prevent collisions. Try to set guarantees on collision avoidance (for example, "If I stay 4 seconds behind the car in front of me I'm guaranteed to be able to avoid it if it suddenly brakes"). In which situations do your guarantees fail?
   - The vehicle's definition of safety is based on its internal model of the world, and thus its sensors. This model might not match the model of the vehicle's driver in some situations. For example, a noisy sensor might detect an obstacle that isn't there (or fail to detect one that is), or the human might need to break "safety" in order to perform some maneuver (like driving on the wrong side of the road to avoid a pothole). How might the vehicle and its driver communicate in these situations? Is there a natural way for the human to counteract the vehicle's input?

7 Resources

Here are some resources that might be helpful to you:

- Gazebo and MuJoCo are two simulators you can use. Gazebo tends to be used more for ROS-based things, while MuJoCo is usually used in machine learning, but both can probably be used for either purpose. OpenAI Gym might also have some useful environments.
- The Robotarium is an excellent platform for mobile robot or swarm research.
- Harvard's Soft Robotics Toolkit is a great resource for soft robotics projects.
- Adafruit and similar sites sell relatively cheap hardware and sensors you can use for experiments at home.

- Most vision-based projects only require a (cheap) webcam. Valmik uses Logitech C920 cameras, and the lab uses Logitech C922's (the enterprise version of the C920). Intel sells RealSense cameras on their website. Microsoft Kinects are also pretty cheap, and if you have an XBox you might have one lying around already.
- If you want to do some hardware work at home, but money is a major obstacle for you, let us know and we might be able to help out.

8 Available Equipment

- Robots:

  Sawyers

  Tello Drone

  Turtlebots

  Dynamixel servos

  Your Own: You can always use some other hardware not provided by the course. You can contact some other professors to see if they are willing to let you use their hardware.
- Cameras:

  Logitech C922

  Kinect v1 & v2

  Intel RealSense