Robotic Systems Engineering
Coursework 2: Jacobian, Inverse Kinematics and Path Planning

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To get full credit for an answer, you are *required* to provide a full working solution. For some questions, you will be asked to write code; for these you are expected to include a *full print out* of any requested results or graphs in the report, as well as a simple breakdown of the algorithms used in the coding solution. Furthermore, you will be required to *upload* your code to Moodle along with your submitted coursework manuscript in .zip extension. The necessary packages are available on https://github.com/surgical-vision/comp0127_lab

Jacobian and Inverse Kinematics

1. How many inverse kinematic solutions exist for a 2D 4R-planar manipulator, if an achievable pose of the end-effector x_e is given? Give a full explanation to support your answer. [5 marks]

2. Suppose that the robot is moving in a free space (i.e. there is no obstacle) and that more than one inverse kinematic solution exist for a desired pose of the end-effector x_e, what criteria should you consider when choosing an optimal solution? [5 marks]

3. When is the output of the function atan2(x, y) different from atan$(\frac{x}{y})$? [5 marks]

4. The complete standard DH parameters of the YouBot are given in Table 1. Complete the questions by filling in the code in the package "cw2/cw2q4". A simple code breakdown in the report is required for all subquestions, except subquestion b which is report only.

   a. Write a script to compute a Jacobian matrix for the YouBot manipulator. [2 (report) + 8 (code) marks]

   b. Derive the closed-form inverse kinematics solutions for the YouBot manipulator. You can represent any non-zero length parameters as variables. [10 marks]

   c. Write a script to compute the iterative inverse kinematic solution. [2 (report) + 8 (code) marks]

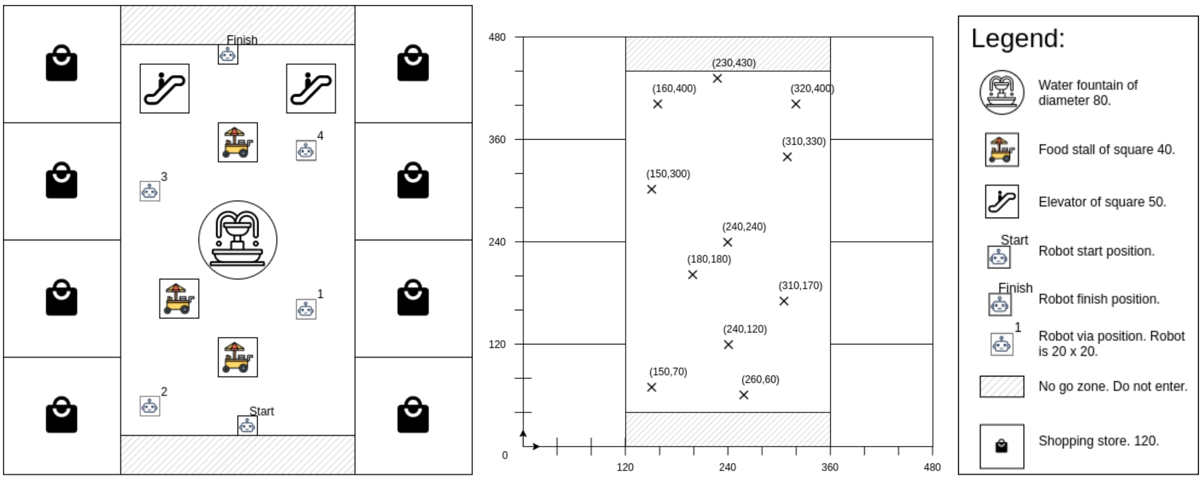
   d. Write a script to detect singularity in any input pose. [2 (report) + 3 (code) marks]

Table 1: DH parameters for YouBot manipulator

i	a_i	α_i	d_i	θ_i
1	-0.033	$\frac{\pi}{2}$	0.145	$\theta_1 + \pi$
2	0.155	0	0	$\theta_2 + \frac{\pi}{2}$
3	0.135	0	0	θ_3
4	-0.002	$\frac{\pi}{2}$	0	$\theta_4 - \frac{\pi}{2}$
5	0	π	-0.185	$\theta_5 + \pi$

Path and Trajectory Planning

5. Assume the following scenario: A shopping mall is testing autonomous cleaning robots to clean floors of a section of the mall. They have given you the following floor map defining no go zones, cleaning via points and obstacles. Cleaning will occur at night, so no dynamic obstacles will be present. Consider only passing through via points not total floor coverage. They also allow external cameras and tracking, so perfect odometry can be assumed. Present a robotic solution by choosing a drive system to complete the task, addressing path planning and trajectory planning. You can assume the configuration of your chosen robot is $q = (x, y, \theta)$. When designing the drive system, consider that the vacuum is located at the back of the robot so during turns and rotations, the vacuum may miss water pickup. Your solution should address the following specifically. (Recommended answer is up to 50 words per sub-question and the word count for the entire question should not exceed 300 words.)



(a) Map (b) Coordinates (c) Legend

Figure 1: Map, coordinates and legend of shopping mall cleaning area.

a. Present your drive system configuration. Is it holonomic or non-holonomic and why? What is the configuration space? [5 marks]

b. Describe how you would find a path that goes from the starting point to the final point while passing through all the via points in order. How would planning change if the ordering did not matter? [4 marks]

c. Describe a time scaling function you would use when constructing a trajectory. Consider initial and final accelerations. [2 marks]

d. The robot is designed with a water vacuum at the back of the robot, meaning during turns and rotations, the vacuum may miss water pick-up. What ways can you design your path or trajectory to prevent left-over water? [2 marks]

e. Describe a path planning approach for full floor coverage while avoiding obstacles. [2 marks]

6. Create a ROS node to perform trajectory planning from the checkpoint data. For subquestion b, you will have to work with obstacles in the scene whose positions and physical dimensions can be obtained from the gazebo simulator. These properties can be hard-coded into your scripts. There is no time constraint on subquestions a and b. You can input any value in "time_from_start" as appropriate. A simple code breakdown in the report is required for all subquestions.

   a. Use the data "data1.bag" in the package "cw2/cw2q6" to perform trajectory planning and achieve the shortest path (measured by the distance travelling by the end-effector). For this subquestion, you are allowed to shuffle the checkpoint to get the shortest path. [6 (report) + 9 (code) marks]

      - The five shortest paths among the submissions will get 5 extra marks. These marks will be added to your coursework mark if the full score has not already been achieved. The maximum score cannot be exceeded in such manner.

   b. Use the data "data2.bag" in the package "cw2/cw2q6" to perform trajectory planning. The report should explain how you avoid obstacles in your path planning algorithm. [8 (report) + 12 (code) marks]

END OF COURSEWORK