16350 HW2: Implementation of PRM, RRT-Connect, & RRT for N-DoF Manipulator Planning

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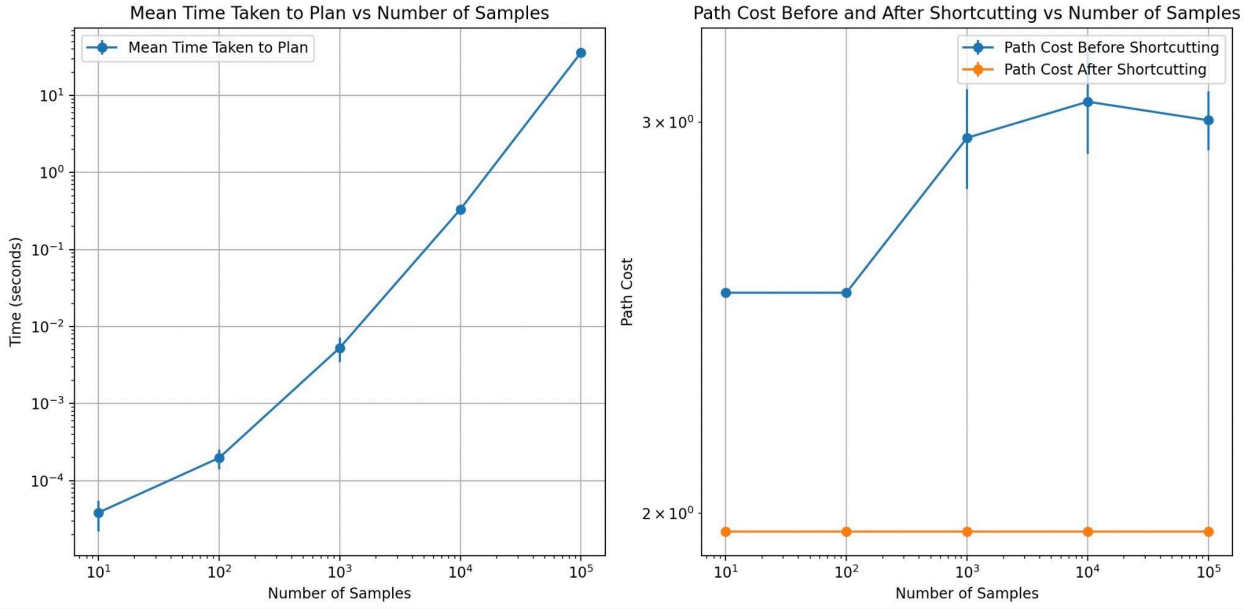
Definitions

Path costs were measured using the euclidean vector distances between each subsequent state in the path. The planning time is measured from the time the planner is called to the time it terminates, which doesn't include shortcutting.

PRM

Summary of Approach

The PRM planner constructs a roadmap with 500 random samples of the configuration space. The planner is randomly seeded to produce a different random sample set of the configuration space on each run. For each sample in the configuration space, the planner will attempt to connect it with up to 10 closest neighbors. Once the roadmap is constructed, the planner runs Dijkstra's to produce a path. The number of samples had the greatest impact on the time to generate a plan and the sub-optimality of the generated plan, but the planner was observed to reliably return solutions with 500 samples. To circumvent the possibility of not finding a valid plan with 500 samples, the planner is configured to continue sampling and constructing the roadmap until a valid solution is found.



It was found that the quality of the solution decreased as the number of samples was increased, but was improved with shortcutting. Yet, it was found that the generated solution after shortcutting did not greatly differ in quality as the number of samples was increased.

Experiments

Note - the quantity of vertices generated is determined by not the number of samples generated, which is 500, but rather the quantity that were included in the final roadmap.

Trial 1: 3 DoF, Start: <1.57, .78, 1.57> , Goal: <.392, 2.35, 3.14>
Planning Time: Mean - .00218 seconds, STD - .000345 seconds
Path Costs: Mean - 2.95, STD - .328
Vertices Generated: Mean - 67.5 vertices, STD - 2.5 vertices
Success Rate: 100%
Trial 2: 4 DoF, Start: <1.75, 2.5, 3.5, 4.5>, Goal: <.392, 2.35, 3.14, 0>
Planning Time: Mean - .0019 seconds, STD - 5.435e-5 seconds
Path Costs: Mean - 5.57, STD - .196
Vertices Generated: Mean - 42 vertices, STD - 2.75 vertices
Success Rate: 100%
Trial 3: 5 DoF: Start: <1.8, 2.5, 3.5, 4.5, 1.9>, Goal: <.392, 2.35, 3.14, 0, 3>
Planning Time: Mean - .00104 seconds, STD - 6.183e-5 seconds
Path Costs: Mean - 7.58, STD - 1.247
Vertices Generated: Mean - 32.75 vertices, STD - 1.5 vertices
Success Rate: 100%
Trial 4: 6 DoF: Start: <1.8, 2.5, 3.5, 4.5, 1.9, 4.9>, Goal: <.392, 2.35, 1.5, 0, 3, 0>
Planning Time: Mean - .000576 seconds, STD - 1.116e-4 seconds
Path Costs: Mean - 9.19, STD - 8.93e-5
Vertices Generated: Mean - 22 vertices, STD - 4.24 vertices
Success Rate: 100%
Trial 5: 1 DoF: Start: <1.57>, Goal: <.392>
Planning Time: Mean - .01963 seconds, STD - .00203 seconds
Path Costs: Mean - 1.178, STD - 0
Vertices Generated: Mean - 223.5 vertices, STD - 141.59 vertices
Success Rate: 100%

RRT-Connect

Summary of Approach

Two trees are initialized at the start and goal configurations, each represented as configuration vectors. A maximum number of iterations is defined, and the trees are extended to a randomly sampled configuration, checking for mutual connection on each iteration. If a connection is present, the path is generated by simply concatenating the path to the bridging configuration from the start state with the reverse of the path from the goal state to the bridging configuration. The same shortcutting mechanism is

used as with PRM to post-process the solution. The only parameter defined is the maximum number of iterations, which was arbitrarily determined.

Experiments

Trial 1: 3 DoF, Start: <1.57, .78, 1.57> , Goal: <.392, 2.35, 3.14>
Planning Time: Mean - 5.166e-6 seconds, STD - 5.54e-7 seconds
Path Costs: Mean - 2.51346, STD - 0
Vertices Generated: Mean - 3, STD - 0
Success Rate: 100%
Trial 2: 4 DoF, Start: <1.75, 2.5, 3.5, 4.5>, Goal: <.392, 2.35, 3.14, 0>
Planning Time: Mean - 6.64e-6 seconds, STD - 1.78e-6 seconds
Path Costs: Mean - 4.71, STD - 0
Vertices Generated: Mean - 3 vertices, STD - 0 vertices
Success Rate: 100%
Trial 3: 5 DoF: Start: <1.8, 2.5, 3.5, 4.5, 1.9>, Goal: <.392, 2.35, 3.14, 0, 3>
Planning Time: Mean - 6.75e-6 seconds, STD - 1.196e-6 seconds
Path Costs: Mean - 4.85742, STD - 0
Vertices Generated: Mean - 3 vertices, STD - 0 vertices
Success Rate: 100%
Trial 4: 6 DoF: Start: <1.8, 2.5, 3.5, 4.5, 1.9, 4.9>, Goal: <.392, 2.35, 1.5, 0, 3, 0>
Planning Time: Mean - 8.58e-6 seconds, STD - 7.75e-8 seconds
Path Costs: Mean - 7.17461, STD - 0
Vertices Generated: Mean - 3 vertices, STD - 0 vertices
Success Rate: 100%
Trial 5: 1 DoF: Start: <1.57>, Goal: <.392>
Planning Time: Mean - 7.46e-6 seconds, STD - 8.66e-7 seconds
Path Costs: Mean - 1.178, STD - 0
Vertices Generated: Mean - 3 vertices, STD - 0 vertices
Success Rate: 100%

RRT

Summary of Approach

The planner initializes a tree with the starting configuration of the manipulator. The step size value to extend by was set to 10.0, which was experimentally determined to reliably yield quick results; smaller step sizes generated unreasonable paths without shortcutting. Additionally, a goal bias is defined. Without the goal bias, the planner was found to be unable to reliably generate solutions. With the goal bias, the planner samples the goal state with a defined frequency to encourage tree growth towards the goal state; this frequency was set at 100, which was found to reliably generate solutions. Thus, for every 100 samples that are collected, one will be the goal state and the rest will be random. The planner continues to grow the tree until the goal state is reached or the maximum number of iterations is reached.

Experiments

Trial 1: 3 DoF, Start: <1.57, .78, 1.57> , Goal: <.392, 2.35, 3.14>
Planning Time: Mean - 7.55e-6 seconds, STD - 7.9e-7 seconds
Path Costs: Mean - 2.51346, STD - 0
Vertices Generated: Mean - 2, STD - 0 vertices
Success Rate: 100%
Trial 2: 4 DoF, Start: <1.75, 2.5, 3.5, 4.5>, Goal: <.392, 2.35, 3.14, 0>
Planning Time: Mean - 6.47e-6 seconds, STD - 9.86e-7 seconds
Path Costs: Mean - 4.717, STD - 0
Vertices Generated: Mean - 2 vertices, STD - 0 vertices
Success Rate: 100%
Trial 3: 5 DoF: Start: <1.8, 2.5, 3.5, 4.5, 1.9>, Goal: <.392, 2.35, 3.14, 0, 3>
Planning Time: Mean - 5.98e-6 seconds, STD - 1.82e-6 seconds
Path Costs: Mean - 4.857, STD - 0
Vertices Generated: Mean - 2 vertices, STD - 0 vertices
Success Rate: 100%
Trial 4: 6 DoF: Start: <1.8, 2.5, 3.5, 4.5, 1.9, 4.9>, Goal: <.392, 2.35, 1.5, 0, 3, 0>
Planning Time: Mean - 8.58e-6 seconds, STD - 7.57e-8 seconds
Path Costs: Mean - 7.17461, STD - 0
Vertices Generated: Mean - 2 vertices, STD - 0 vertices
Success Rate: 100%
Trial 5: 1 DoF: Start: <1.57>, Goal: <.392>
Planning Time: Mean - 5.38-6 seconds, STD - 5.1e-7 seconds
Path Costs: Mean - 1.178, STD - 0
Vertices Generated: Mean - 2 vertices, STD - 0 vertices
Success Rate: 100%

Conclusions

RRT-Connect is likely best suited for this planning problem without shortcutting. Unlike RRT, it does not only extend by a predetermined step size towards a sampled configuration, which results in highly suboptimal and non-smooth paths being produced by RRT before shortcutting. PRM has a similar advantage of not requiring the step size parameter, but the number of expanded configurations was observed to be far greater than with RRT-Connect, resulting in significantly smaller planning times. Yet, RRT-Connect is still highly suboptimal. Even with shortcutting, the produced path is likely to be highly suboptimal since the quantity of explored configurations is likely to be lower than with PRM or RRT. If shortcutting is employed, and the time constraint on producing a path is loose, then RRT may be a superior choice to RRT-Connect because of the way it explores the configuration space uniformly, meaning that a lower step size may result in a graph with a finer and more constant discretization (than even PRM, for example) which will result in more optimal paths after smoothing.