Project
Planning and Decision Making

Due date: Monday, 16^{th} **January 2023**, before the end of the day, submit report and code via Brightspace

Course: RO4705 Planning and Decision Making, TU Delft
Contact (setup/report): Siyuan Wu, email: s.wu-14@student.tudelft.nl
Contact (setup/methods): Max Spahn, email: m.spahn@tudelft.nl

Alternative contacts for specific projects:
Contact (MAVs): Alvaro Serra , email: A.SerraGomez@tudelft.nl
Contact (cars): Oscar de Groot , email: O.M.deGroot@tudelft.nl
Contact (mobile manipulators): Max Spahn , email: m.spahn@tudelft.nl
Contact (algorithms): Javier Alonso-Mora, email: j.alonsomora@tudelft.nl

PLEASE READ THE WHOLE DOCUMENT CAREFULLY AS IT CONTAINS IMPORTANT INFORMATION!

1 Introduction

In this course you will learn several methods for motion planning and you will be able to answer questions such as:

- How does an autonomous car safely navigate in a dynamic environment?
- How does a micro air vehicle find its way in a building?
- How does a mobile manipulator coordinate its degrees of freedom to manipulate objects?

In this project you will choose a robotic application of your interest. Then, you will describe the kinematics of the robot, implement a path/motion planner, and apply it to solve a navigation task. By doing this, you will solve a challenging problem and practice at least one of the methods learned in this course.
In the last week of the course you will present your work to the class and learn from the experience of other groups.

2 Learning objectives

The goal of the project is to understand the kinematics of a simple robotic model, implement a motion planning algorithm in a simulation environment and validate its performance. By doing so, you will implement a full (simpflified) motion planning pipeline for a robot of your choice.
Within the scope of your project, the learning objectives are:

- Identify the robotic system and the associated mathematical model for its kinematics, dynamics and motion equation.
- Identify the workspace and configuration space in which the robot operates.
- Describe the chosen algorithm for motion planning and control of the mobile robot. You will also justify your choice.
- Design, implement and evaluate the chosen motion planner to solve a motion-planning task and navigate a mobile robot.
- Describe the latest developments in planning and decision-making for mobile robots. This includes the comparison between different methods.

3 Instructions

The project consists of several deliverables and deadlines described in the following.
The project is to be performed in groups of four students, with a single submission per group. Your group must be registered in Brightspace by **the end of the first week**. Register with your group in the next available group slot. If you do not have a group, please register on the last available group slot. Groups with only 1, 2 or 3 students will be split or merged after the registration period with other semi-full groups. Only groups of 4 students are allowed.
The project is compulsory. If you are not registered by the deadline, you are assumed not to follow the course.
Submit by Brightspace in the designated area.

4 Topic

For the project you must select **one motion planner** and **one robot morphology** from the list below. You may propose a different topic (related to the course) to be discussed with the lecturer. The topic must be chosen by the end of the **second** week and specified in the preliminary submission for feedback. The robot morphology or the motion planner can be changed afterwards upon agreement with the lecturer.

- Robot morphology: Choose **one** robot morphology from: car, quadrotor or mobile manipulator and pick the corresponding simulation environment
- Motion planner: Choose **one** category of motion planner approach from: motion primitives (e.g., lattice), sampling-based motion planning (e.g., RRT) or model predictive control.
- Environment: Define an environment, which may contain static and/or moving obstacles. The environment should be defined in the simulation environment and we recommend you to start simple (e.g., a couple static obstacles) and increase complexity if time allows. Your planner must compute collision-free paths or trajectories to be followed by the robot. You may employ an existing controller (e.g. controllers that your implemented in Robot Dynamic Control course) for the robot to follow those paths or trajectories, or assume that It can perfectly follow them.

We recommend using one of the following simulation environments:

- gym_envs_urdf: Pybullet through open-ai-gym wrapper for mobile robots, robotic arms, simple drones and mobile manipulators. You can also add a custom robot based on the urdf-file.
- gym-pybullet-drones: Pybullet through open-ai-gym wrapper for more complex drone simulation.

Feel free to use any other visualization or simulation for your project.

For the planning algorithm, you can choose between two options:

1. Implement a planning algorithm from scratch yourself. You can use simulation we provide above or other existing simulations. In that case, motivate your choice and elaborate on the theoretical properties of the algorithm at hand.
2. Build upon existing software libraries for motion planning, see links at the end of this description. In that case, state clearly which library you have used and motivate your choice. If you choose this option, you are expected to implement substantial modifications or adaptations on top of the existing library.

5 Clarification on reusing existing code

It is perfectly fine and expected to rely on solvers and toolboxes (if/when needed). It is **not ok** to reuse code from another team, or groups from other years, or anything similar. For usage of open source code available online (allowed) you should use your own judgment and discuss with the lecturer when in doubt. As such, we ask groups to a) be transparent in the report, b) understand the code that you use and c) if you build upon an existing planning framework, we expect a more complete motion planning pipeline addressing a more complex scenario than if you write your own planner. Specifically, projects that build upon an existing planning framework should be tested in more complicated environments or with an advanced robot morphology.

6 Deliverables

Three deliverables are required at the end of the project, **a report, a presentation and the source files**. The weight of each part is given as percentage of the total. A group grade will be computed, which can be adjusted with an individual performance index if desired by the members of the team. A peer review form will be provided at the end of the course.

6.1 Report

Employ the provided template in Brightspace!
(80%) The report shall have a maximum of five pages in IEEE conference format (A4, 11pt), including figures. References do not count towards the page limit. The first page must include the title of the project and the student names and netIDs.
Your report shall consist of the following parts:

1. (10%) Introduction: brief description of the project and brief comparison to state of the art (with references to publications used in the project or relevant to the project). Brief description of the task to be achieved by the robot. Recommended length: 1/2 page.
2. (15%) Robot model: Description and equations (with brief derivation) of the robot kinematic/dynamic model and the equations of motion (10%). Describe the workspace and configuration space (5%). Recommended length: 1/2-1 page.
3. (15%) Motion planning: Description and algorithm for the chosen motion planner, with the required adjustments for the project. Recommended length: 1/2-1 page.
4. (20%) Results: Description of the simulation setup. Description of results, including figures and plots. Note: You may use the same figures and results for the presentation. You may include a link to a video showing the performance of the system. Recommended length: 1 page.

5. (20%) Discussion: Both theoretical (e.g., is the method optimal? complete? what is the complexity?) and practical (e.g., did it perform well, would another planner have performed better? what are the limitations of the method?). Your discussion must be supported by the results (15%). Recommendations for extensions with how the planners could be improved (5%). Recommended length: 1/2-1 page.

6. Bibliography: References used in the project or in the comparison to state of the art. Recommended length: 1/4-1/2 page.

Note: Up to 10% additional bonus will be given to innovative/challenging projects and to groups that implement their own algorithms, up to a maximum grade of 100%.

6.2 Presentation

See the provided template in Brightspace!
(20%) A three minutes presentation, with the following format (template):

1. Title slide, group number + title + members
2. (5%) One slide with project brief description of robot and planner
3. (10%) One slide: video with simulation results
4. (5%) One slide: discussion

6.3 Source files

(10% bonus) You must submit in Brightspace a folder with all the source code developed in the project (model, controller, planner, simulation) and necessary instructions (readme file) so that we can run it if needed. We will test the program on our system and verify if the results reported can be reproduced. If it runs out of the box, you will get bonus points.

6.4 Group peer review

By default, all group members get the same grade. At the end of the course, you may evaluate your own work and that of your group members. For each of you, the evaluations by all team members will be combined in an individual performance factor [IPF] with range 0.8-1.2. The average IPF of all the students in a group will be 1.0. If the variations between students in a group are small, then all students in the group will get an IPF of 1.0. A google form may be shared after completion of the project.

7 Deadlines

The following deadlines are observed (for exact dates refer to the course syllabus in Brightspace).

- **END OF COURSE WEEK ONE**: Register groups (or indicate participation in project).
- **TUESDAY, COURSE WEEK TWO**: Groups will be assigned to participants without a group.
- **END OF COURSE WEEK TWO**: Register topic of the project in Brightspace.
- **END OF WEDNESDAY, COURSE WEEK THREE**: Submit 1-2 page report with the robot model, equations of motion and your plans with respect to the motion planner and environment to be used. [NOT GRADED, feedback only]

- **COURSE WEEK FOUR**: Feedback will be provided on the submitted reports.
- **MONDAY. LAST COURSE WEEK**: report is due.
- **LAST WEEK OF THE COURSE**: presentations.

8 Grading

Grading of the report and the presentation will follow a standard grading rubric (available in Brightspace). The weight of each part is specified in the Deliverables section. This will lead to a group grade [GP]. The individual grade will then be given by [GP]$\times$[IPF] and converted to a 0-10 scale with a maximum of 10.

9 Tips

To record the video you may use screen capture in your computer.

10 Links to some software packages available online

- Robotics Toolbox: `http://petercorke.com/wordpress/toolboxes/robotics-toolbox`
- Python Robotics: `https://github.com/AtsushiSakai/PythonRobotics`
- OMPL: `http://ompl.kavrakilab.org/`
- MPC solver Acado: `http://acado.github.io/`
- MPC solver Forces PRO (trial license): `https://www.embotech.com/forces-pro/`
- Optimal control solver Casadi: `https://web.casadi.org/`
- MAV simulator in ROS: `https://github.com/ethz-asl/rotors_simulator`
- Do-MPC `https://www.do-mpc.com/en/latest/`
- Control Toolbox `https://ethz-adrl.github.io/ct/ct_doc/doc/html/index.html`