Robotics I

Mini-Project 1: Planar Mobile Robot Motion

Assigned: August 30, 2021
Due: September 14, 2021

Check back here regularly for the latest update
Submit your project report to `Gradescope` and your code through your private GitHub repository. Discussion with your peers is encouraged (particularly on WebEx Team and Piazza), but you must hand in your own work and be able to explain what you have done in the project. **Verbatim copying (whether you copy from someone or let someone copy your work) of derivation, writing, software code, etc., is considered cheating and will result in zero for the project grade and notification to the Class Dean and Dean of Students. Multiple instances of cheating will result in failing of the course.**
This course will use the MATLAB Robotics Toolbox. You are welcome to use other simulation platforms such as ROS/Gazebo, MATLAB ROS Toolbox, Webot, Unity, and others.

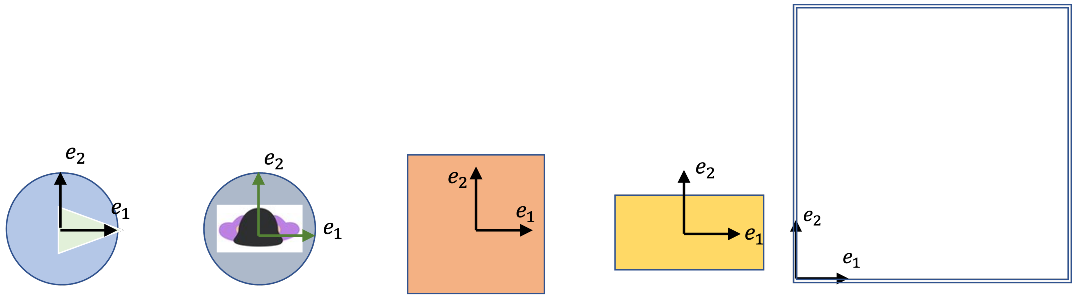
Things to Do

- Complete course survey https://forms.gle/sKHQ2uhzj1P8ntTX9.
- Set up your own GitHub and first repository Project 1. Make it private and share it with the Instructor and the TA – See link. The TA Burak Aksoy will also have a tutorial session on setting up GitHub.
- Use the course WebEx Team Space (under Mini-Project 1) or course Piazza page to pose/answer questions.
- Check out RPI Robotics GitHub and the following repositories: General Robotics Toolbox (MATLAB) and General Robotics Toolbox (Python)

Task Description

1. Consider a 5 m×5 m room with the following items with the body frames shown:
    1. A mobile robot base shaped like a circle with radius 0.3 m. The triangle indicates the heading direction (i.e., in the body $\vec{e}_1$ axis).
    2. A person, represented as a circle with radius 0.2 m.
    3. A square table with 0.5 m length of each side.
    4. A rectangle-shaped shelf with dimension 0.3 m×0.8 m

Denote the origin of body i by $\mathcal{O}_i$ and the orthonormal frame of body i by $\mathcal{E}_i$. Denote the room frame by $(\mathcal{E}_0, \mathcal{O}_0)$.



The objects are located based on the following information:

(a) The room frame with respect to the robot frame ($\mathcal{E}_0$ represented in $\mathcal{E}_1$, and $\mathcal{O}_0$ from $\mathcal{O}_1$ represented in $\mathcal{E}_1$) is

$$R_{10} = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}, \; [p_{10}]_1 = \begin{bmatrix} -0.5 \\ 4 \end{bmatrix} \quad [p_{01}]_0$$

$$[p_{01}]_1 = \begin{bmatrix} 0.5 \\ -4 \end{bmatrix}$$

(b) The person is facing up (north) and the robot is at the distance vector $\begin{bmatrix} 3 \\ 0 \end{bmatrix}$ away in the person frame.

(c) The table is at center of the room with its first coordinate axis $\vec{e}_1$ pointing in the northeast direction.

(d) The shelf is facing east (i.e., $\vec{e}_2$ is pointing to the right) and is located 3.5 m to the north of the person.

Indicate the coordinate frames (origins and orthonormal frames) of the room and all objects in a diagram (MATLAB generated or hand drawn) and find the poses (i.e., orientation and position) of all objects in the room frame, (R_{0i}, p_{0i}).

2. Find the following target poses of the robot in the room frame:

   (a) The robot faces the front of the shelf (where the arrow of $\vec{e}_2$ for the shelf is) and the edge of the robot is 0.1 m away from the edge of the shelf. Denote this pose by (θ_a^*, p_a^*)

   (b) The robot faces the front of the person (where the arrow $\vec{e}_2$ for the person is) and the edge of the robot is 0.1 m away from the cylinder enclosing the person. Denote this pose by (θ_b^*, p_b^*)

3. Suppose the robot is omnidirectional, i.e., it can rotate and translate in x-y directions. The differential kinematics of such robot may be modeled as

$$\begin{aligned} \dot{p}_{01} &= \begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \\ \dot{\theta} &= w \end{aligned} \tag{1}$$

where p_{01} is $\vec{p}_{01}$ in $\mathcal{E}_0$.

(a) (Extra) Explain how omni-directional vehicles work.

(b) Find a path consisting of the least number of straight line segments for the robot to go to (θ_a^*, p_a^*) and then to (θ_b^*, p_b^*) without collision. The path should be parameterized by the path length, λ.

(c) Suppose $|u_i| \leq 2$ m/s and $|w| \leq 1$ rad/s. Generate the trajectory (i.e., the path indexed with time, i.e., $\lambda(t)$). Adjust the path so that the robot can complete the path in the minimum amount of time.

(d) (Grad section): Suppose the robot the following acceleration constraint $|\dot{u}_i| \leq 0.2$ m/s^2 and $|\dot{w}| \leq 0.1$ rad/s^2. Generate the trajectory to traverse the (final) path in part 3c in the minimum amount of time. Adjust the path to reduce the total amount of path traversal time.

4. Now consider a nonholonomic wheeled mobile robot (like a Roomba) that can translate in the heading direction and rotate. The differential kinematics is given by

$$\begin{aligned} \dot{p}_{01} &= \begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} = \begin{bmatrix} \cos\theta \\ \sin\theta \end{bmatrix} u \\ \dot{\theta} &= w \end{aligned} \tag{2}$$

(a) Explain how the kinematics follows from the the wheel no-slip condition.

(b) Find (u, w) to follow the (final) path in part 3c. Does your motion take longer?

(c) (Grad section): Suppose (x, y, θ) are measured at every time. Find a *feedback* strategy, i.e., (u, w) in terms of (x, y, θ) and the trajectory from part 3c so that the robot can visit target poses a and b by using the trajectory in part 3d as a reference. Compare the travel time with the result from part 4b. Explain the difference.

Note that a path means the geometric description of a curve and a trajectory means a path indexed with time (how fast you travel along the path).

Deliverable

1. Your project report should be structured as follows:

(a) Cover page with your name, course number, date, project title, and a statement on academic integrity (stating that you did this project by yourself).

(b) Summary: what did you try to do and accomplished.

(c) Technical Content: containing the following for each section:

i. Description of the problem

ii. Derivation of the solution

iii. Results based on your simulation

The key is to **show that you understand what you are doing**, not just tweaking the code.

(d) Conclusion: what you learned and what can be improved.

2. Put your code in your private GitHub repository (shared with the Instructor and TA).
3. If you have any video of your results, provide a link (e.g., YouTube).