ME/CS 132 (and ME 131):
Introduction to Robot Motion Planning & Navigation

CS/ME 132 Lecturer: Prof. Joel Burdick, Thomas 319, x4139, *jwb@robotics.caltech.edu*

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T.A. office hours: TBD

Class Meeting Time and Location: (3 lecture hours/week, time to be arranged)

<u>Intended Scope of ME/CS 132</u>

This two-quarter course[1] will focus on *Robot Motion Planning.* A robot motion planning algorithm enables an autonomous mobile robot to determine its movements in a cluttered environment so as to achieve a variety of goals while avoiding collisions. The ability of a robot to plan its motions without explicit human guidance is a basic prerequisite for robotic autonomy. This course will try to strike a balance between a review of the basic philosophies underpinning motion planning, practical algorithms, and theorems/proofs underlying important motion planning results.

ME/CS 132 will focus primarily on the basic theories underlying *classical* robot motion planning–planning when the geometry of the robot's stationary surroundings is known in advance. ME/CS 132 will also introduce students to *sensor-based motion planning*–planning in the presence of a priori unknown or poorly known geometry of the robot's surroundings. ME 131 will review more advanced sensor-based planning algorithms, and introduce students to robotic mapping and localization methods.

The heuristic goals of ME/CS 132 are to:

- introduce basic robotic motion planning problems.
- provide students with a basic review of *classical* motion planning theory and an introduction to the most widely used classical motion planning algorithms.
- introduce sufficient terminology and concepts so that interested students can independently read the robotic motion planning research literature.
- introduce the basic concepts behind *sensor-based motion planning algorithms.*
- expose students practical issues involved in implementing a planner via laboratories involving small mobile robots.

[1]ME/CS 132 is only a single quarter course (winter 2008-2009). However, ME 131 will be offered in the spring quarter, and this year ME 131 will in effect be the second quarter of ME 132. However, students can have a complete and self-contained experience without continuing on to ME 131.

The heuristic goals of ME 131 are to:

- extend the review of sensor-based planning algorithms studied in ME/CS 132.
- review some of the basic sensor-processing issues and algorithms needed to process the outputs of typical robotic sensors.
- enable students to implement sensor-based planning algorithms on a mobile robot.
- introduce and review the basic problems in robotic localization and mapping.
- review conventional estimation techniques (Kalman filter and Particle Filter) that underly localization and mapping algorithms.
- review estimation-based localizaton and mapping techniques.
- allow students to implement a significant robot motion planning project.

Tentative Syllabus of ME/CS 132

The course lectures and content will roughly follow this tentative outline:

- An overview of robot motion planning problems.
- Review of basic kinematics of rigid body motion.
- The configuration space of a rigid body.
- The classical motion planning paradigms:
  - the roadmap
  - the potential field method
  - the cellular decomposition and approximate cellular decomposition approaches
- Graph search and discrete planning algorithms.
- Sensor-Based Motion Planning Algorithms
  - the "Bug" algorithms
  - the TangentBug algorithm
  - the incremental Voronoi Graph
  - the D^* algorithm

The first 5-6 weeks of ME/CS 132 will focus on the *classical motion planning* framework, where the geometry of the environment is a priori known. With this theory in mind, the remainder of the course will focus on *sensor-based motion planning* problems, where the geometry of the robot's environment is either a priori unknown, or poorly known. ME 131 will extend the study of sensor-based planning algorithms, as well as introduce and incorporate the important capabilities of robotic localization and mapping.

Course Prerequisites

Traditionally, this course assumes ME 115(a,b) as a background prerequisite. However, since ME 115 has not been regularly taught in recent years, it is not a prerequisite this year. A review of basic rigid body kinematics will be provided for those students who have not taken ME 115. The lectures will also be presented in a style which doesn't require an excessive amount of knowledge from ME 115.

Some of the homeworks, and all of the labs, will require programming. There is no preferred programming language for the course, though Mathematica or MATLAB should suffice for most homeworks. For programming the laboratory robots, a minimal amount of knowledge of C or C++ programming languages is required. The coursework in ME 131 will be focused more on algorithm implementation, laboratories, and a final project. Hence there will be a heavier burden on programming in the second quarter. As an option for the final projects, some students may choose to take advantage of the recently released **OOPSMP** motion planning package (*http://www.kavrakilab.org/OOPSMP/index.html*), which implements several of the most popular classical motion planning algorithms. Knowledge of C++ is required to most conveniently use this package.

Course Mechanics and Grading

The course-work will consist of 4-5 homeworks, approximately 2-3 labs, and a small final project.

Homework:	45%
Labs:	35%
Final Project:	25%

The homework is not intended to be difficult, but rather to reinforce the topics presented in the lectures.

Course Web Site: The web site for this course can be found at:

http://robotics.caltech.edu/~jwb/courses/ME132/ME132.html

This site will contain copies of homework assignments, homework solutions, and most class handouts (all the ones that are available in electronic form). Important information about the class, such as changes in due dates, homework errata, etc. can be found in the "Bulletins" section. You should visit this site if you miss class.

<u>**References**</u>

1. The following text will provide the main background for the first half of the course:

- **Planning Algorithms** by *Steve LaValle* (Cambridge Univ. Press, New York, 2006).

This book is strong on classical motion planning theory and algorithms. It also includes excellent reference material on information-space approaches to planning, and evasion-pursuit algorithms. While these subjects are beyond the immediate scope of this class, they accessible to interested students. For those of you interested in motion planning, I would recommend buying this book (on Amazon for example) as a reference. Fortunately, all of the relevant portions of the book arne available freely on line at: *http://msl.cs.uiuc.edu/planning/*.

2. The following *recommended* text covers some of the same material as the LaValle book, but is strong on sensor-based motion planning algorithms, which is the subject of the second half of the course:

- **Principles of Robot Motion: Theory, Algorithms, and Implementations** (by *Howie Choset, Kevin Lynch, Seth Hutchinson, George Kantor, Wolfram Burgard, Lydia Kavraki, and Sebastian Thrun*).

This text is also available at Amazon (in both new and used versions).

3. The following *recommended* text will be used for a significant portion of ME 131:

- **Probabilistic Robotics** (by *Sebastian Thrun, Wolfram Burgard, and Dieter Fox Lynch*). MIT Press, 2005.

4. Interested students may also wish to consult the following classic (but now somewhat dated) text on robotic motion planning:

- **Robot Motion Planning** by *J.C. Latombe.*

This is a classic book on robot motion planning, but it is now out of print. It contains good descriptions of some of the foundational motion planning results. A copy is available in the Caltech library, and I have a personal copy that I can loan out for short periods.