ME 570: Robot Motion Planning

Prof. Tron

Fall 2017

1 Course description: What this course is all about

Imagine going from one side of an office to the other while avoiding chairs and desks, or solving a maze puzzle. Sounds easy, right? Ok, now program a robot to do the same. How do you represent the environment? How do you find a collision-free path? How can you know that it is the best possible path? What if you need to find a solution faster? How can you ensure that you will always find a path that the robot can follow with limitations in sensing and actuation?

This class provides an overview of the "lessons" learned by the robot path planning research community in the last 30 years. We will examine approaches based on potential functions, graphs (roadmaps and cell decompositions) and sampling methods. We will also examine basic modeling and localization techniques. During the class, you will learn how to identify and evaluate assumptions, models and solutions in papers published in recent literature and written by your peers. You will be challenged to apply what you learn to new problems, propose novel solutions, present your findings and receive feedback according to professional standards.

More broadly, this class will give you a set of "tools" that you can use in tackling new problems, and encourage you to think how your solutions fit in the larger picture of a complex system such as an autonomous robot.

2 Instructor information: How I make myself available to you

Instructor Prof. Roberto Tron

Office Room 301, 110 Cummington Mall.

Email `tron@bu.edu`

Office hours You can also just stop by my office, but if you schedule an appointment I can guarantee that you will have enough time reserved for you. For best results, come together as small studying group; I enjoy a lot small group discussions.

Instructor $\iff$ Students communication I will use the class Blackboard website to make announcements, to post material from the class and to post and collect assignments. Please let me know as soon as possible if you cannot find something.

3 Prerequisites: What you need to know already

A significant part of your evaluation (homework, final project) will involve coding for implementing and evaluating algorithms. This requires at least knowing how to plot 2-D/3-D functions, manipulating arrays and other data structures in addition to standard constructs (loops, functions, etc.) Matlab is the preferred language, but Python is also acceptable (I am less versed in the latter, so I wont be able to help you as much if you encounter problems, but you would at least get to teach *me* something).

4 Course objectives: Why you should take this class

4.1 What you will know

You will be able to explain and implement the basic principles of:

- Gradient-based;
- Roadmap and cell decomposition graph-based algorithms;
- Sampling-based algorithms;
- Filtering-based localization;
- Modeling of mechanical systems.

4.2 How you will learn what you do not know

You will be able to take a current research paper and:

- Identify what you need to know to understand the paper;
- Reflect on the limitations and assumptions;
- Identify the context in the literature.

4.3 How you will apply what you know

You will identify a problem that requires path planning and develop an original solution to it.

4.4 How you will present your work

You will communicate a solution by writing a paper that meets the expectations of the research community through:

- Containing relevant, precise and extensive citations;
- Reviewing the state-of-the-art and putting the proposed solution in perspective;
- Precisely describing the proposed solution;
- Properly evaluating the proposed solution.

5 Resources: What materials we will use

5.1 Textbook

Our reference text will be:

Choset, Howie M. *"Principles of robot motion: theory, algorithms, and implementation"*. MIT press, 2005.

The book is not strictly necessary, as I will cover the material sufficiently in class, but highly encouraged, as you might find it useful as an additional resource.

5.2 Reference manager

We will work with many articles available online. It will be helpful for you during the class and in the future to use a reference manager to organize the literature you get in contact with. For this class, we will use Mendeley (`https://www.mendeley.com`).

6 Assessment: How we will know that you are learning effectively

The assessment of your progress will be evaluated in different ways. Toward the beginning of the class, you will be engaged more with homework and exploration of the literature. Toward the end of the class, you will be working more on your course project in collaboration with your peers. Throughout the class we will monitor our learning progress with informal quizzes.

6.1 Homework

We will have five homework assignments during the semester (an introductory one plus one after each of the first Themes of the schedule). Each assignment will have a significant programming component, but might also include a few theoretical questions. The assignments will count together as 26% of the final grade. Both correctness of the solution and clarity of the presentation will be evaluated. See Grading criteria for details.

Objectives of the activity You will reach a deeper understanding of the material by going through the motions of implementing it. This will also be my way to assess if you have properly understood the founding knowledge of the class.

Late homework policy For the entire semester, you will have *two* late-homework credits. You can use one credit to submit your work up to 24 hours later than the normal deadline without penalty (no question asked); just include the statement *"I am using a late-homework credit for this assignment"* at the top of your report. You can also use the two credits together to get a 48 hours extension, but then you would have to submit all your successive assignment on time. If you do not use a credit or run out, the credit you will receive will halve after the deadline, and after each successive 24 hours period (that is, 50% after the deadline, 25% after 24 hours, 12.5% after 48 hours, etc.) If you feel that you are falling behind on multiple assignments, please come to see me to discuss.

6.2 Reading-group-style exploration of the literature

After examining the basics of each topic (each Theme in the schedule), we will devote some time to explore the most recent literature on the subject. You will select one paper to read before each session in the schedule, and then six/seven people will present during each session. For each session, the selection of the students that present will be based first on volunteers, and then on random selection if not enough volunteers are available. You will be required to do only one presentation throughout the semester.

Required materials Please bring your laptop/tablet/phone or print all the papers of your group in advance.

Choosing the papers : I will provide you with paper suggestions, but you are encouraged to explore the literature independently and propose your choices. Either case, you will have to decide and let me know the titles at least 72 hours before the corresponding reading group (we will use an online shared document to keep track of the assignments).

Presenting the papers The presentation will be without slides, but you can use the blackboard/whiteboard, and you can assume that the audience will be able to follow on their own copy of the paper. You will have to consider and you will be evaluated on how well you are able to cover the traits described in the Grading criteria section. A presentation will be considered successful if the audience (and in particular, myself) can get the gist of the paper without having to read it fully.

Objectives of the activity The goal of this assessment is twofold. First, you will get a sense of where the field is. Second, you will learn by example what aspects you should pay attention while reading a paper, and what makes a paper interesting. The presenters of the selected papers will be lightly graded (12% of the final grade). We will have a system to ensure a uniform rotation of the presenters from each group during the semester.

7   Participation and continuous feedback

We will have regular clicker-based quizzes at the beginning and end of classes. We will use a web-based system to collect answers. The answers will not be graded, but the overall participation in the course will count for 5% of the final grade.

Objectives of the activity We will use these quizzes to have frequent feedback on the learning process.

8   Course project and final paper

The main evaluation of your performance in this class will rely on the course project related to the course material, and will culminate in a final research-quality paper. For the project, you can work alone or in groups of two. To help you succeed and to encourage good working habits, you will be guided by a sequence of steps. These steps will include providing and receiving feedback in a format similar to what you would experience during a conference submission. The total marks for this part of the assessment (which will count for 57% of the final grade) will be a cumulative sum of the marks obtained in each step.

  1) Abstract (1): you will submit to me (via email) an abstract describing your chosen topic and an overview of what your paper will be about. I will provide you with a list of possible topics, but you are encouraged to propose and discuss with me your personal ideas. If you are carrying out research outside of this class, I encourage you to think how the tools of this class could be applied in your area. You will be evaluated on the clarity of your plan.

  2) Review of prior work (2): you will explore the existing literature on your chosen topic, producing a synthesis assessing what has already been done and identifying better where you can make a contribution. You will be evaluated on the breadth and quality

of the references you include, and on your capacity to organize them in a succinct but effective way. The reading-group class discussions will help you with this part.

3) Initial drafts and first round of reviews (1): As you work on your topic, you will be required to write a rough draft of the final paper containing your results up to that point. This draft will be submitted to three of your peers for review. In turn, you will receive the papers of some of your peers, and you will be required to write a review. You will include constructive comments on ways to improve the paper (remember to write a review like one you would like to receive). I will try to emulate (asking for your collaboration) a double-blind system, as commonly used in conferences. I will evaluate your reviews, which will need to contain a fair and detailed assessment of the aforementioned points.

4) Final papers (6): as the end of the semester approaches, you will complete your paper with the final results of your work. This final version will hopefully benefit by the comments received in the first round of reviews, and will be submitted to the same reviewers for another round of shorter comments and final scoring.

Best paper award we will publicly award the best paper and two runner-ups. The choice will be based on the scores given in the last round of reviews plus (with a reduced weight) my scores. While proceeding through the steps and while writing the reviews, you will be evaluated according to the traits described in the Grading criteria section.

Objectives of the activity This experience will help you hone your professional skills and teach you how to give and receive meaningful feedback. These skills are valuable in both academic and industrial settings, and will serve you well in the future. The best outcome of this activity would be to have a paper of sufficient quality and originality that could be submitted to a real conference.

9 Grading criteria

9.1 Homework

Each exercise will count a fixed amount of points, but the final grade for each assignment can be adjusted with up to +/- 3 beauty-contest points that I will add/remove to my discretion. This will be based on how clear and professional is the explanation of your work. I will put my best effort to evaluate the correctness of your work, but I will reward you if you make my job easier. To give you an idea, these could be two extreme situations:

- You do not include any comment in your code, you do not explain why you are doing the derivations, and I have to spend more than a reasonable amount of time to understand your work: subtract 3 points, even if the results are technically correct.

- You meaningfully comment and organize your code, it is easy to see your reasoning process, and you type your answers in LaTeX: add 3 points, even if the results are not completely correct.

9.2 Paper evaluation

There are a few traits that make a paper good or bad:

1) Organization: the abstract is concise, accurate, and complete; the sectioning and distribution of the content is complete (contains all the expected material) and balanced.

2) Review of prior work: the citations are sufficient in number, pertinent to the present paper, and from good quality sources; the paper organizes them in asuccinct but meaningful and useful manner, forming a balanced and clear picture of the state of the art; the paper clearly places its contributions with respect to this state of the art.

3) Presentation of the results: the proposed theory/method is presented in a detailed manner and one can easily follow the authors train of thoughts.

4) Evaluation of the results: the authors provide compelling simulations/experiments to verify the validity of the results; the paper includes comparison with baselines or competing methods; the results could be easily reproduced (e.g., an implementation is available online).

5) Originality of the work: the paper proposes a new approach to a problem, identifies a new problem or adapts known techniques to new, unexpected domains; the contributions are radical (totally new, unexpected) as opposed to incremental (minor modifications of the state of the art).

These are the traits that you will have to consider when presenting the paper in the reading group section, when writing your paper, and when reviewing papers from your peers. These are also the same traits used by (good) reviewers to judge papers in professional conferences (there are also not-so-good reviewers, but that is another story). I will use the same criteria to evaluate and grade your performance in the class.