Robot Navigation in Confined Spaces

- Devaiah Ulliyada Arun

Introduction

Introduction:

- Navigation in indoor structured environment includes traversing in open spaces, narrow confined static spaces or heavily crowded dynamic areas.

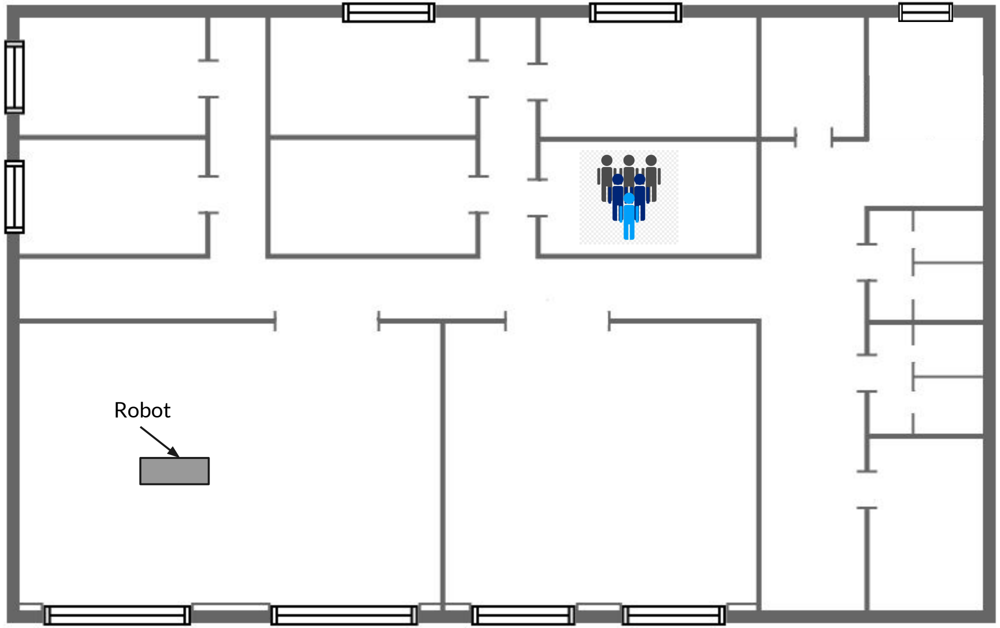

Figure 1: Indoor Structured Environment with areas with different spaces

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- Navigation in indoor structured environment includes traversing in open spaces, narrow confined static spaces or heavily crowded dynamic areas.

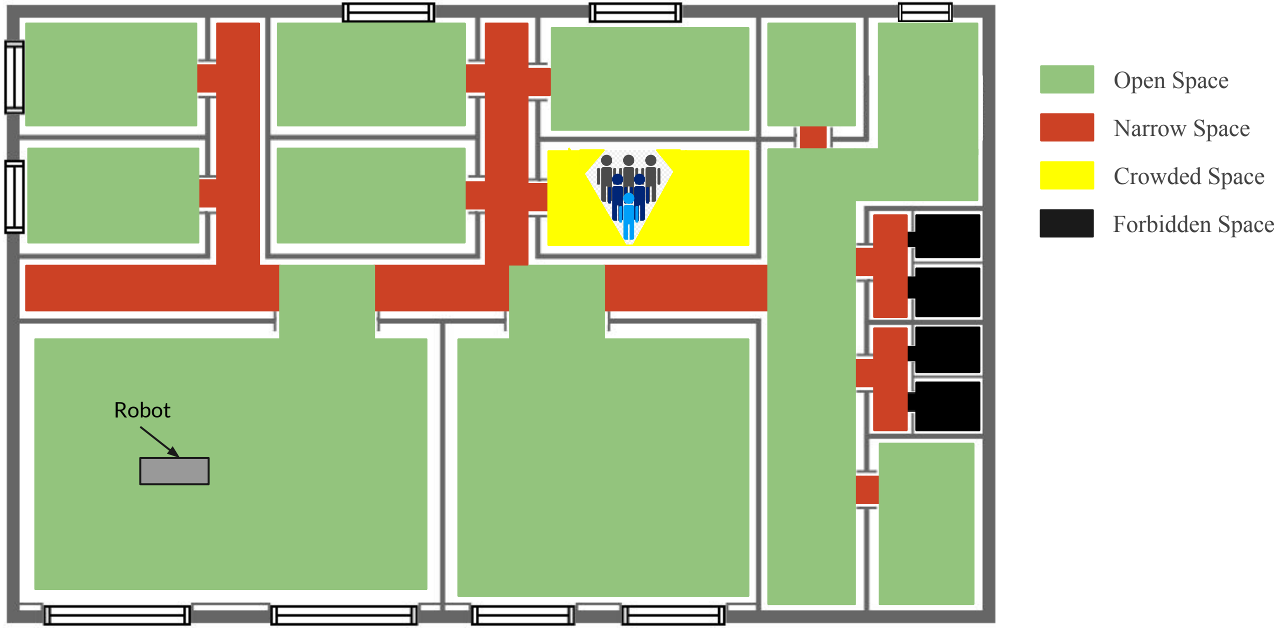


Figure 1: Indoor Structured Environment with areas with different spaces

Motivation:

- Traditional planners, usually built for long range open space navigation tend to inefficiently work in confined spaces or could fail to solve it.
    - Solutions available are either specific to certain scenarios or particular platforms or mainly forward motion navigation.

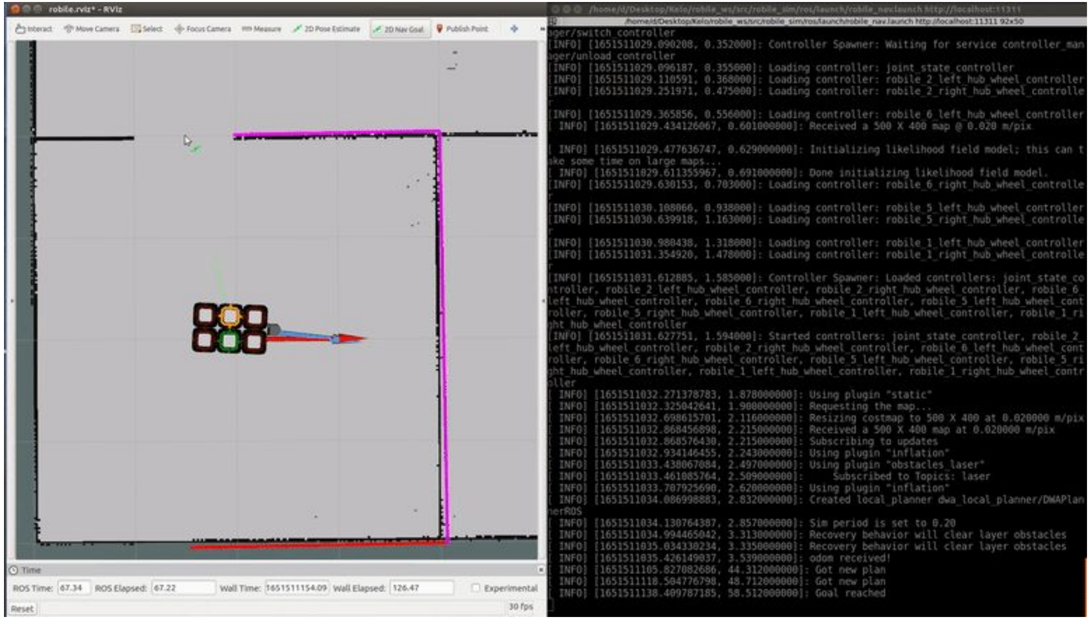


Figure 2: ROS navigation ‘move_base’ failing to maneuver through doorway

Introduction

Motivation:

- Another level of complexity would be added if the robot has size and shape constraints.
    - Irregular polygon shape (edges are unequal) of the robot allows it to exist only in certain poses in confined space.

(a) ROEQ (MiR500)

(b) iFollow (iL – 300)

(c) Kelo (Robile)

(d) Sick Bed (ROPOD)

Figure 3: Non square bulky robotic platform (a) 1304 x 864 x 95 (mm) (b) 1435 x 760 x 176 (mm) (c) 690 x 460 x 230 (mm)

Introduction

Motivation:

- Use cases for confined space planning (corridor, intersections, doorways and dynamic obstacle restricting spaces).

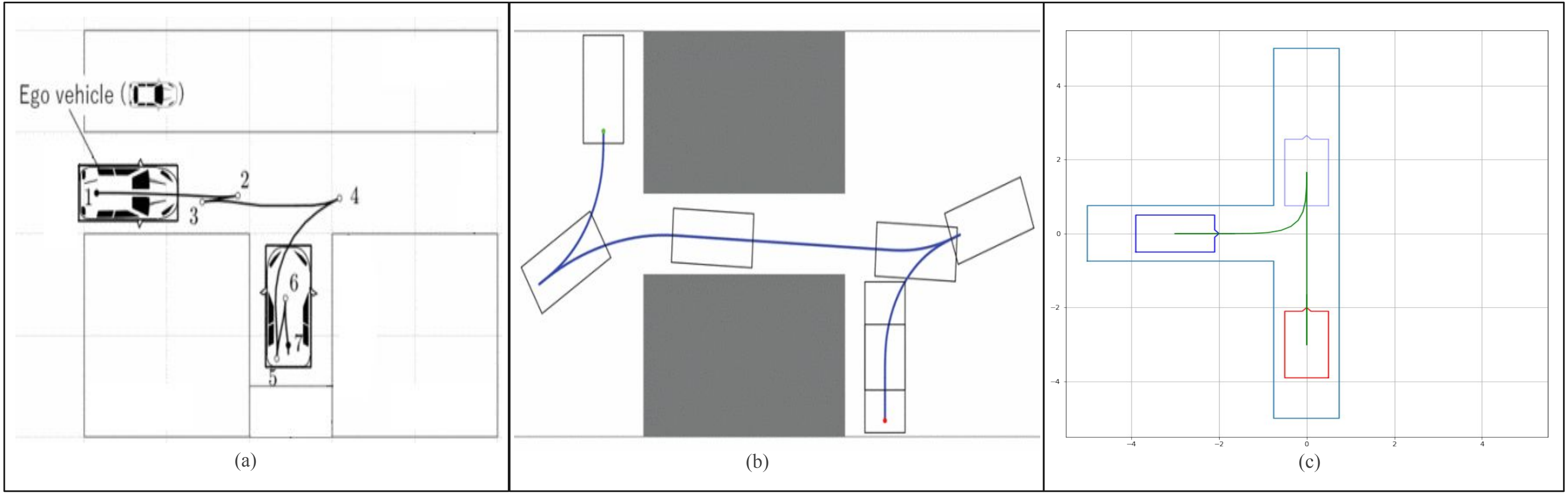


Figure 4: (a) Reverse parking (b) Maneuvering in narrow corridor (c) Maneuvering through intersection

Proposal Outline

Related Work:

- Related work organised:
  - Physics based approaches:
    - Near optimal planning for Piano Mover's Problem
    - Cylindrical Algebraic Decompositions (CAD)
  - Robot planning approaches:
    - Modified Rapid Random Trees (RRTs) for narrow space planning
    - Spline based planning
  - Automotive planning approaches:
    - Model predictive path planning
    - Hybrid A* with numerical optimizers
- Summarizing state-of-the-art planner and optimizer approaches

Problem Formulation:

- Listing drawbacks and finding gaps in current work
- Structuring the problem
  - Thesis objectives
  - Evaluation of state-of-the-art approached
  - Propose an idea for a novel geometric planner

Related Work

Related Work

Related work categorization:

- Physics Based Approaches:
    - Earlier works on planning in narrow spaces were classically formulated as the ‘Piano Mover's Problem’.
    - Assumes a single robot moving in a static, completely known environment without any dynamic constraint.
    - It guarantees to find a path if one exists at a given environment resolution and all the paths that it returns are safe.
    - Although a path is guaranteed, the complexity grows exponentially with the number of degrees of freedom of the robot. Also, the approaches become highly inefficient in dynamic environment.

Related Work

Near Optimal Planning for Piano Mover's Problem

- **Requirements**: *Occupancy map, robot's dimensions, motion primitives*
- Each cell carries certain set of information
- Exploring step involves **8-geometry maze router**
- Path obtained by **backtracking** with minimum cost

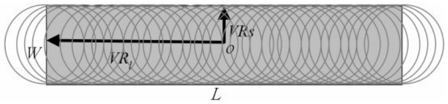


Figure 5: The rectangle model of a robot configuration.

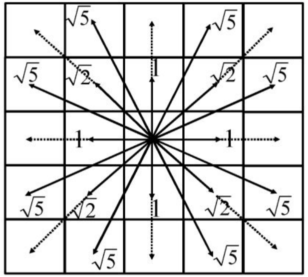


Figure 6: 8-geometry maze router.

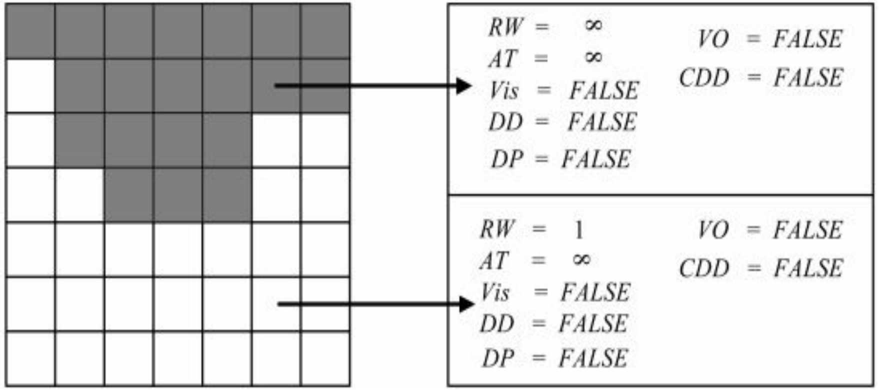


Figure 7: Cells data structures used for generating cost function.

1. Gene Eu Jan, Tong-Ying Juang, Jun-Da Huang, Chien-Min Su and Chih-Yung Cheng, "A fast path planning algorithm for piano mover's problem on raster," Proceedings, 2005 IEEE/ASME International Conference on Advanced Intelligent Mechatronics., 2005, pp. 522-527, doi: 10.1109/AIM.2005.1511035.

Related Work

Near Optimal Planning for Piano Mover's Problem

- **Requirements**: *Occupancy map, robot's dimensions, motion primitives*
- Each cell carries certain set of information
- Exploring step involves **8-geometry maze router**
- Path obtained by **backtracking** with minimum cost
- **Drawbacks**: *Complexity increases as the resolution or size of the environment or number of motion primitives increase. Not suitable for long range navigation.*

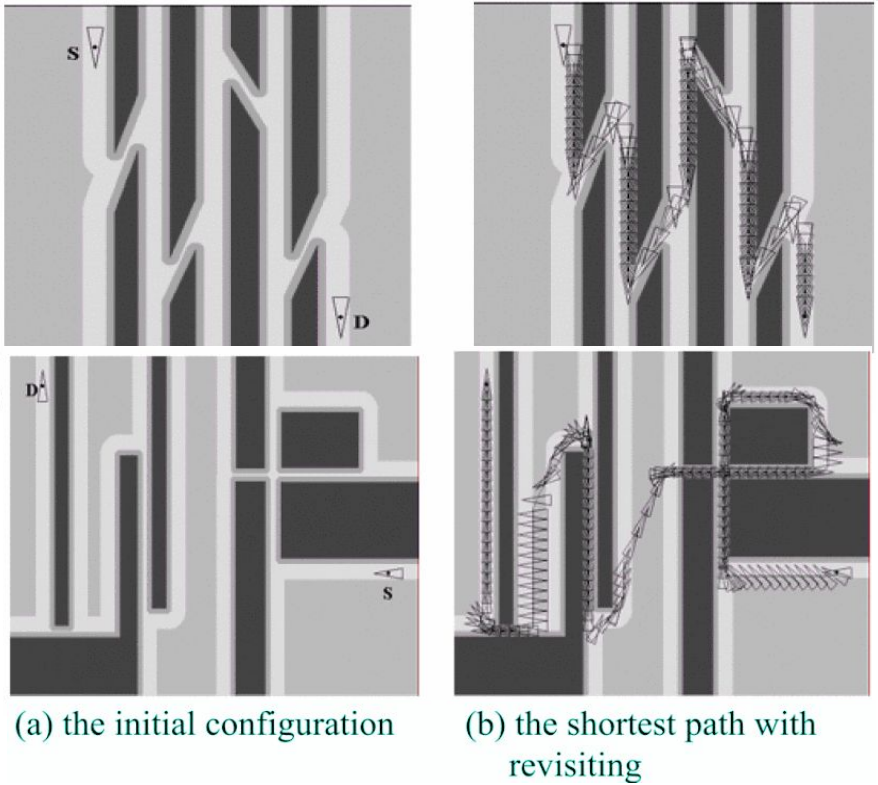


Figure 8: Illustration of the path planning of robot motion using rectangle model.

1. Gene Eu Jan, Tong-Ying Juang, Jun-Da Huang, Chien-Min Su and Chih-Yung Cheng, "A fast path planning algorithm for piano mover's problem on raster," Proceedings, 2005 IEEE/ASME International Conference on Advanced Intelligent Mechatronics., 2005, pp. 522-527, doi: 10.1109/AIM.2005.1511035.

Related Work

Cylindrical Algebraic Decompositions (CAD)

- **Requirements**: *Geometric map, robot's dimensions.*
- Moving ladder ([x, y], [w, z]) in **configuration space**
- Negation of logically expressed invalid regions taken
- **Quantifier Elimination by Partial CAD** (QEPCAD) used to construct cells described by semi-algebraic set of equations

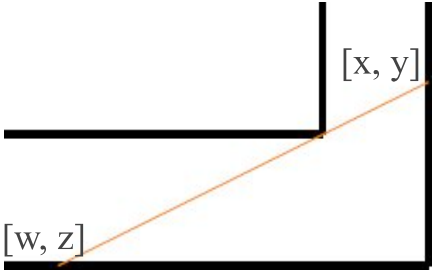
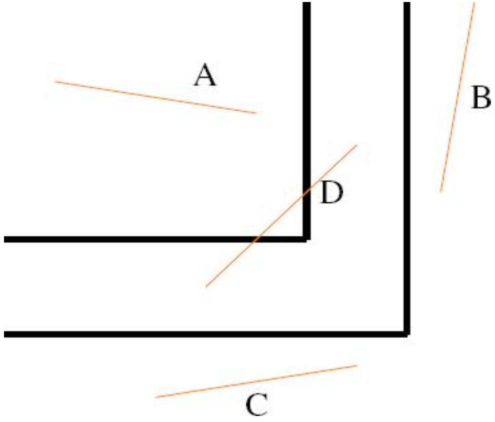


Figure 9: A configuration of a ladder in which the endpoints are in opposite branches of the corridor.



$$[x<-1\wedge y>1]\vee[w<-1\wedge z>1]\vee[x>0]$$
$$V[w>0]\vee[y<0]\vee[z<0]\vee(\exists t)[0<t\wedge t<1$$
$$\wedge x+t(w-x)<-1\wedge y+t(z-y)>1].$$

Figure 10: Four canonical invalid positions of the ladder and their expression.

2. D. Wilson, J. H. Davenport, M. England and R. Bradford, "A "Piano Movers" Problem Reformulated," 2013 15th International Symposium on Symbolic and Numeric Algorithms for Scientific Computing, 2013, pp. 53-60, doi: 10.1109/SYNASC.2013.14.

Related Work

Cylindrical Algebraic Decompositions (CAD)

- **Requirements**: *Geometric map, robot's dimensions.*
- Moving ladder ([x, y], [w, z]) in **configuration space**
- Negation of logically expressed invalid regions taken
- **Quantifier Elimination by Partial CAD** (QEPCAD) used to construct cells described by semi-algebraic set of equations
- **Drawbacks**: *Finding adjacency and connectedness of cells is not currently possible with any existing technology.*

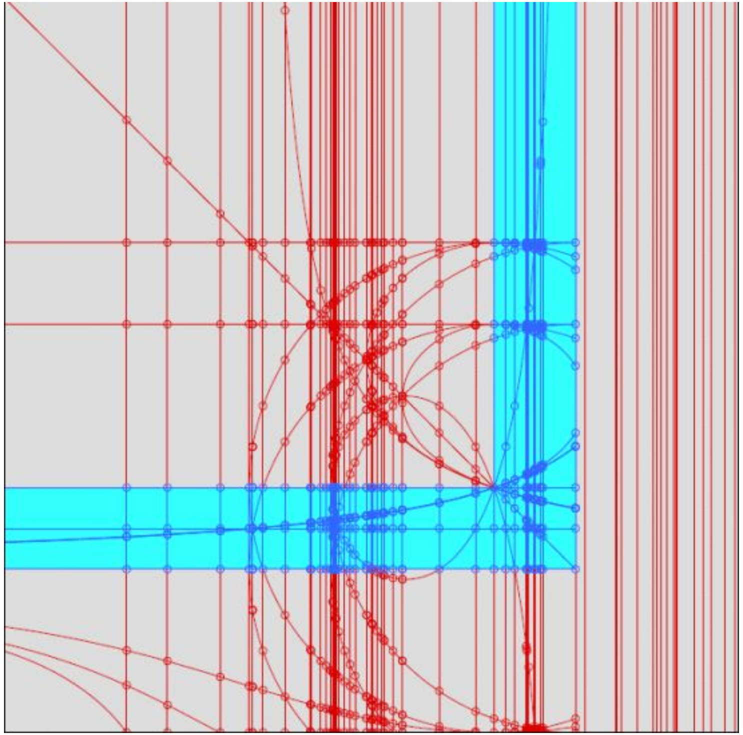


Figure 11: A two-dimensional CAD of just [x,y] point in configuration space.

2. D. Wilson, J. H. Davenport, M. England and R. Bradford, "A "Piano Movers" Problem Reformulated," 2013 15th International Symposium on Symbolic and Numeric Algorithms for Scientific Computing, 2013, pp. 53-60, doi: 10.1109/SYNASC.2013.14.

Related Work

Related work categorization:

- Robot Planning Approaches:
    - Indoor environment are represented using cell decomposition or applying potential field or setting heuristic rules.
    - Roadmap approaches such as Voronoi diagram, visibility graph, and some other topological retractions are popular.
    - Most papers use some robot dimensional information to represent the environment creating a configuration space.
    - General path planning uses potential field algorithm, sampling based algorithm or heuristic search algorithm.
    - To tackle collision constraints and dynamic environment, optimizers and local planners such as Dynamic Window Approach or Elastic Bands are implemented.

Related Work

Locally Guided Multiple Bi-RRT*

- **Requirements**: *Occupancy map*
- Sampling using **Bridge Test**
- **K-means++** used obtain Identification Points (IP)
- Bi-directional RRT* applied between IPs
- **Drawbacks**: *Although fast, this approach does not account for the orientation or dimensions of the robot important for maneuvering.*

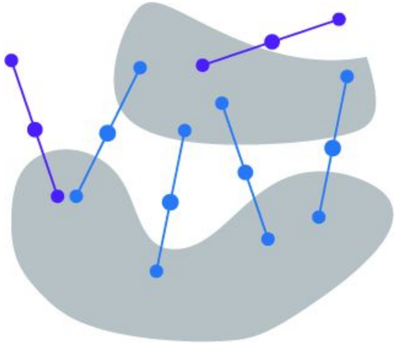


Figure 12: The color in blue indicates passing the test, otherwise don't passing.

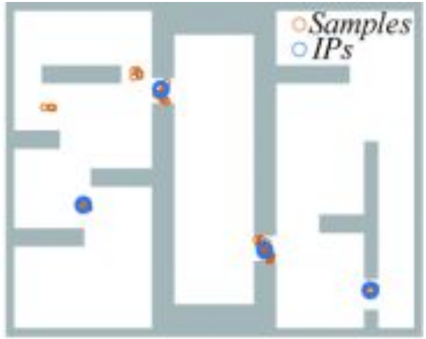


Figure 13: The improved bridge-test method with cluster analysis.

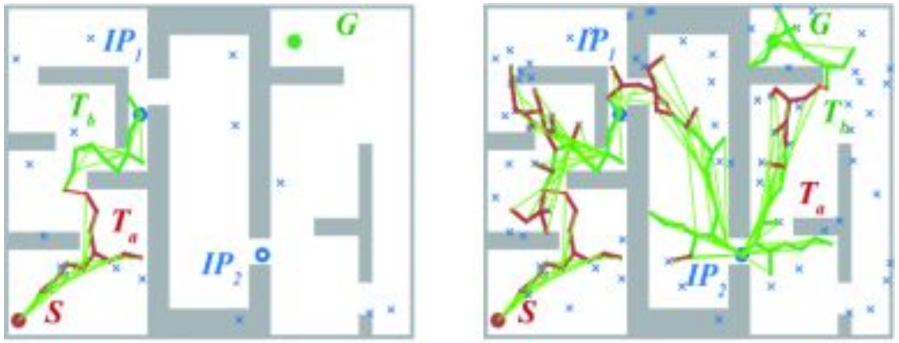


Figure 14: BRRT* applied between IPs and concatenated for a final path

3. X. Shu, F. Ni, Z. Zhou, Y. Liu, H. Liu and T. Zou, "Locally Guided Multiple Bi-RRT* for Fast Path Planning in Narrow Passages," 2019 IEEE International Conference on Robotics and Biomimetics (ROBIO), 2019, pp. 2085-2091, doi: 10.1109/ROBIO49542.2019.8961757.

Fast Bi-Directional Kinematic RRT

- **Requirements**: *Occupancy map*
- Prunes nodes that fail to expand
- Growing **Rapid Random Vines** along narrow passages
- **Drawbacks**: *Although fast, this approach does not account for the orientation or dimensions of the robot important for maneuvering.*

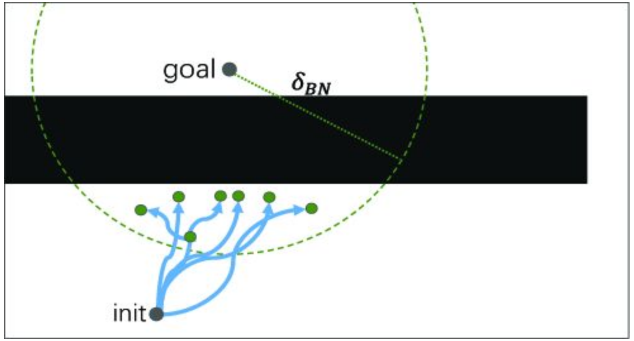


Figure 15: Nodes near obstacles failing to expand

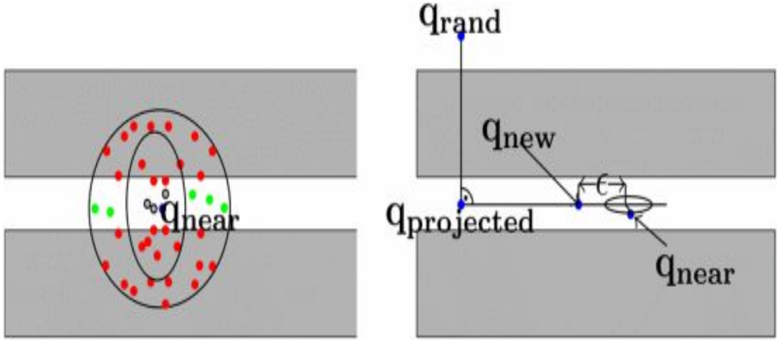


Figure 16: After PCA has been conducted, the vine grows along the passage

4. J. Peng, Y. Chen, Y. Duan, Y. Zhang, J. Ji and Y. Zhang, "Towards an Online RRT-based Path Planning Algorithm for Ackermann-steering Vehicles," 2021 IEEE International Conference on Robotics and Automation (ICRA), 2021, pp. 7407-7413, doi: 10.1109/ICRA48506.2021.9561207.

Related Work

Spline-Based Planning

- **Requirements**: *Potential field map, dynamic obstacles information*
- Initial straight line path expressed with equally spaces '**via points**'
- Via points pushed to a free space from potential field

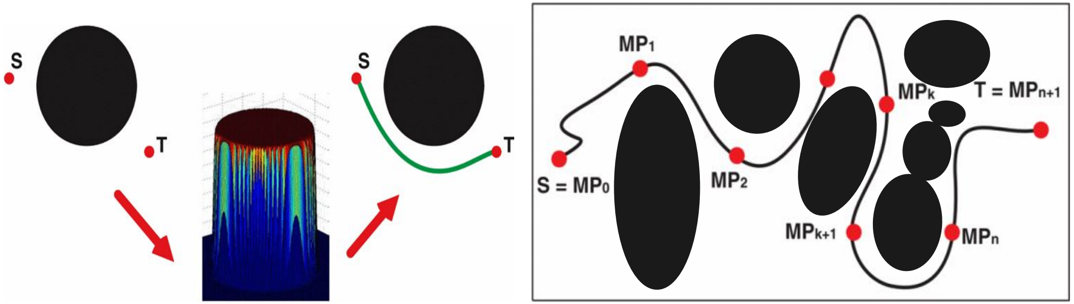


Figure 17: Generating spline by creating potential field.

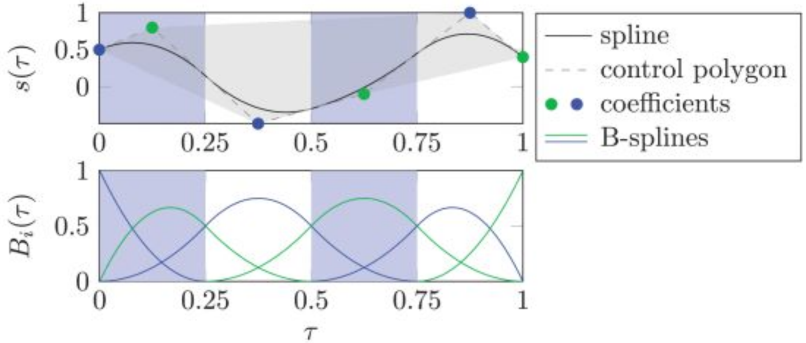


Figure 18: Optimizing spline globally.

5. T. Mercy, R. Van Parys and G. Pipeleers, "Spline-Based Motion Planning for Autonomous Guided Vehicles in a Dynamic Environment," in IEEE Transactions on Control Systems Technology, vol. 26, no. 6, pp. 2182-2189, Nov. 2018, doi: 10.1109/TCST.2017.2739706.

Related Work

Spline-Based Planning

- **Requirements**: *Potential field map, dynamic obstacles information*
- Initial straight line path expressed with equally spaces '**via points**'
- Via points pushed to a free space from potential field
- Splines updated continuously with linear prediction model for moving obstacles
- **Drawbacks**: *Dynamic obstacles velocity and positions are previously known. Splines considers forwards motion.*

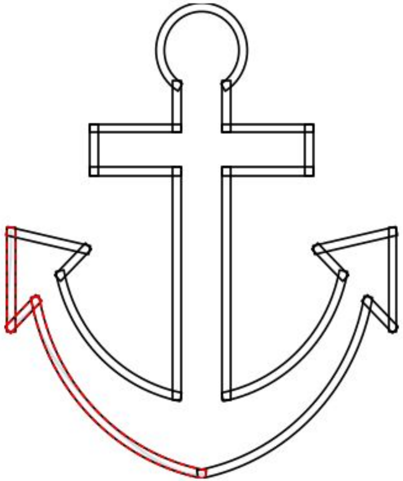


Figure 19: Spline planning in narrow spaces.

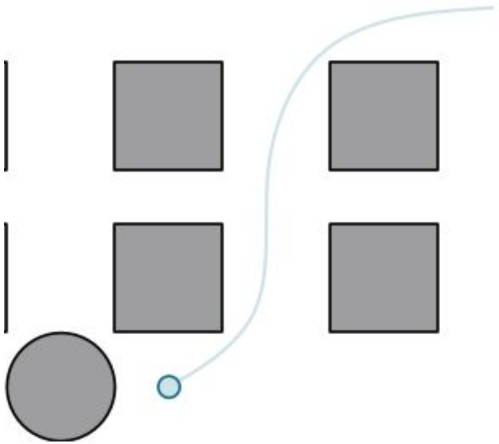


Figure 20: Spline planning with dynamic obstacles.

5. T. Mercy, R. Van Parys and G. Pipeleers, "Spline-Based Motion Planning for Autonomous Guided Vehicles in a Dynamic Environment," in IEEE Transactions on Control Systems Technology, vol. 26, no. 6, pp. 2182-2189, Nov. 2018, doi: 10.1109/TCST.2017.2739706.

Related Work

Related work categorization:

- Automotive Planning Approaches:
    - Specific scenarios are tackled for completely autonomous driving or driving assistance systems.
    - Reverse parking is known as one of the troublesome driving tasks. Furthermore, kinematic constraints of a car make parking in narrow spaces harder.
    - Although the planning is similar to robot planning, these approaches are applied in partially known environment, hence apart from traditional planning they use Model Predictive Control (MPC) not only as the controller but also as the path planners for continuous collision avoidance.

Model Predictive Path Planning Based on Projected C-Space

- **Requirements**: *Configuration space, vehicle kinematics*
- Rectangular robot transformed to circle equivalently dilating obstacles
- State equations includes vehicle model, input bounds and safety constraints

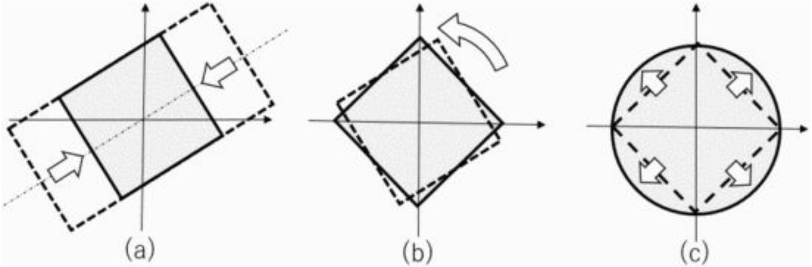


Figure 21: Coordinate transformation to map rectangular collision avoidance area to circular shape.

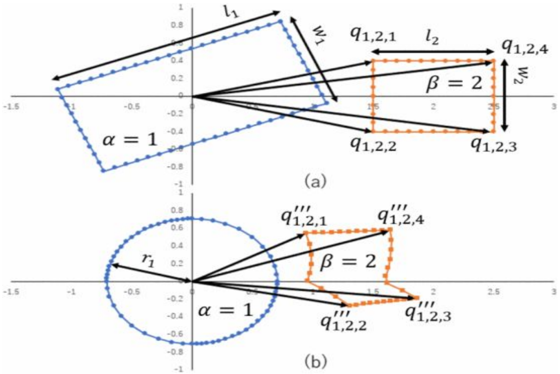


Figure 22: Transformation from rectangle to circle original rectangle collision area (a) is transformed to circle form (b).

6. T. Yamaguchi, T. Ishiguro, H. Okuda and T. Suzuki, "Model Predictive Path Planning for Autonomous Parking Based on Projected C-Space," 2021 IEEE International Intelligent Transportation Systems Conference (ITSC), 2021, pp. 929-935, doi: 10.1109/ITSC48978.2021.9564599.

Related Work

Model Predictive Path Planning Based on Projected C-Space

- **Requirements**: *Configuration space, vehicle kinematics*
- Rectangular robot transformed to circle equivalently dilating obstacles
- State equations includes vehicle model, input bounds and safety constraints
- **Model Predictive Control** (MPC) includes collision constraint for reverse parking scenario
- **Drawbacks**: *Obstacles are to be know and in polygon form to apply transformation. Works well in short range planning, as the number of obstacles increases so does the complexity.*

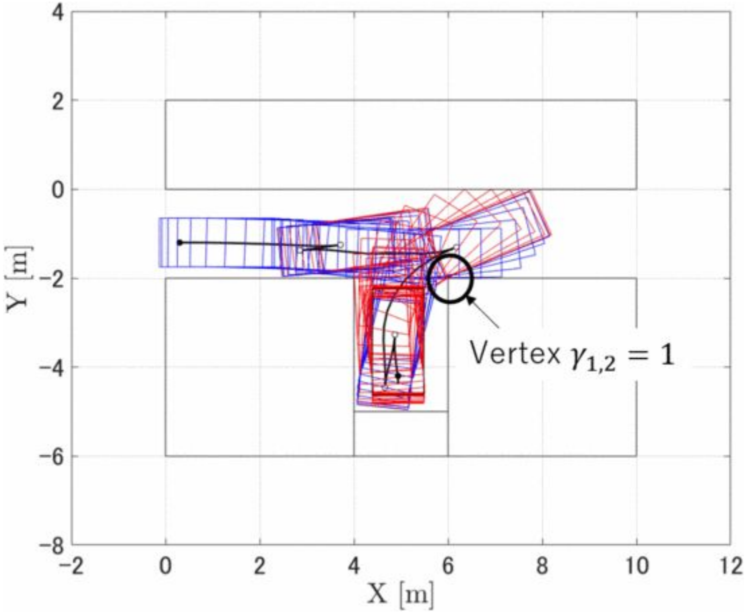


Figure 23: Vehicle position and posture in reverse parking.

6. T. Yamaguchi, T. Ishiguro, H. Okuda and T. Suzuki, "Model Predictive Path Planning for Autonomous Parking Based on Projected C-Space," 2021 IEEE International Intelligent Transportation Systems Conference (ITSC), 2021, pp. 929-935, doi: 10.1109/ITSC48978.2021.9564599.

Multistage Hybrid A* and Numerical Optimal Control

- **Requirements**: *Occupancy grid, vehicle dimensions and kinematics*
- Finds initial path using regular A* and find narrow space through path
- Discretizes sub paths and applies **Improved Safe Travel Corridor** (STC) to solve the optimal control problem

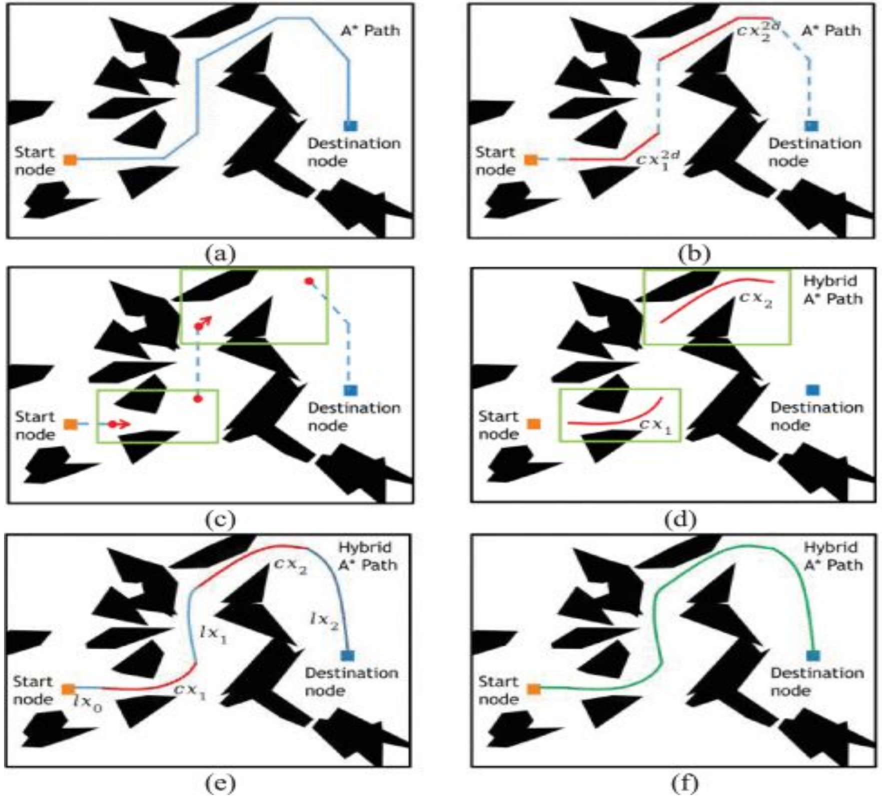


Figure 24: Schematics on the steps in the multistage hybrid A* algorithm.

7. W. Sheng, B. Li and X. Zhong, "Autonomous Parking Trajectory Planning With Tiny Passages: A Combination of Multistage Hybrid A-Star Algorithm and Numerical Optimal Control," in IEEE Access, vol. 9, pp. 102801-102810, 2021, doi: 10.1109/ACCESS.2021.3098676.

Related Work

Multistage Hybrid A* and Numerical Optimal Control

- **Requirements**: *Occupancy grid, vehicle dimensions and kinematics*
- Finds initial path using regular A* and find narrow space through path
- Discretizes sub paths and applies **Improved Safe Travel Corridor** (STC) to solve the optimal control problem
- Subpaths are kinematically feasible (**Reeds-Shepp curves**)
- **Drawbacks**: *Initial coarse path could lead to local minimas. To obtain safer path the number of STCs should be increased which would increase complexity.*

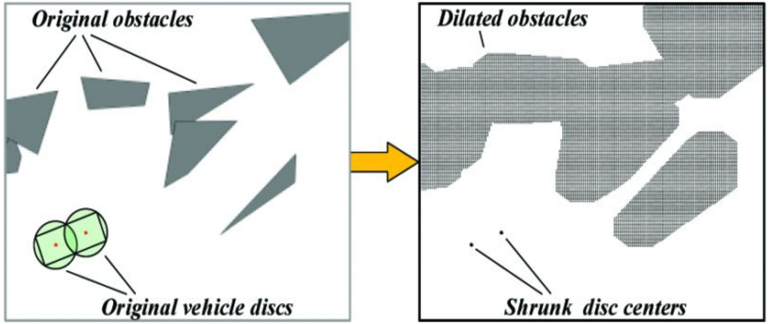


Figure 25: Visualizing the altered environment and robot.

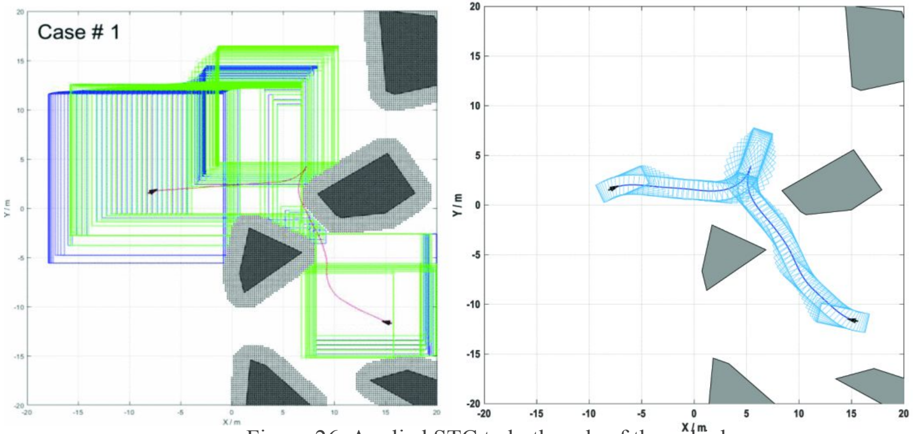


Figure 26: Applied STC to both ends of the vehicle.

7. W. Sheng, B. Li and X. Zhong, "Autonomous Parking Trajectory Planning With Tiny Passages: A Combination of Multistage Hybrid A-Star Algorithm and Numerical Optimal Control," in IEEE Access, vol. 9, pp. 102801-102810, 2021, doi: 10.1109/ACCESS.2021.3098676.

Related Work

Summarizing approaches in robot and automotive planning approaches:

- Global planners:
    - Modified/Hybrid A* algorithms
    - Improved Rapid Random Trees (RRT) algorithms
    - Potential field methods

- Constraint handling optimizers:
    - Improved Safe Travel Corridor (STC)
    - Model Predictive Control (MPC)
    - Adaptive Moment Estimation (ADAM)

Related Work - Summary

Summarizing approaches in robot and automotive planning approaches:

Approaches		Environment Representation	Robot Platform	Tested Scenarios
Modified/Hybrid A* algorithms	Multistage Hybrid A* and Numerical Optimal Control [7]	Configuration Space	Autonomous Car	Autonomous Parking
	Shape-Aware Lifelong A* Planning [12]	Configuration Space	Differential Drive	Open and Narrow Space
	Optimization-Based Maneuver Planning using STC [14]	Occupancy Map	Robot-Trailer	Corridor Navigation
Improved Rapid Random Trees (RRT) algorithms	Locally Guided Multiple Bi-RRT* [3]	Occupancy Map	Omni Drive	Open Space and Doorways
	Rapid Random Vines [4]	Occupancy Map	Omni Drive	Corridor Navigation
	Adaptive Rapidly-Exploring Random Tree Connect [10]	Occupancy Map	Omni Drive	Open and Narrow Spaces
	Obstacle-Guided Sampling for RRTs [11]	Occupancy Map	Omni Drive	Open and Narrow Spaces
	Sampling Based Geometric Planners [8] [9]	Geometric Map	Autonomous Car	Open and Narrow Spaces
Potential field methods	Spline-Based Planning with MPC [5]	Potential Field Map	Omni Drive	Dynamic Structured Setting
	Potential Field with ADAM Optimizer [17]	Potential Field Map	Omni Drive	Narrow Spaces

Problem Formulation

Problem Formulation

Basic evaluation based on open problems addressed in this thesis proposal:

Approaches		Narrow Space Exploration	Reverse Maneuvering	Dynamic Environment	Low Time Complexity
Modified/Hybrid A* algorithms	Multistage Hybrid A* and Numerical Optimal Control [7]	✓	✓		
	Shape-Aware Lifelong A* Planning [12]	✓	✓		
	Optimization-Based Maneuver Planning using STC [14]	✓	✓		
Improved Rapid Random Trees (RRT) algorithms	Locally Guided Multiple Bi-RRT* [3]	✓			✓
	Rapid Random Vines [4]	✓			✓
	Adaptive Rapidly-Exploring Random Tree Connect [10]	✓			✓
	Obstacle-Guided Sampling for RRTs [11]	✓			✓
	Sampling Based Geometric Planners [8] [9]	✓	✓		
Potential field methods	Spline-Based Planning with MPC [5]	✓		✓	
	Potential Field with ADAM Optimizer [17]	✓			

Problem Formulation

Structuring the problem:

- Thesis objectives:
  - Modify and test state-of-art approaches with existing platform/simulation
  - Deal with reverse motions to maneuver in narrow spaces
  - Handle dynamic environments
  - Develop and improve a proposed geometric planner
  - Integrate into a framework which handles different spaces

- Evaluation:
  - Evaluation can be performed in simulation or real life environment (university, hospital or warehouse).
  - Soundness (collision free path in reasonable time), completeness (guaranteed to find a path if it exists) and complexity (time and space performance) can be evaluated for a given scenario.
  - Novel geometric based approach (extended to handle gaps in previous slide) VS mixer of other approaches collected from related work.

Geometric Planner for Confined Spaces

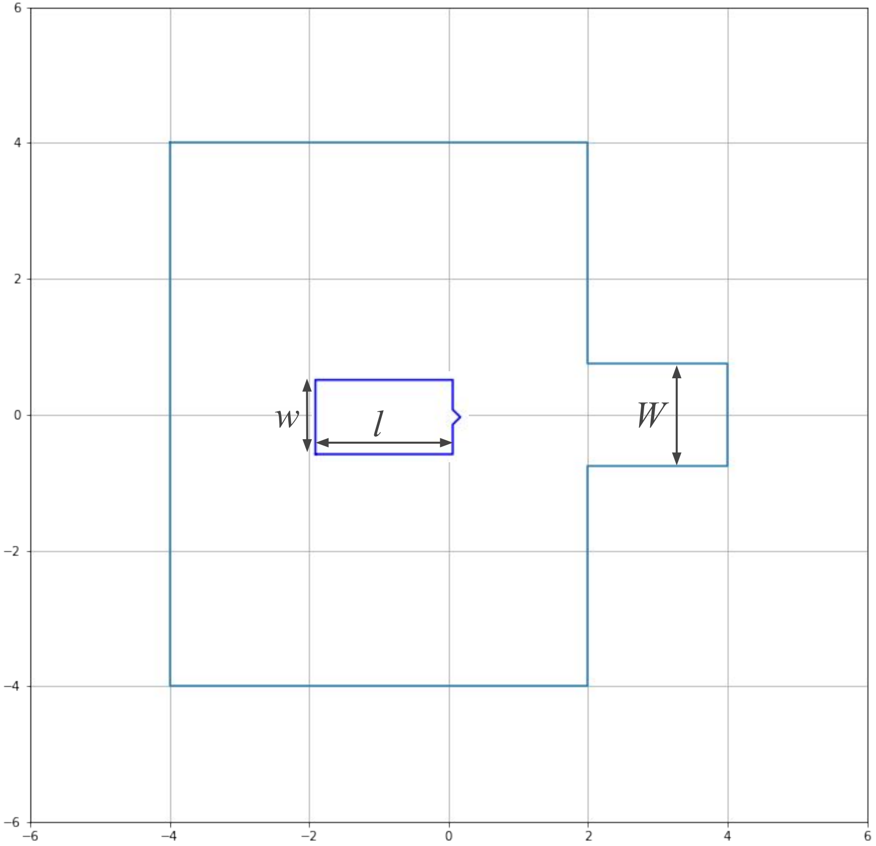


Figure 27

Defining Confined Space:

- Unit: 1m

Geometric Planner for Confined Spaces

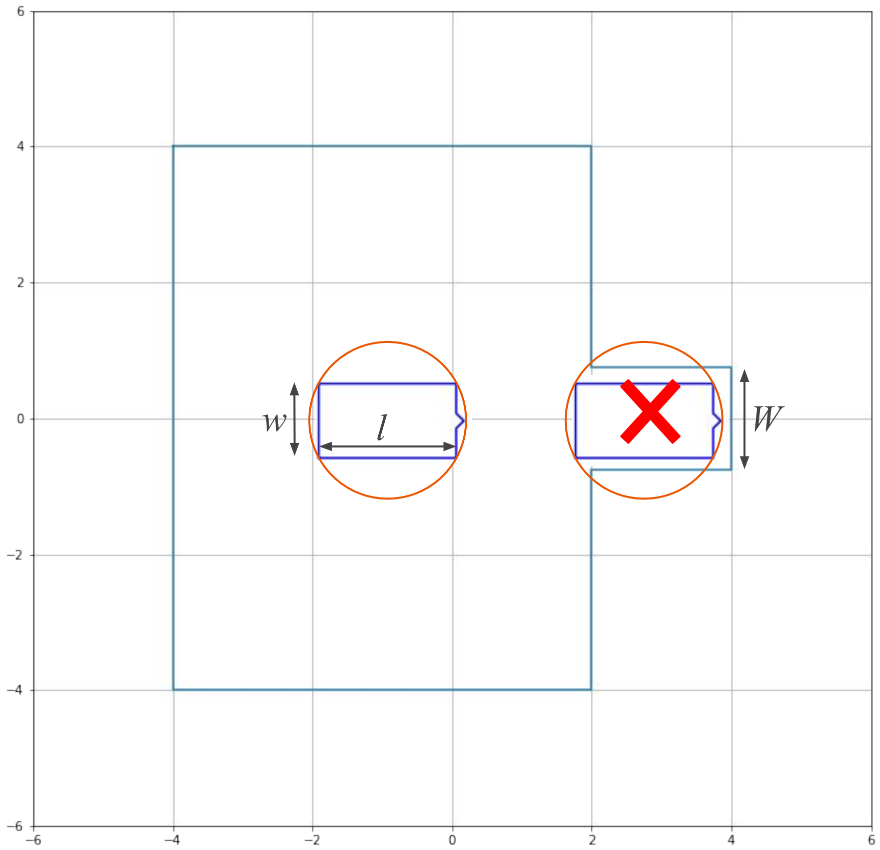


Figure 27

Defining Confined Space:

- Unit: 1m
- Confined space: $w < W < l$

Geometric Planner for Confined Spaces

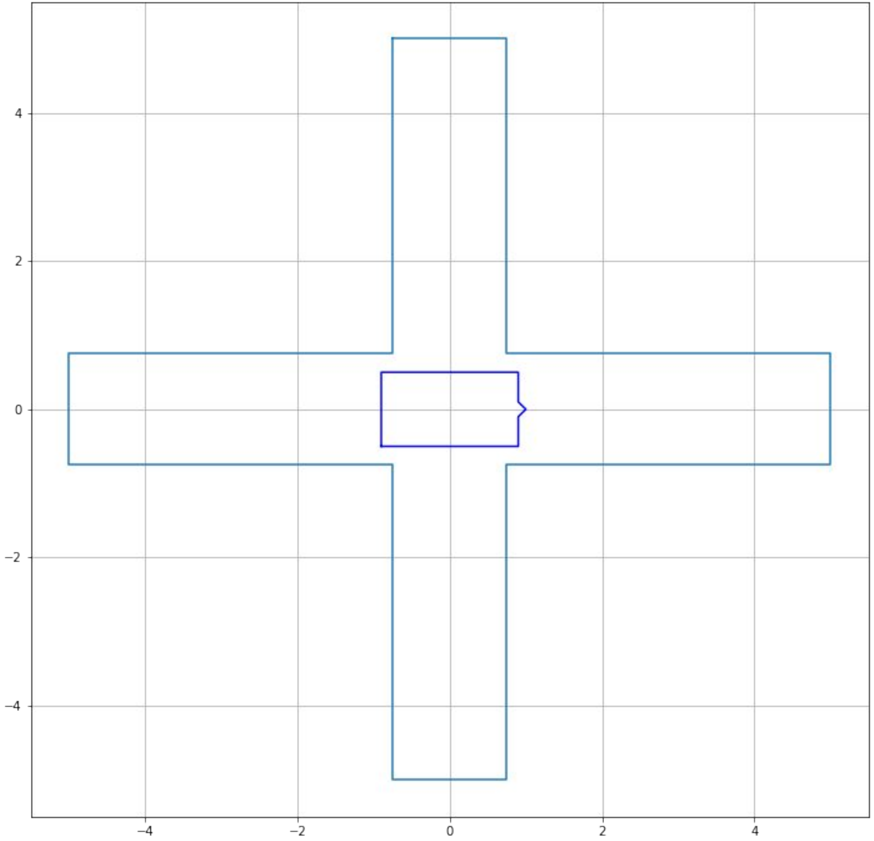


Figure 28

Corridor Intersection:

- Intersection at right angle
- Unit: 1m

Geometric Planner for Confined Spaces

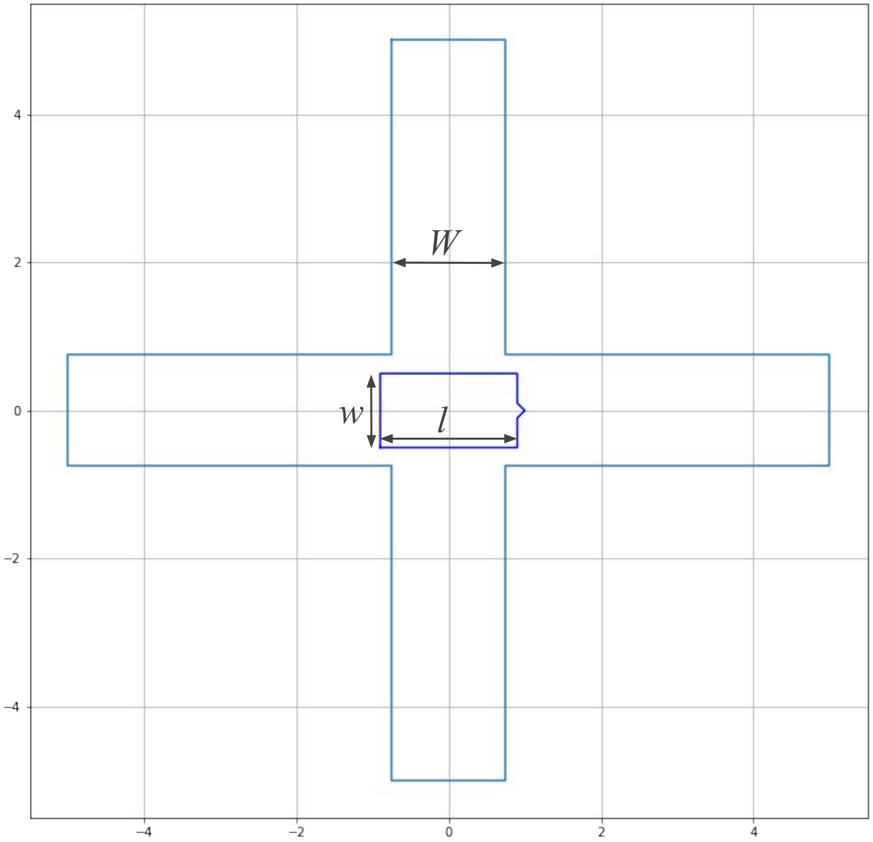


Figure 28

Corridor Intersection:

- Intersection at right angle
- Unit: 1m
- Confined space restriction:
  - $w < W < l < W\sqrt{8}$
    where w : Width of robot
    W: Width of corridor
    l : Length of robot

Geometric Planner for Confined Spaces

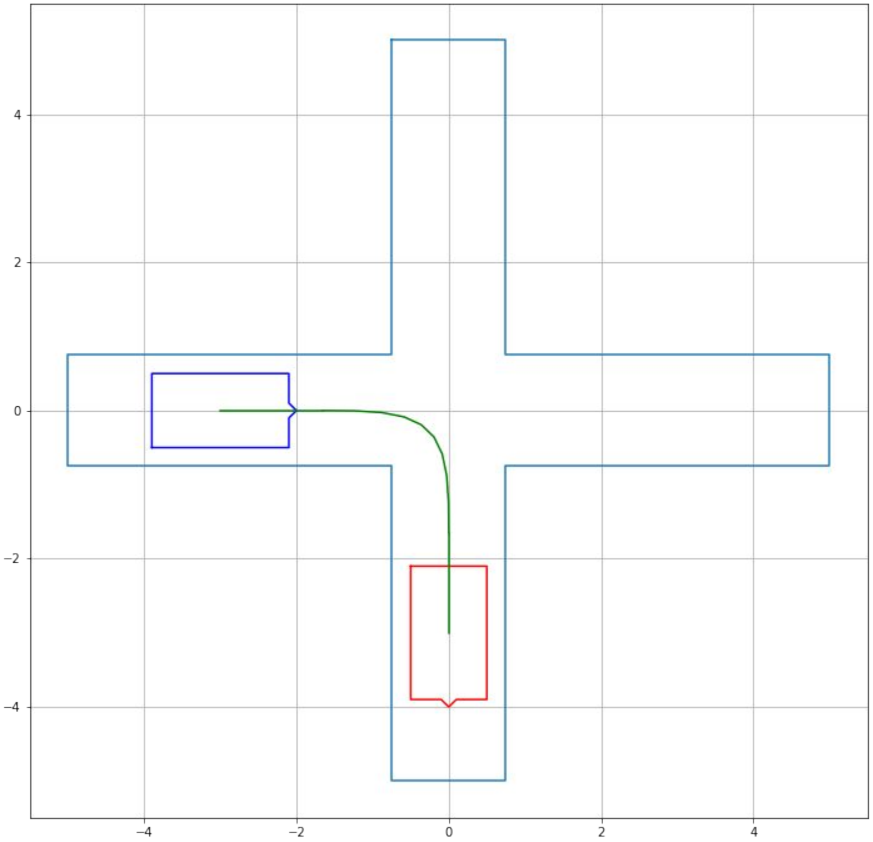


Figure 28

Corridor Intersection:

- Intersection at right angle
- Unit: 1m
- Confined space restriction:
  - $w < W < l < W\sqrt{8}$
    where w : Width of robot
    W: Width of corridor
    l : Length of robot
- Different robot start and end poses

Geometric Planner for Confined Spaces

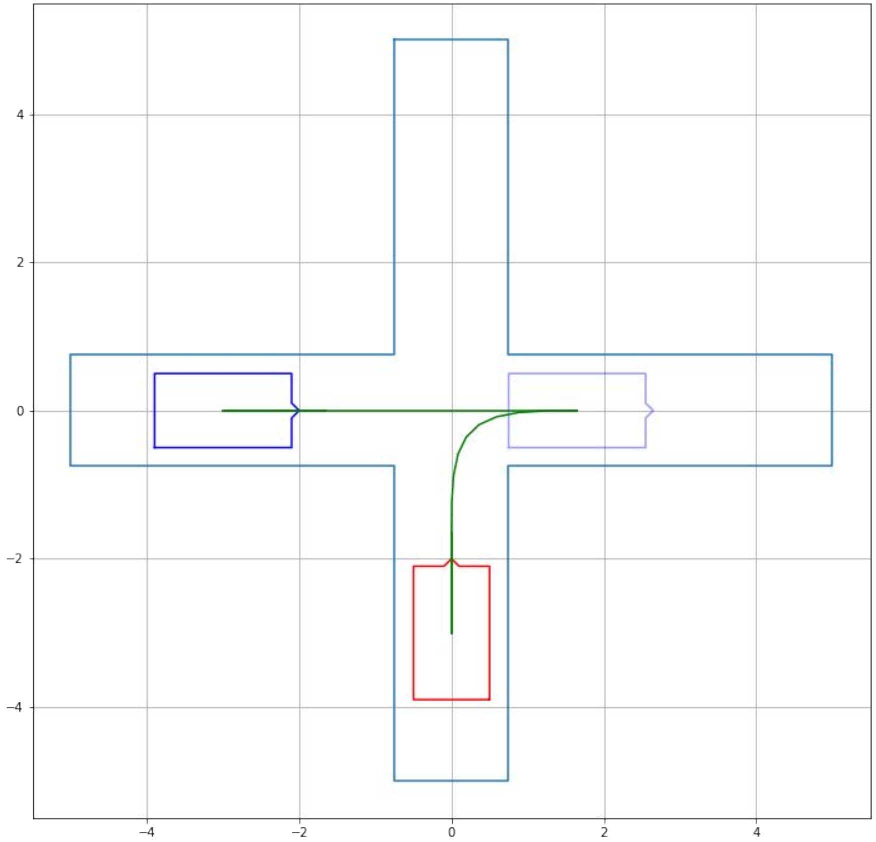
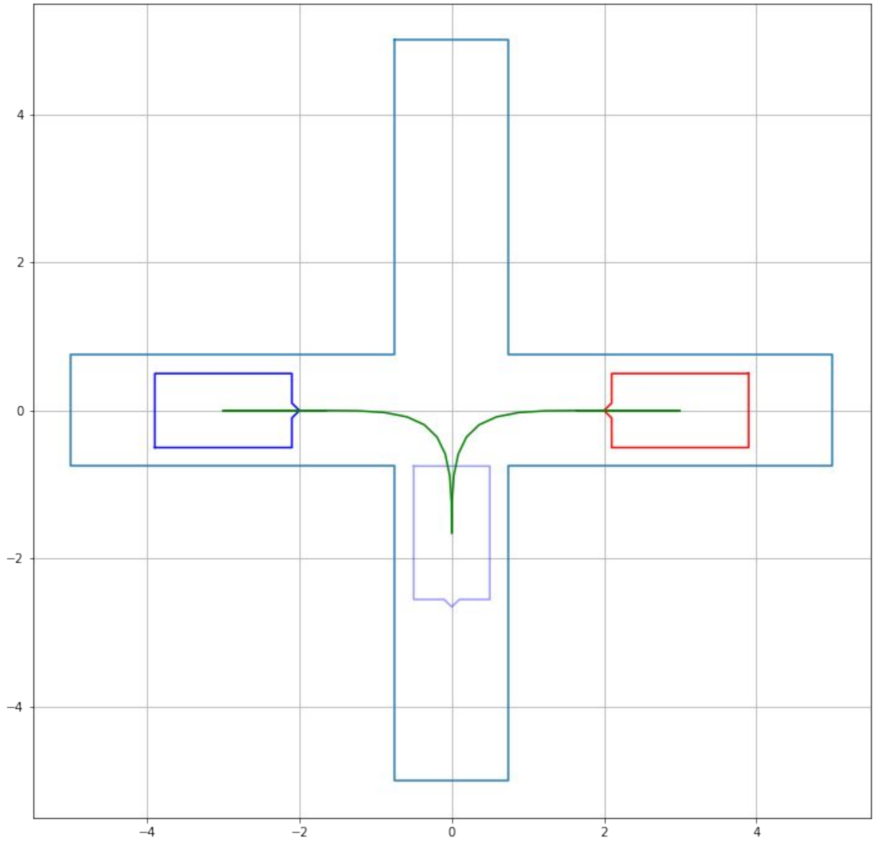


Figure 28

Corridor Intersection:

- Intersection at right angle
- Unit: 1m
- Confined space restriction:
  - $w < W < l < W\sqrt{8}$
    where w : Width of robot
    W: Width of corridor
    l : Length of robot
- Different robot start and end poses

Geometric Planner for Confined Spaces



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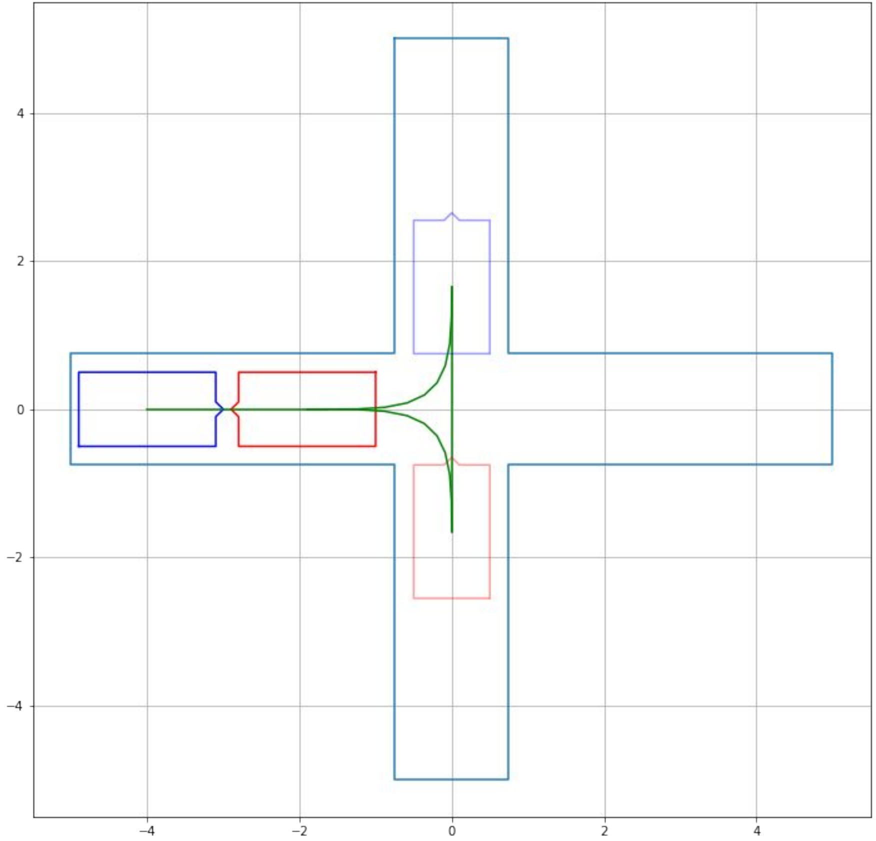
- Different robot start and end poses

Geometric Planner for Confined Spaces



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- Confined space restriction:
  - $w < W < l < W\sqrt{8}$
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    W: Width of corridor
    l : Length of robot
- Different robot start and end poses

Geometric Planner for Confined Spaces

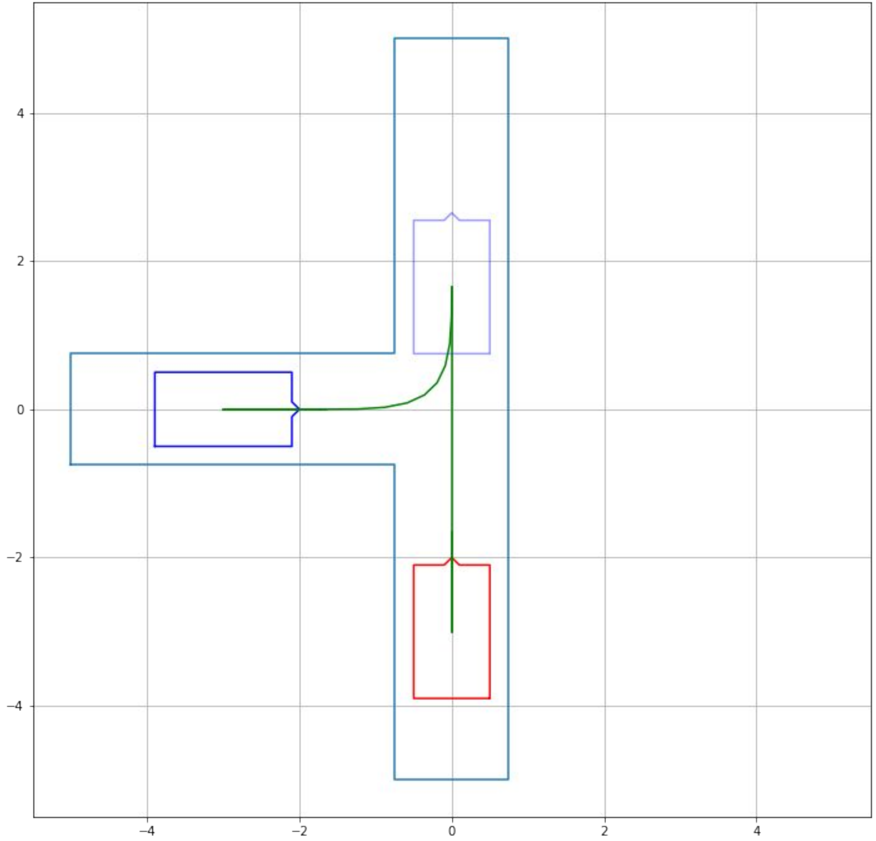


Figure 28

Corridor Intersection:

- Intersection at right angle
- Unit: 1m
- Confined space restriction:
  - $w < W < l < W\sqrt{8}$
    where w : Width of robot
    W: Width of corridor
    l : Length of robot
- Different robot start and end poses
- Different corridor configurations

Geometric Planner for Confined Spaces

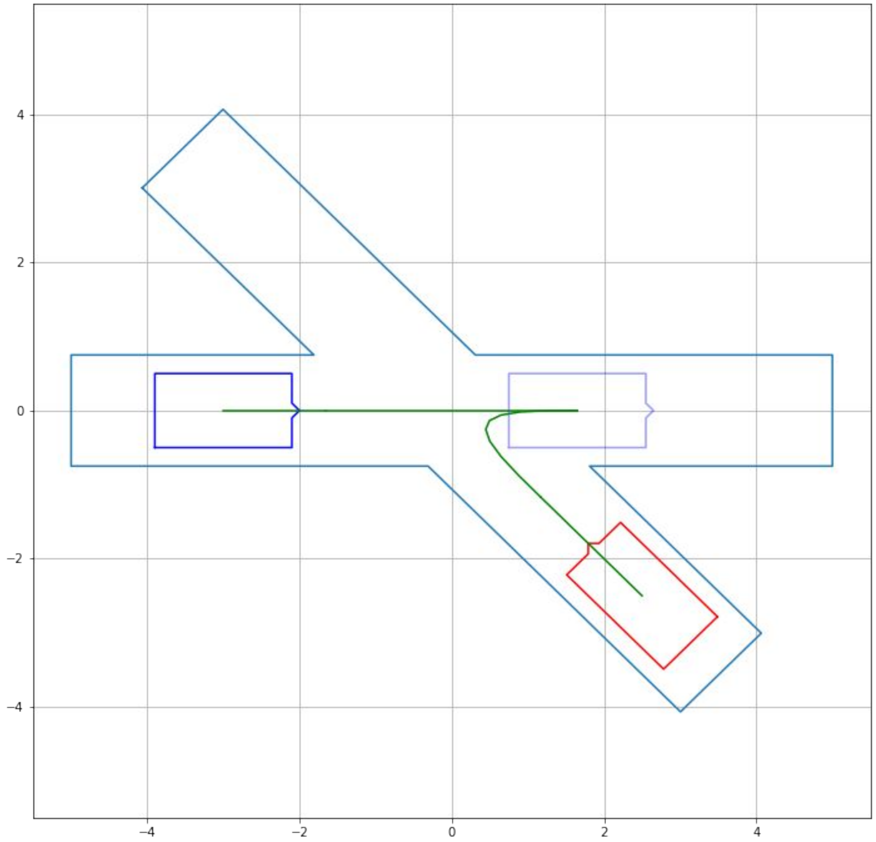


Figure 28

Corridor Intersection:

- Intersection at skewed angle
- Unit: 1m
- Confined space restriction:
  - $w < W < l < W\sqrt{8}$
    where w : Width of robot
    W: Width of corridor
    l : Length of robot
- Different robot start and end poses
- Different corridor configurations

Geometric Planner for Confined Spaces

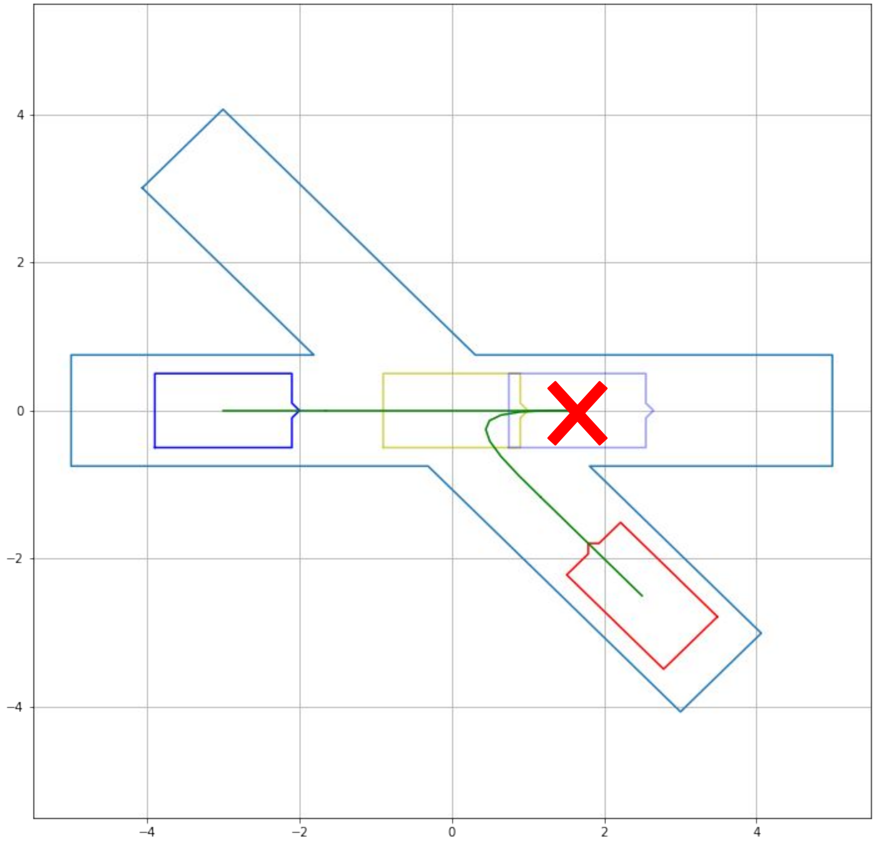


Figure 28

Corridor Intersection:

- Intersection at skewed angle
- Unit: 1m
- Confined space restriction:
  - $w < W < l < W\sqrt{8}$
    where w : Width of robot
    W: Width of corridor
    l : Length of robot
- Different robot start and end poses
- Different corridor configurations
- Online planning

Geometric Planner for Confined Spaces

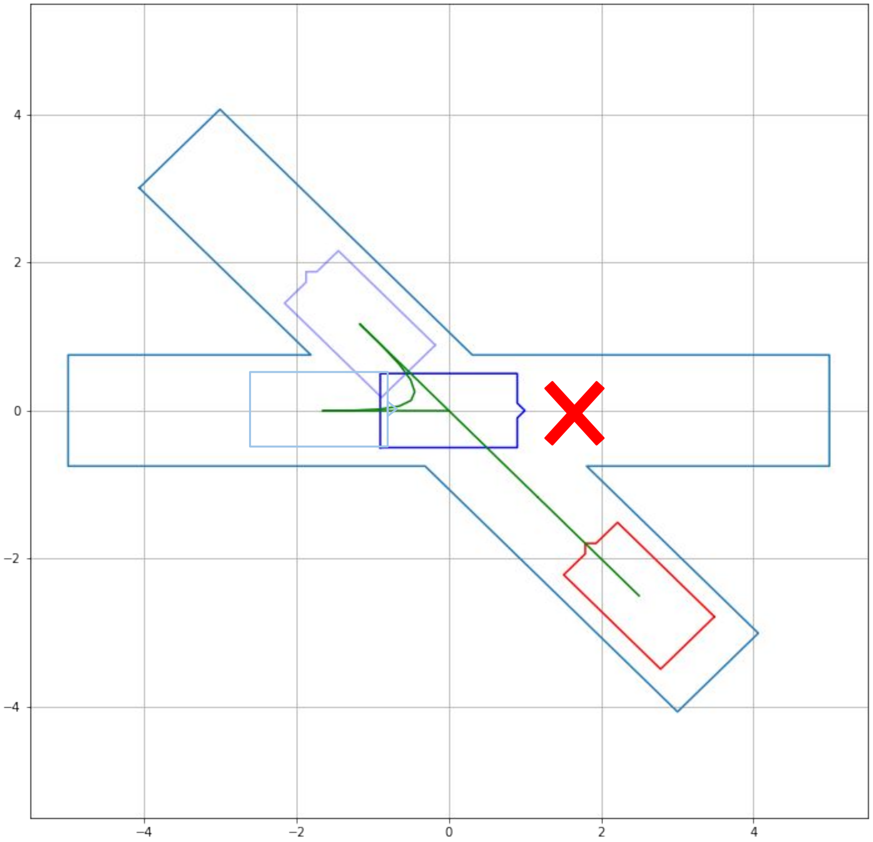


Figure 28

Corridor Intersection:

- Intersection at skewed angle
- Unit: 1m
- Confined space restriction:
  - $w < W < l < W\sqrt{8}$
    where w : Width of robot
    W: Width of corridor
    l : Length of robot
- Different robot start and end poses
- Different corridor configurations
- Online planning: Replanning after obstruction

Geometric Planner for Confined Spaces

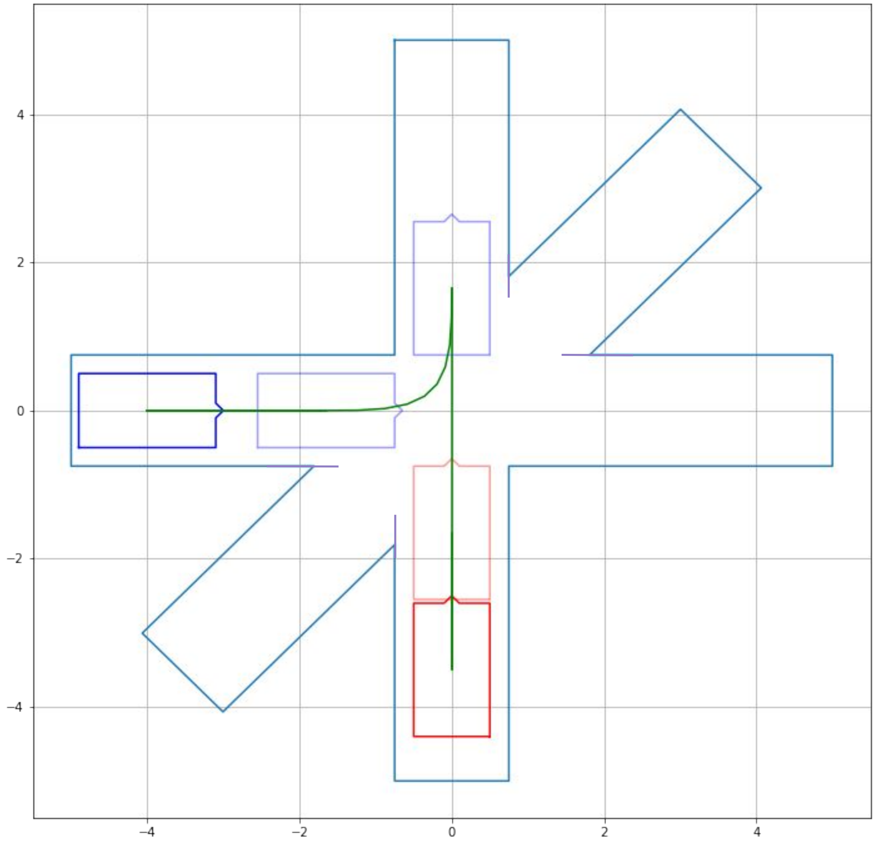


Figure 28

Corridor Intersection:

- Intersection at skewed angle
- Unit: 1m
- Confined space restriction:
  - $w < W < l < W\sqrt{8}$

    where w : Width of robot

    W: Width of corridor

    l : Length of robot
- Different robot start and end poses
- Different corridor configurations
- Online planning: Replanning after obstruction

Geometric Planner for Confined Spaces

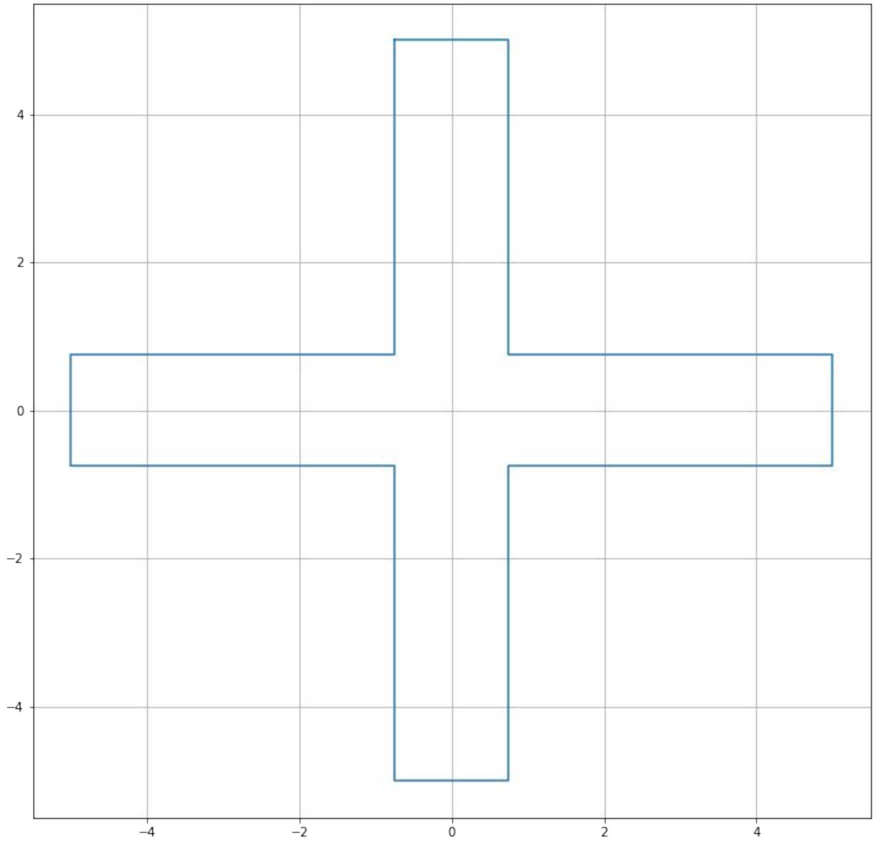


Figure 28

Confined space planner:

- Given an intersection of corridors

Geometric Planner for Confined Spaces

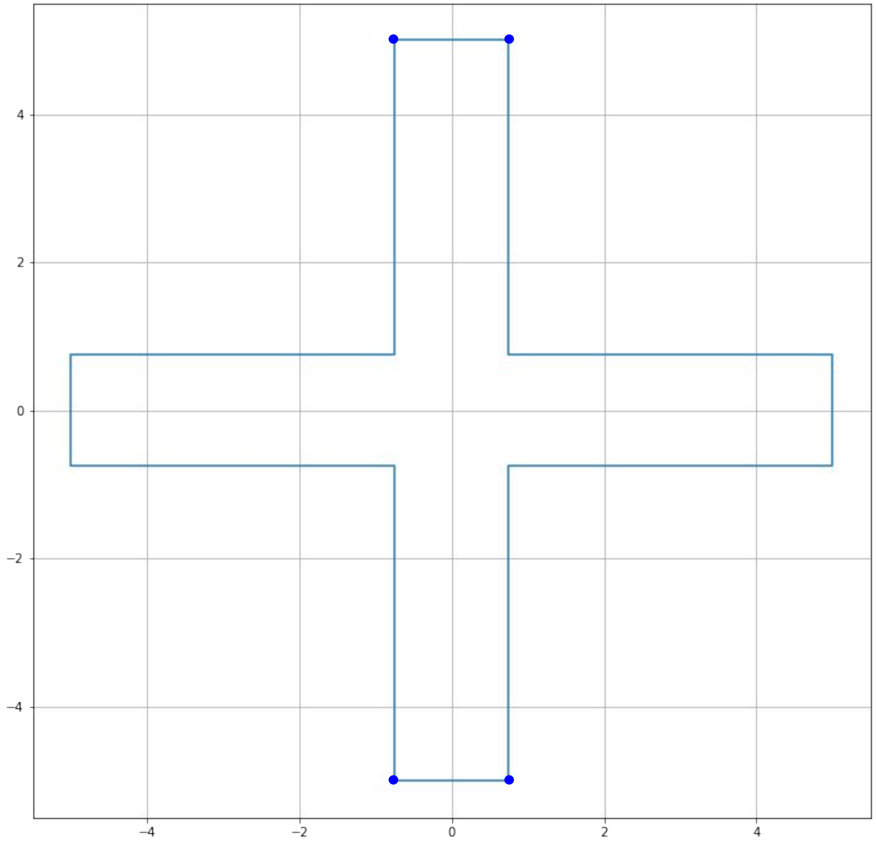
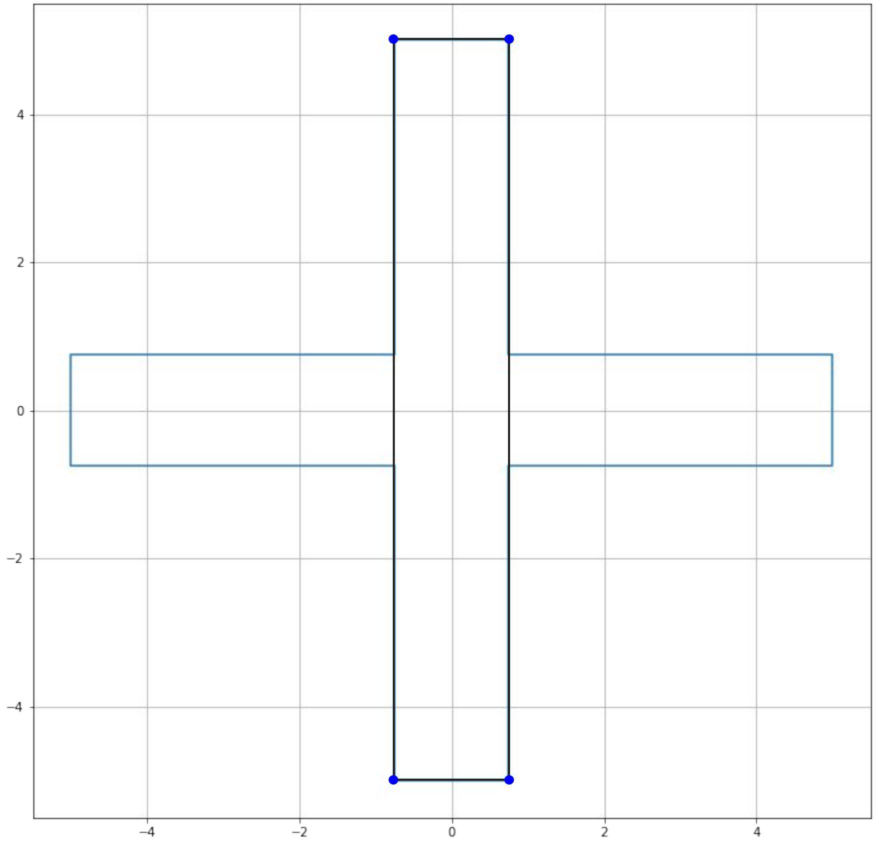


Figure 29

Confined space planner:

- Given an intersection of corridors
- Assign the four corners of the corridor

Geometric Planner for Confined Spaces



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Confined space planner:

- Given an intersection of corridors
- Assign the four corners of the corridor

Geometric Planner for Confined Spaces

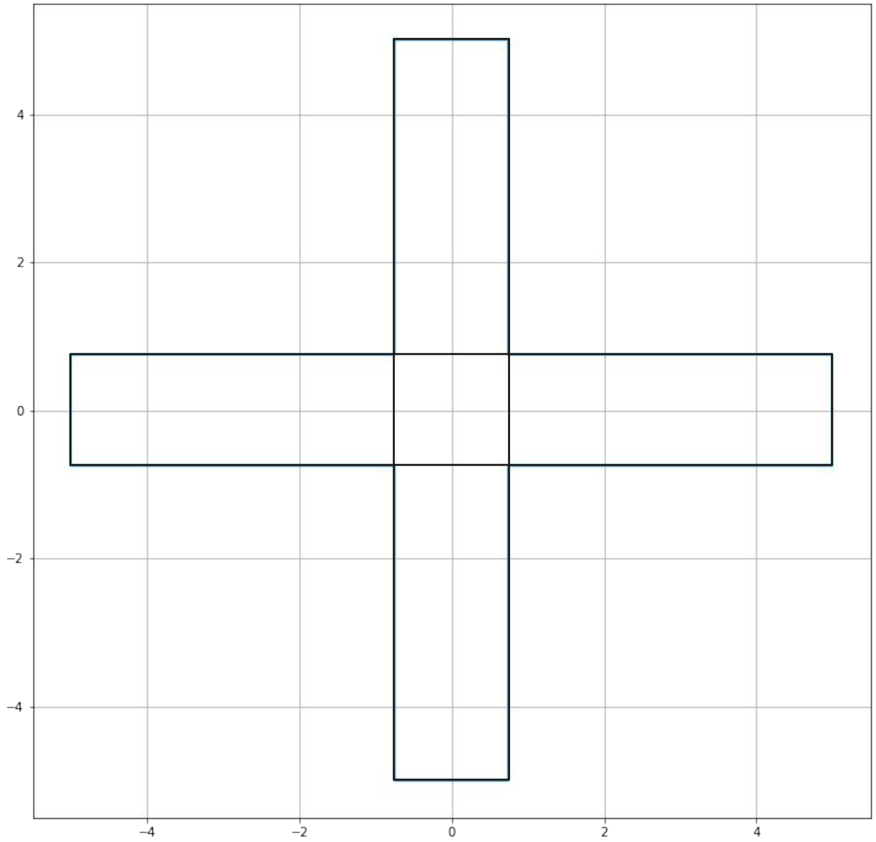


Figure 29

Confined space planner:

- Given an intersection of corridors
- Assign the four corners of the corridor
- Construct shapes for both the corridor

Geometric Planner for Confined Spaces

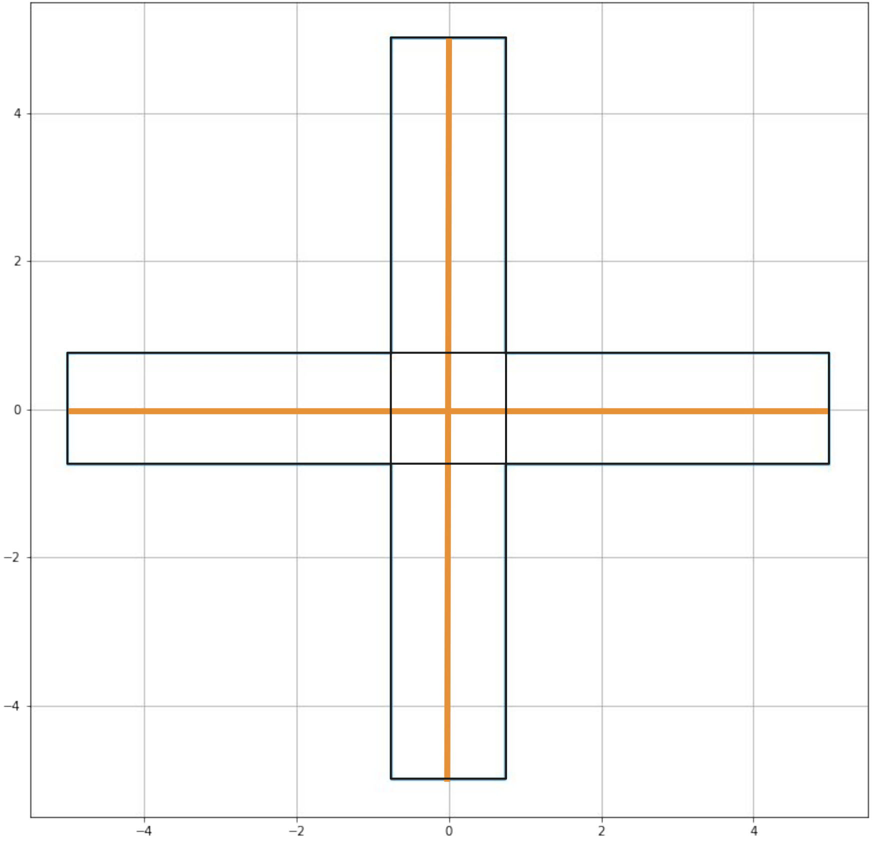
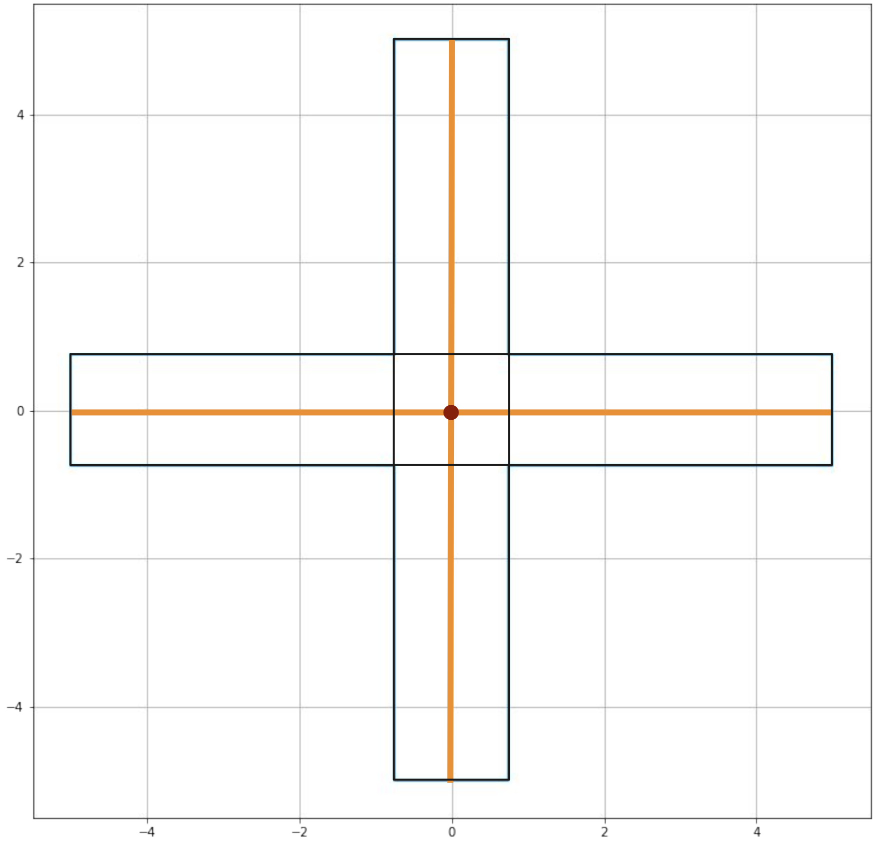


Figure 29

Confined space planner:

- Given an intersection of corridors
- Assign the four corners of the corridor
- Construct shapes for both the corridor
- Find the center of intersection and vectors to the edges

Geometric Planner for Confined Spaces



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Confined space planner:

- Given an intersection of corridors
- Assign the four corners of the corridor
- Construct shapes for both the corridor
- Find the center of intersection and vectors to the edges

Geometric Planner for Confined Spaces

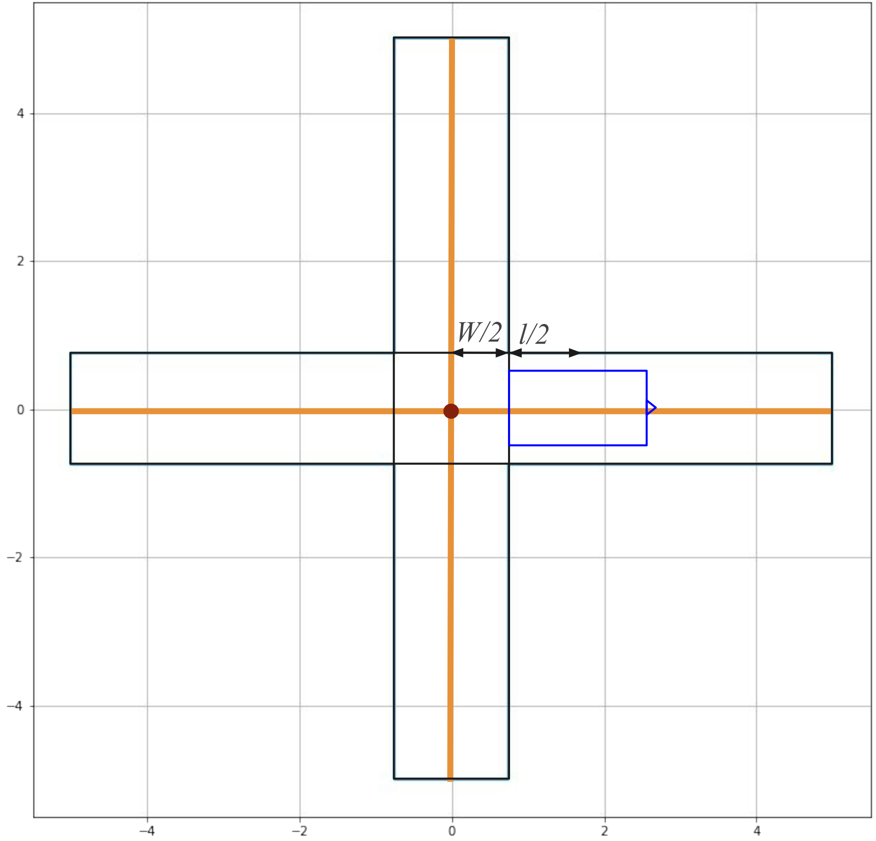
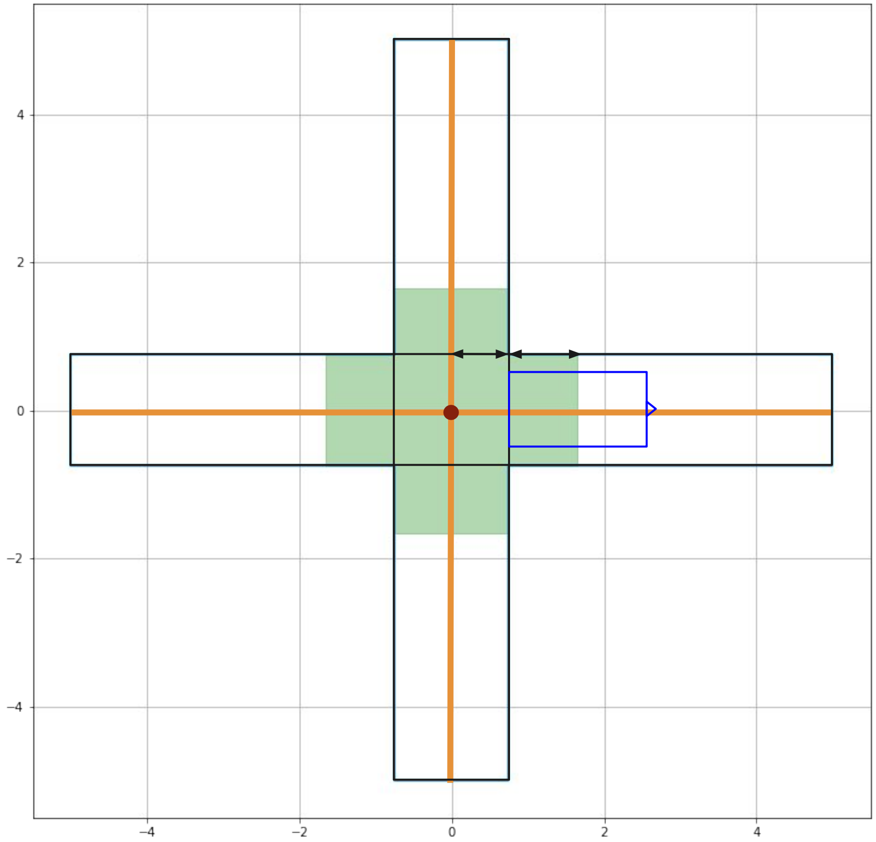


Figure 29

Confined space planner:

- Given an intersection of corridors
- Assign the four corners of the corridor
- Construct shapes for both the corridor
- Find the center of intersection and vectors to the edges
- Construct a junction area where the edges are $W/2 + l/2$ from the center

Geometric Planner for Confined Spaces



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- Given an intersection of corridors
- Assign the four corners of the corridor
- Construct shapes for both the corridor
- Find the center of intersection and vectors to the edges
- Construct a junction area where the edges are $W/2 + l/2$ from the center

Geometric Planner for Confined Spaces

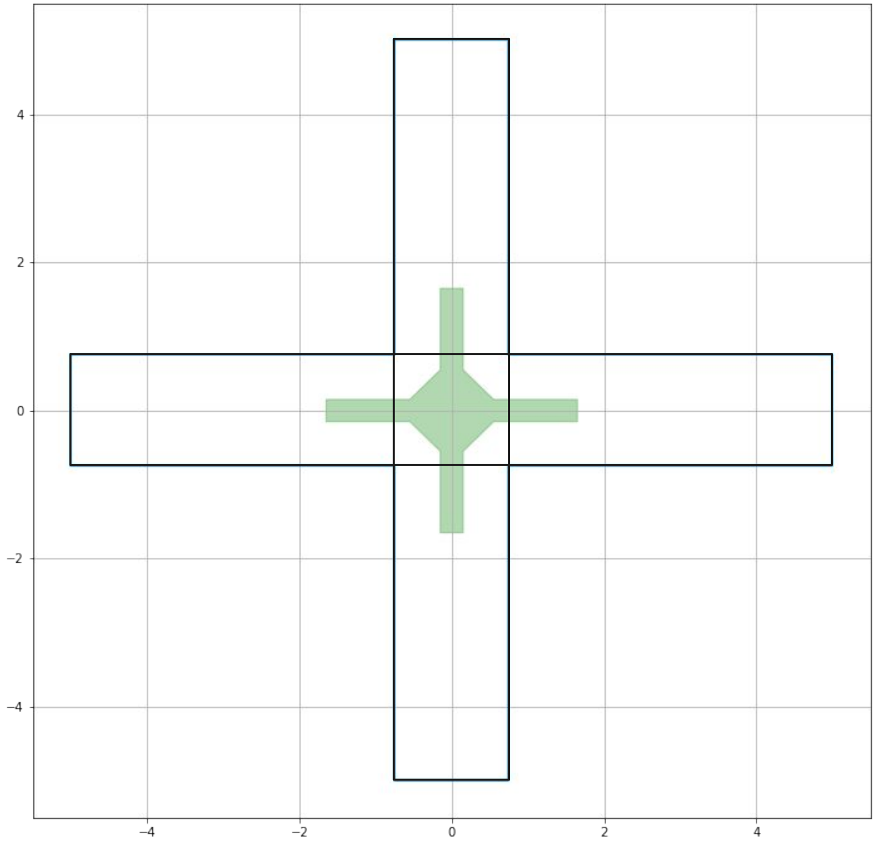


Figure 29

Confined space planner:

- Given an intersection of corridors
- Assign the four corners of the corridor
- Construct shapes for both the corridor
- Find the center of intersection and vectors to the edges
- Construct a junction area where the edges are *W/2 + l/2* from the center
- Transform the junction area to avoid collision (Equivalent Area)

Geometric Planner for Confined Spaces

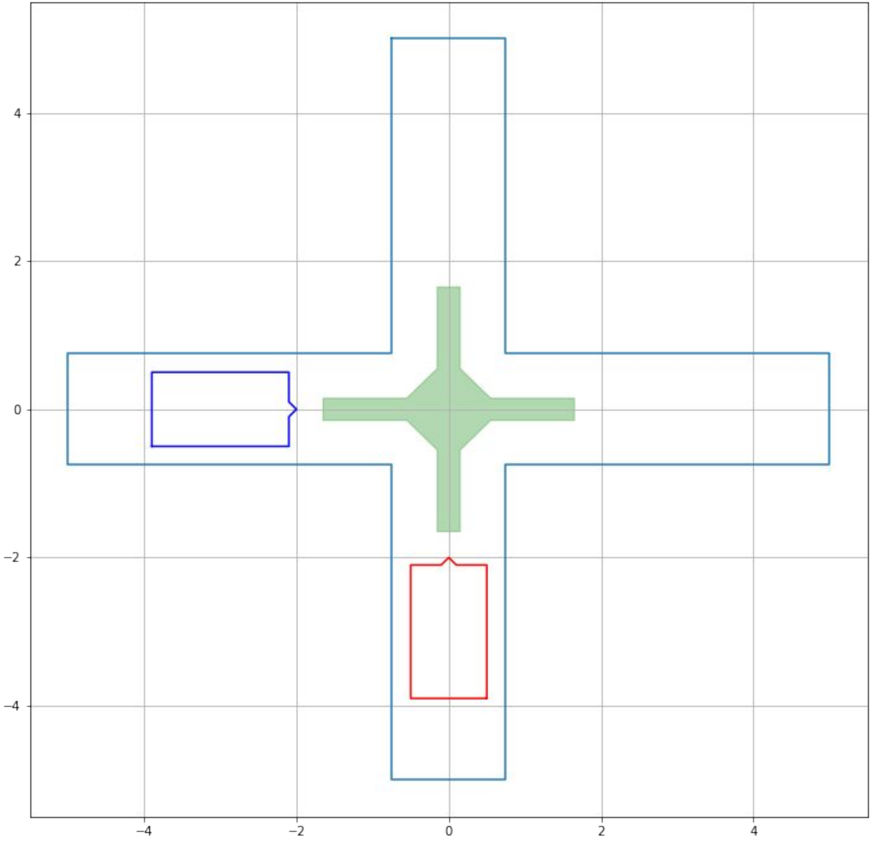


Figure 29

Confined space planner:

- Given start and goal pose of the robot

Geometric Planner for Confined Spaces

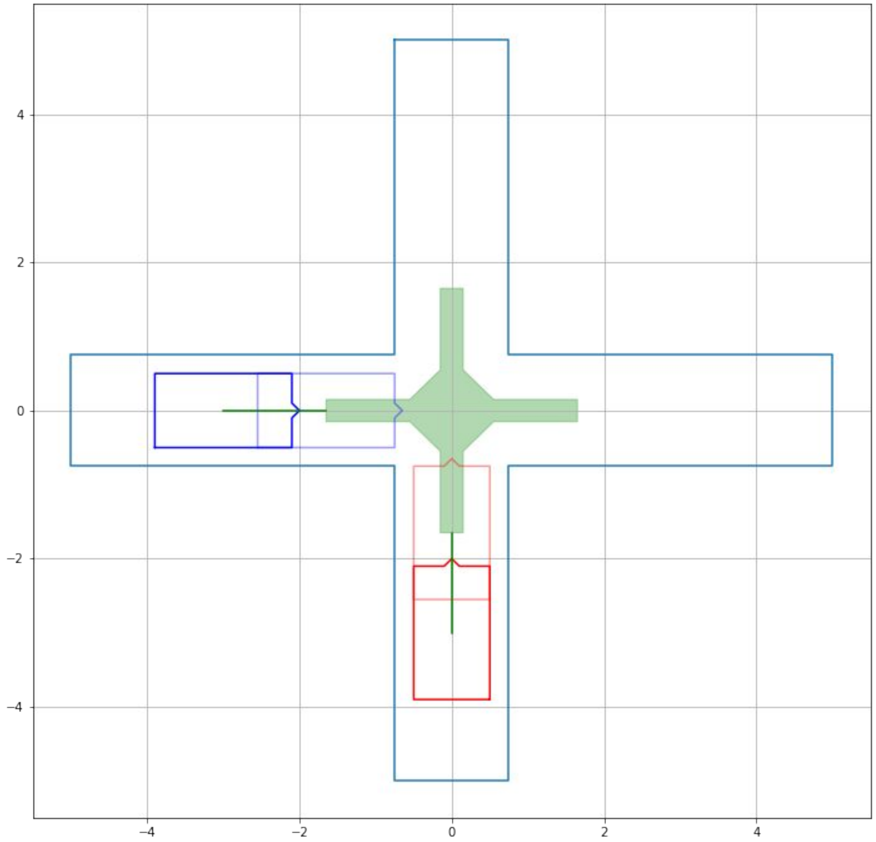


Figure 29

Confined space planner:

- Given start and goal pose of the robot
- Find the nearest edges and orientation towards the center

Geometric Planner for Confined Spaces

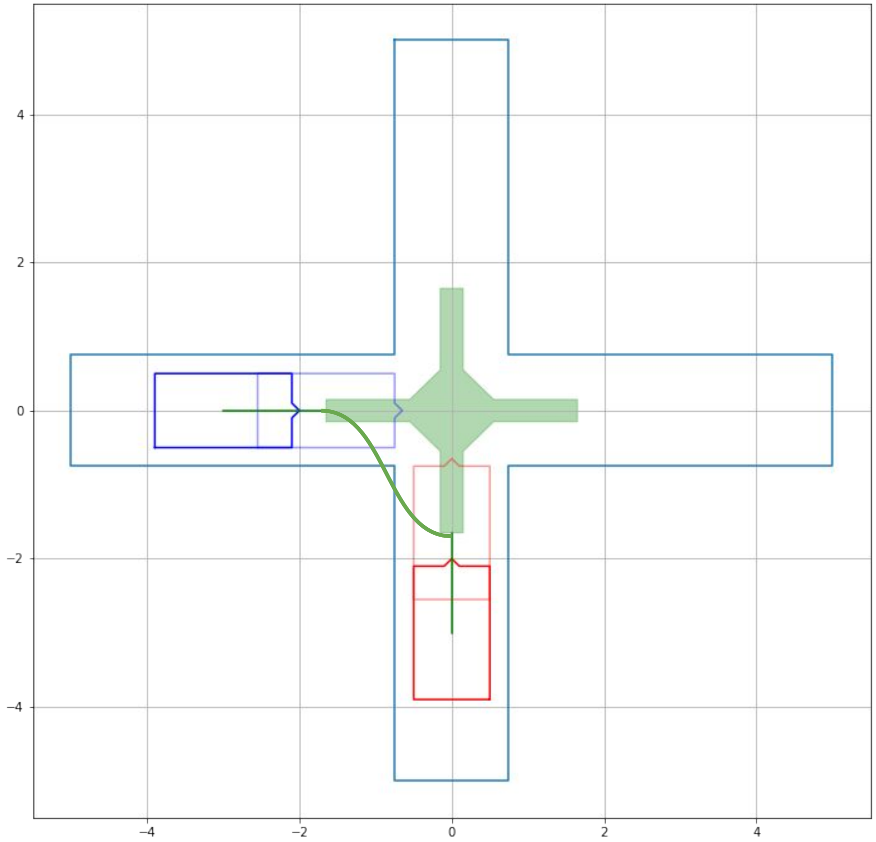
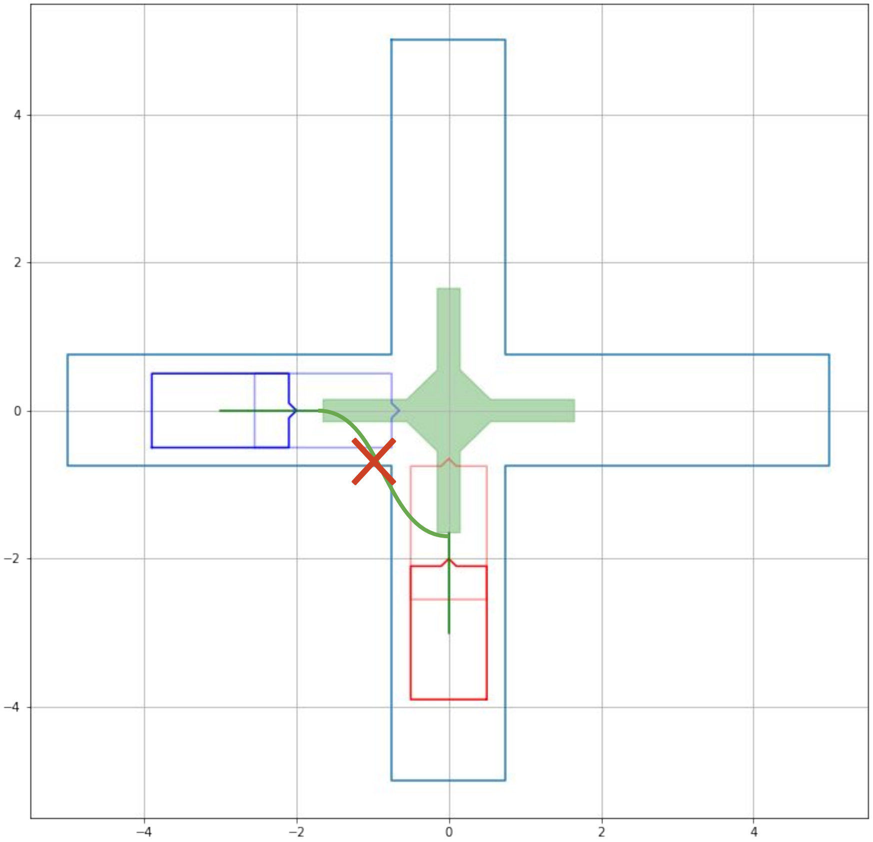


Figure 29

Confined space planner:

- Given start and goal pose of the robot
- Find the nearest edges and orientation towards the center
- Check possible path from the nearest edges

Geometric Planner for Confined Spaces



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Confined space planner:

- Given start and goal pose of the robot
- Find the nearest edges and orientation towards the center
- Check possible path from the nearest edges

Geometric Planner for Confined Spaces

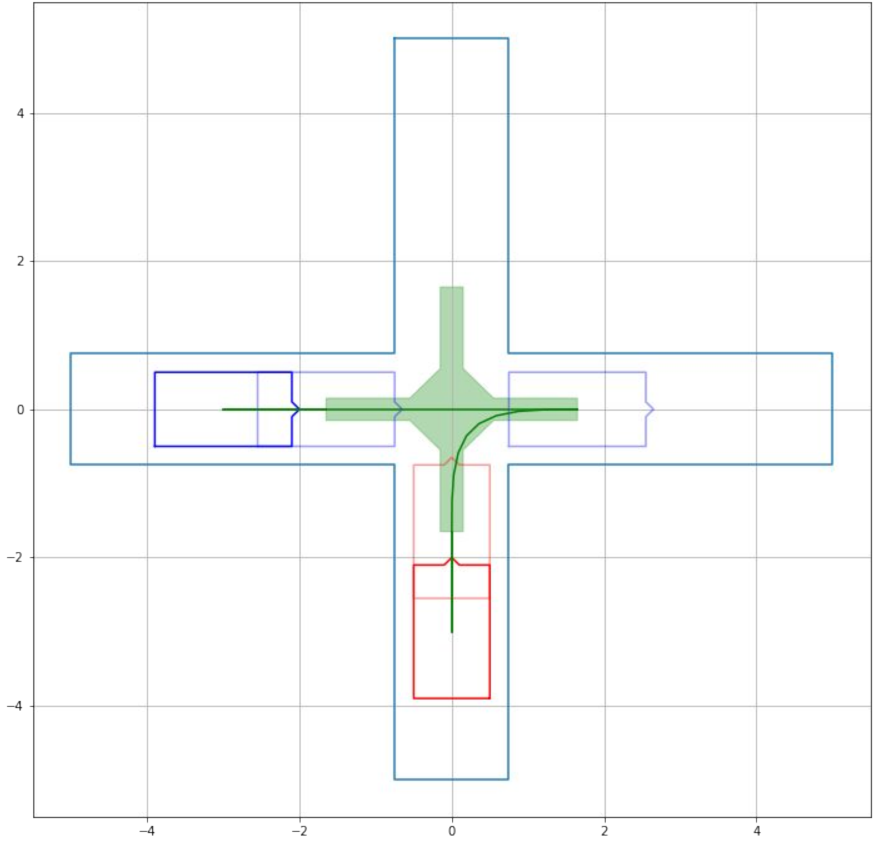


Figure 29

Confined space planner:

- Given start and goal pose of the robot
- Find the nearest edges and orientation towards the center
- Check possible path from the nearest edges
- Find another edge for both orientation towards and away from the center and compute forward and reverse path from the new edge.

Geometric Planner for Confined Spaces

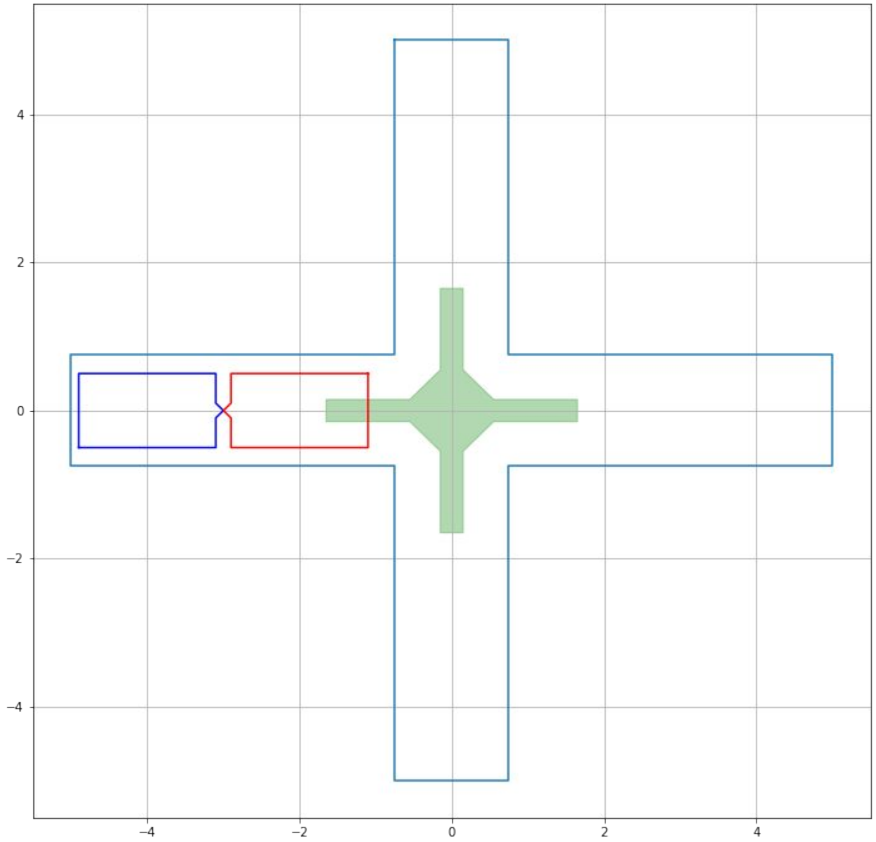
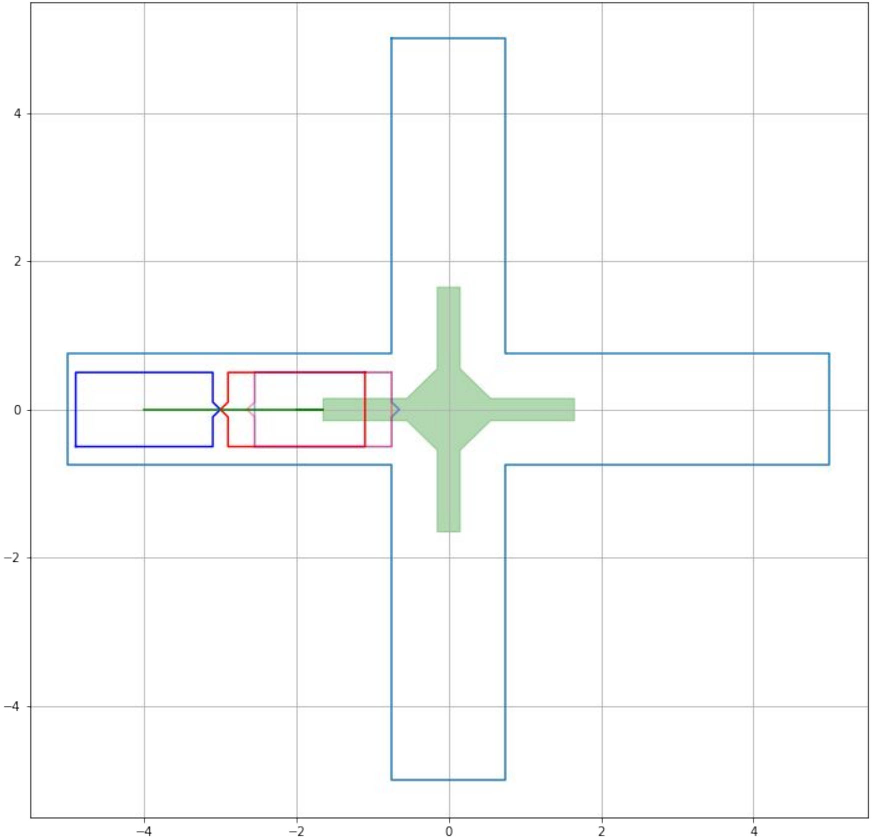


Figure 29

Confined space planner:

- Given start and goal pose of the robot
- Find the nearest edges and orientation towards the center
- Check possible path from the nearest edges
- Find another edge for both orientation towards and away from the center and compute forward and reverse path from the new edge.
- Different start and end poses of robot

Geometric Planner for Confined Spaces



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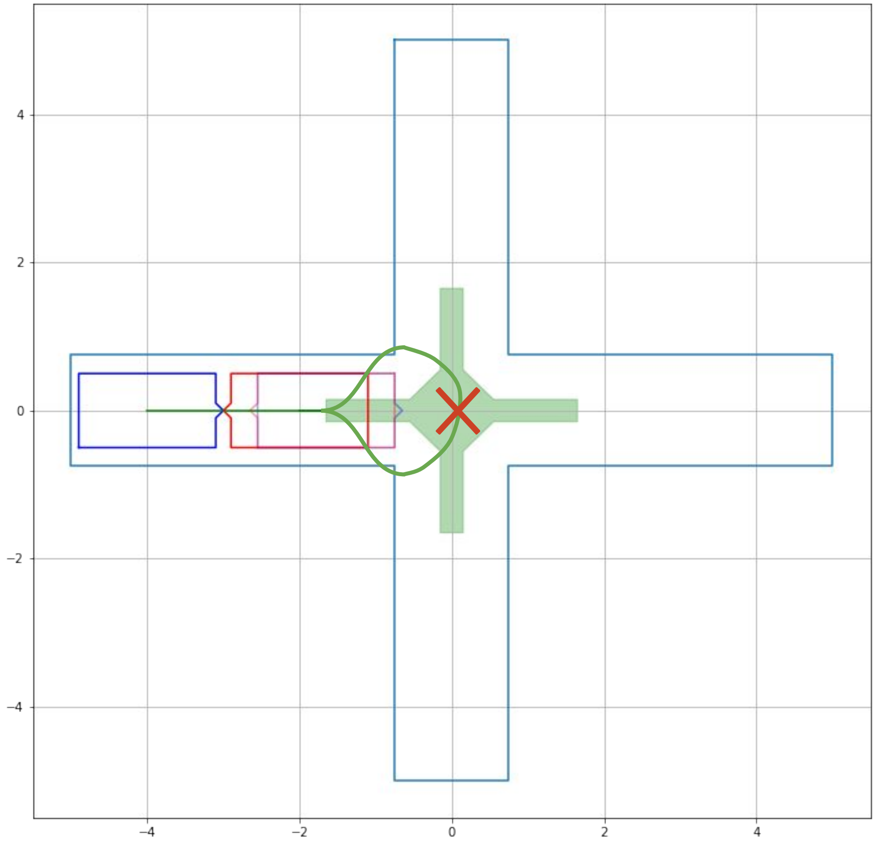
- Find the nearest edges and orientation towards the center
- Check possible path from the nearest edges
- Find another edge for both orientation towards and away from the center and compute forward and reverse path from the new edge.
- Different start and end poses of robot

Geometric Planner for Confined Spaces



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- Find the nearest edges and orientation towards the center
- Check possible path from the nearest edges
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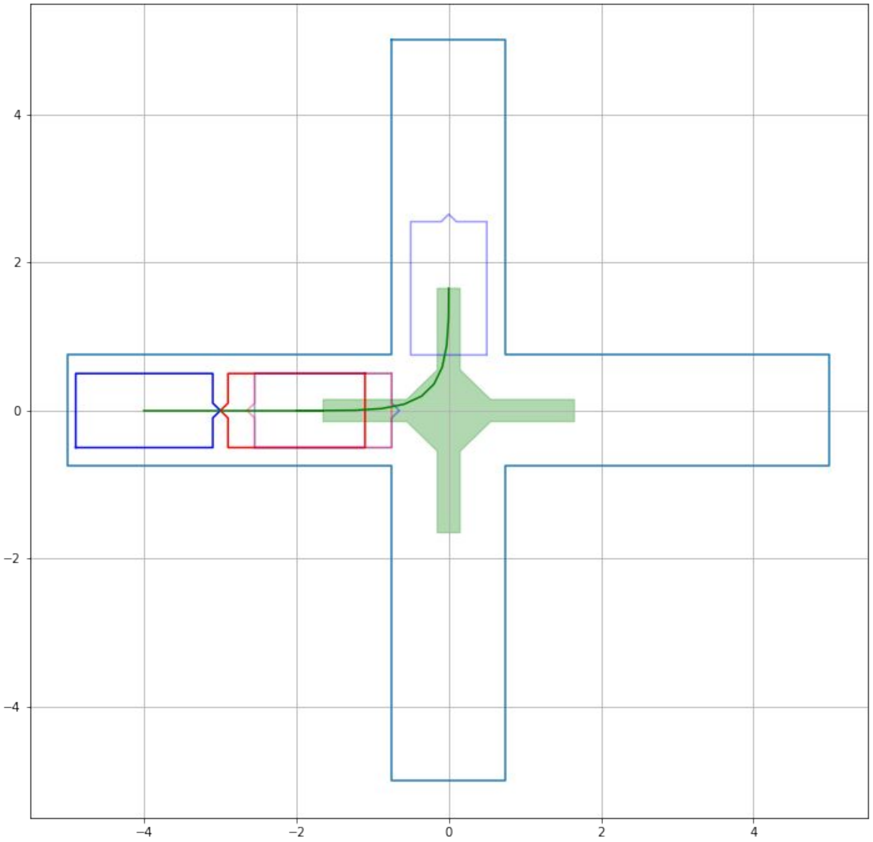
- Different start and end poses of robot

Geometric Planner for Confined Spaces



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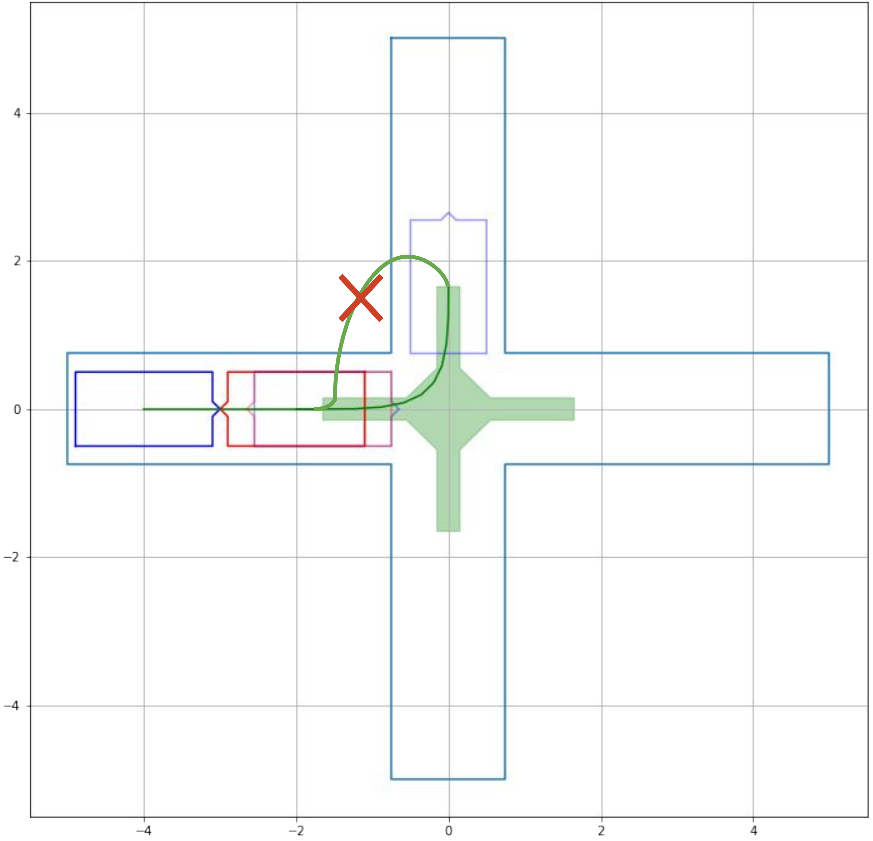
Confined space planner:

- Given start and goal pose of the robot
- Find the nearest edges and orientation towards the center
- Check possible path from the nearest edges
- Find another edge for both orientation towards and away from the center and compute forward and reverse path from the new edge.
- Different start and end poses of robot

Geometric Planner for Confined Spaces



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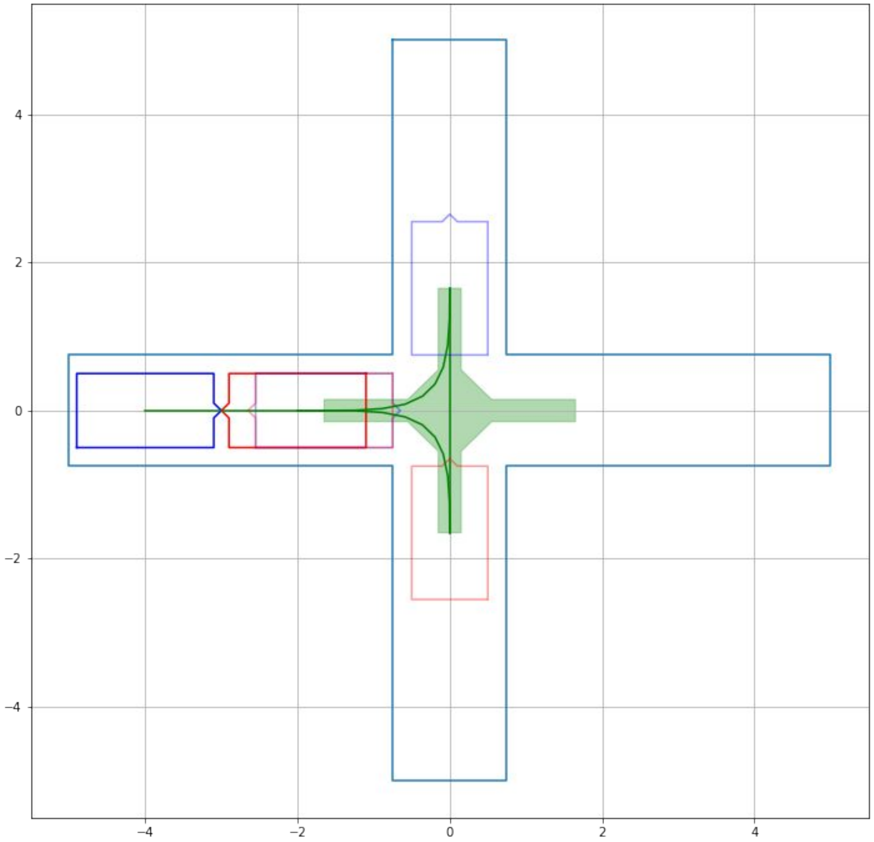
- Different start and end poses of robot

Geometric Planner for Confined Spaces



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- Different start and end poses of robot

Geometric Planner for Confined Spaces

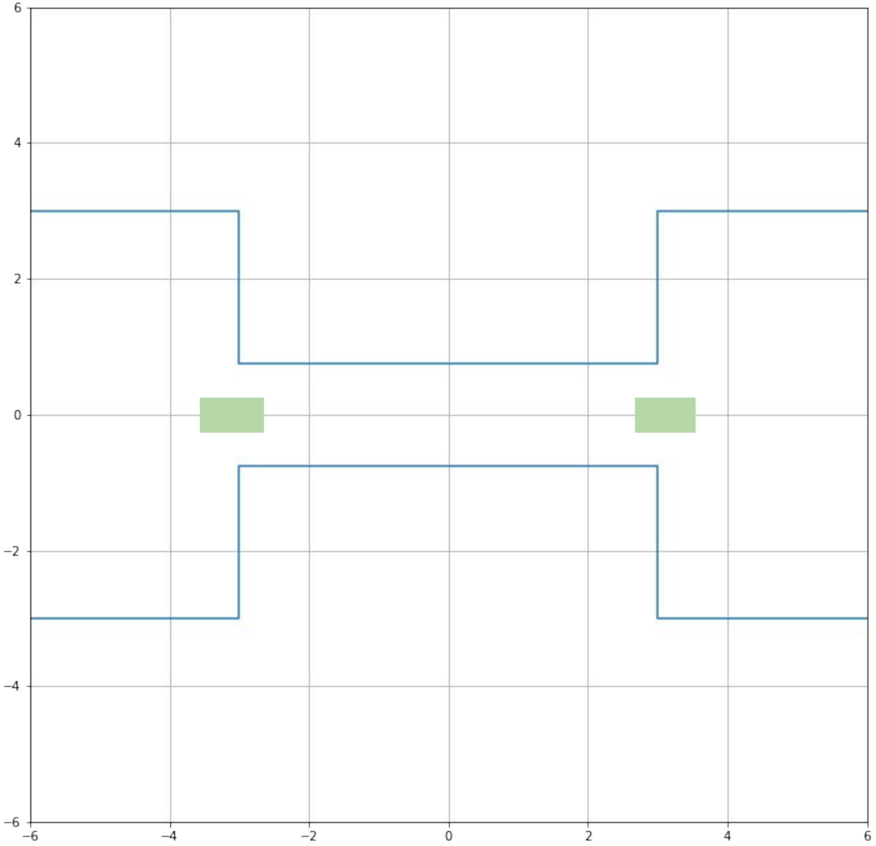

Figure 30

Confined space planner:

- Narrow space between open spaces

Geometric Planner for Confined Spaces

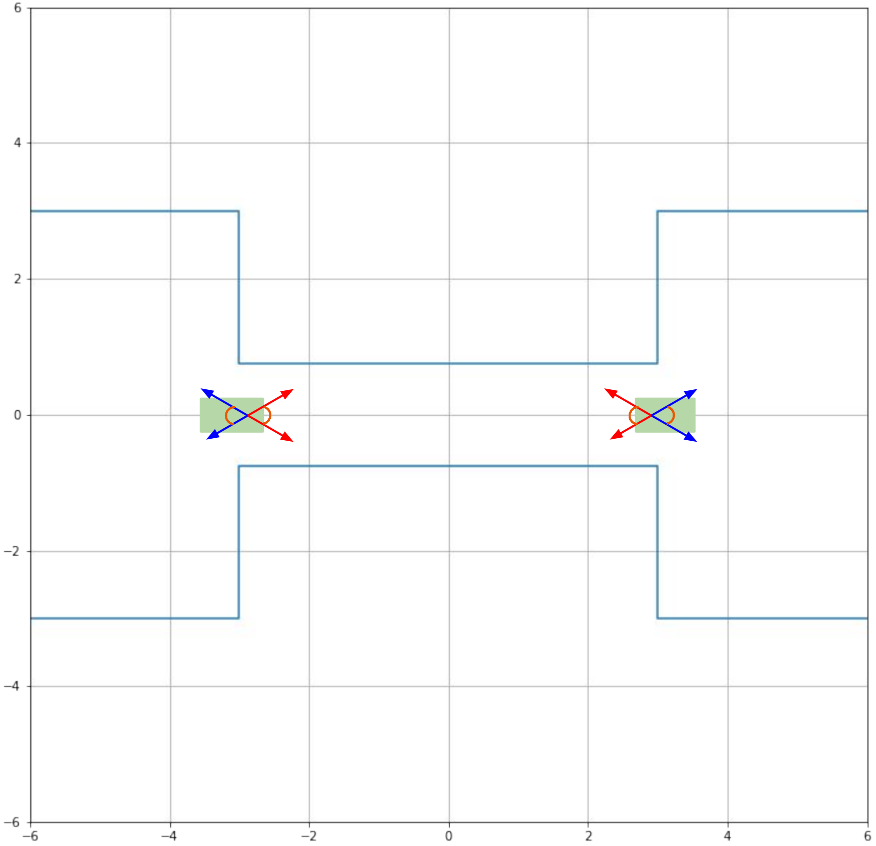

Figure 30

Confined space planner:

- ○ Narrow space between open spaces
- ○ Obtains allowable poses to enter and exit the narrow space

Geometric Planner for Confined Spaces

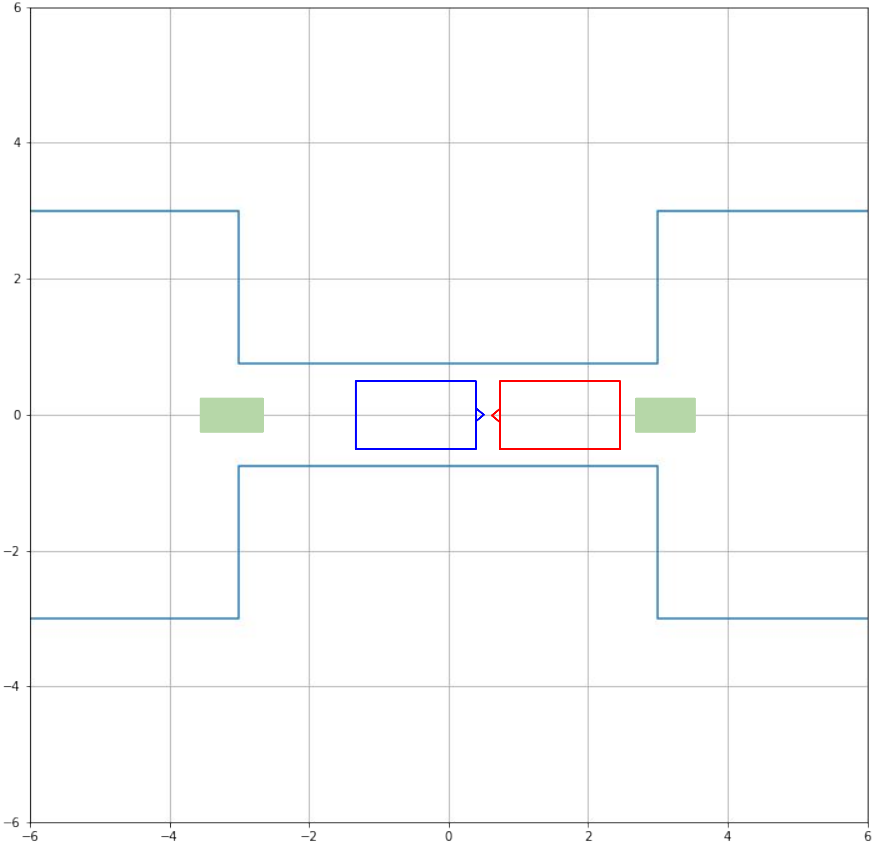

Figure 30

Confined space planner:

- Narrow space between open spaces
- Obtains allowable poses to enter and exit the narrow space

Geometric Planner for Confined Spaces

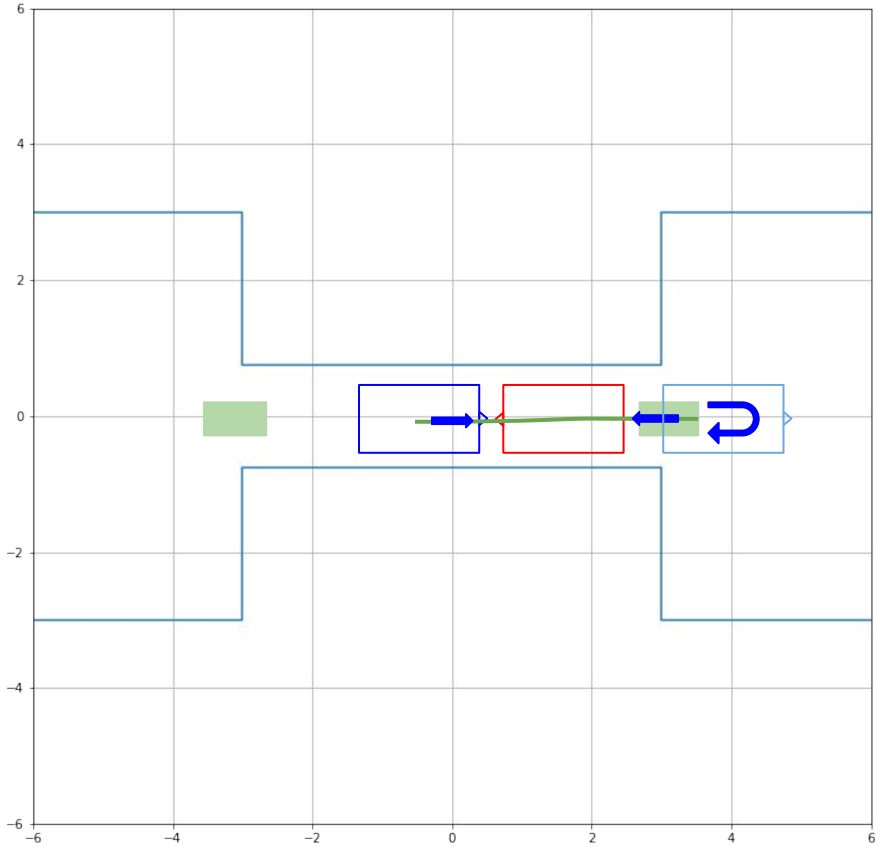

Figure 30

Confined space planner:

- Narrow space between open spaces
- Obtains allowable poses to enter and exit the narrow space

Geometric Planner for Confined Spaces

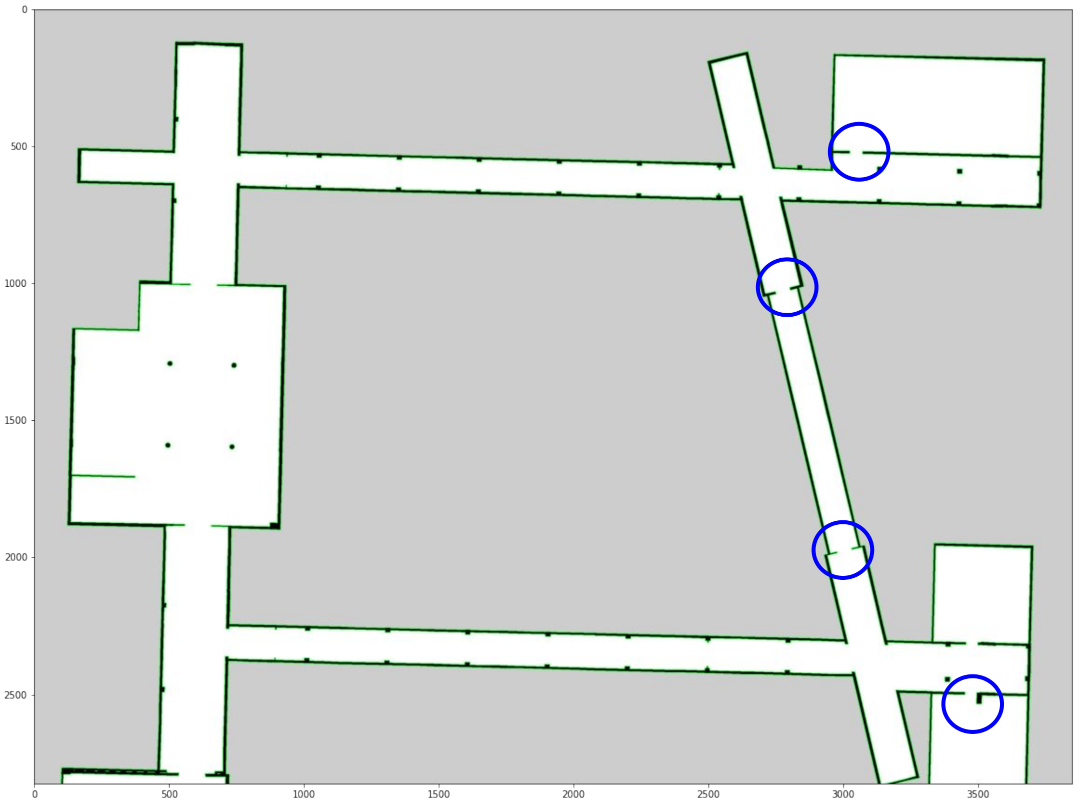

Figure 31

Confined space planner:

- Narrow space between open spaces
- Obtains allowable poses to enter and exit the narrow space

Geometric Planner for Confined Spaces

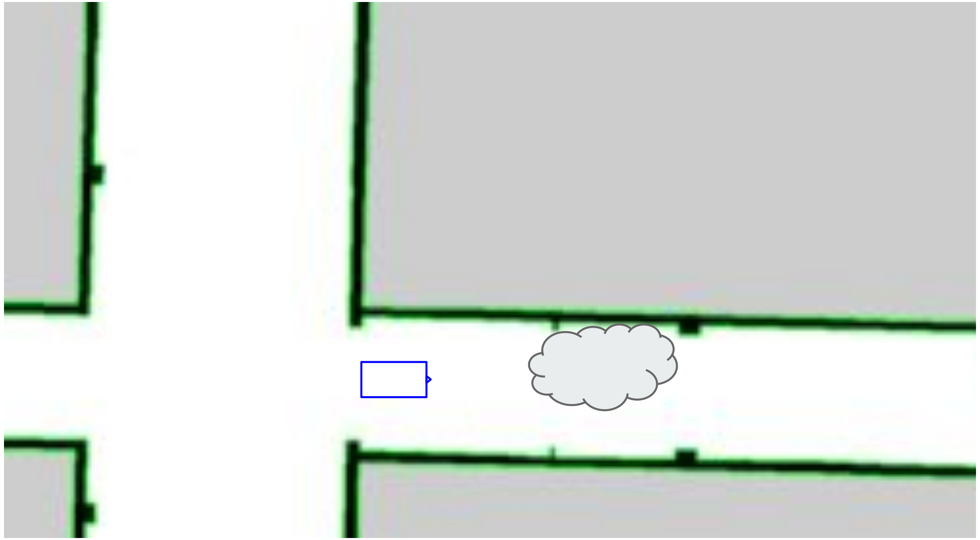

Figure 32

Confined space planner:

- Narrow space between open spaces
- Obtains allowable poses to enter and exit the narrow space

Geometric Planner for Confined Spaces

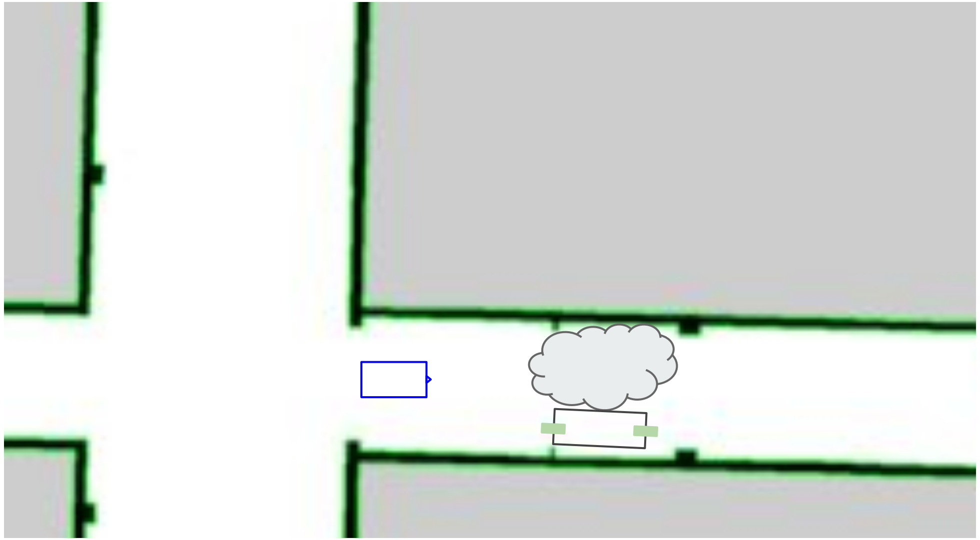

Figure 32

Confined space planner:

- Narrow space between open spaces
- Obtains allowable poses to enter and exit the narrow space
- Creates confined window during obstacles avoidance

Geometric Planner for Confined Spaces

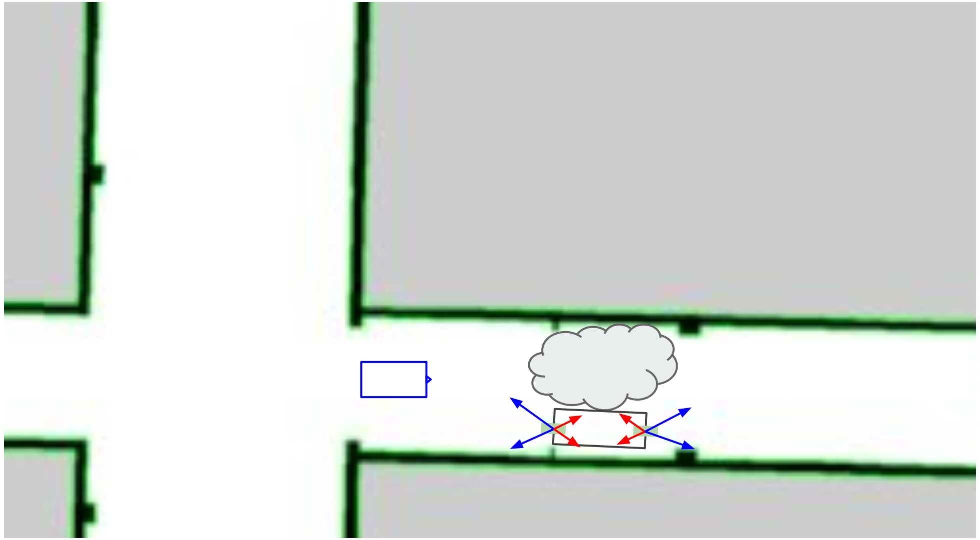

Figure 32

Confined space planner:

- Narrow space between open spaces
- Obtains allowable poses to enter and exit the narrow space
- Creates confined window during obstacles avoidance

Geometric Planner for Confined Spaces

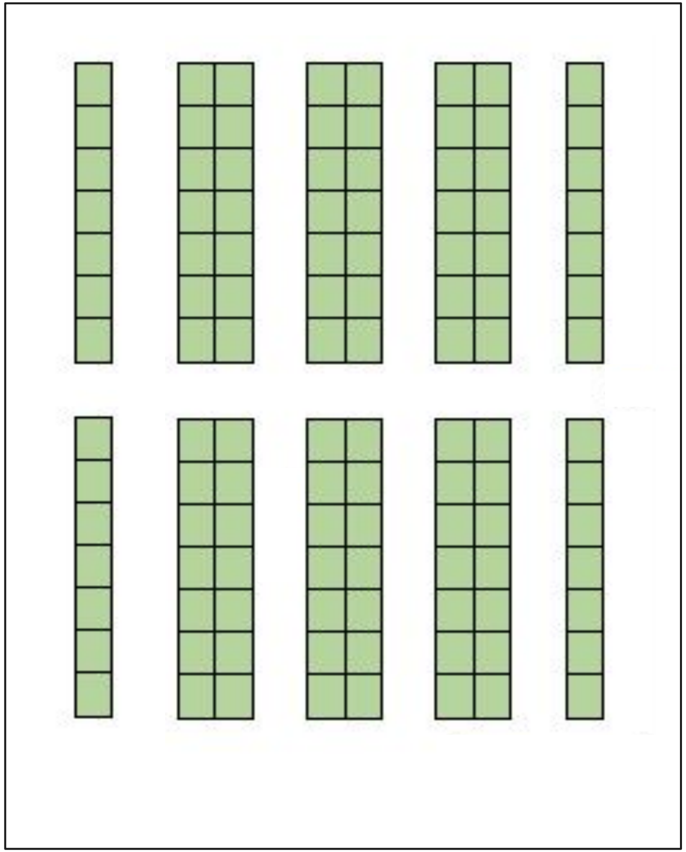

Figure 33

Confined space planner:

- Narrow space between open spaces
- Obtains allowable poses to enter and exit the narrow space
- Creates confined window during obstacles avoidance
- Best suited for warehouse navigation with narrow aisles

Geometric Planner for Confined Spaces

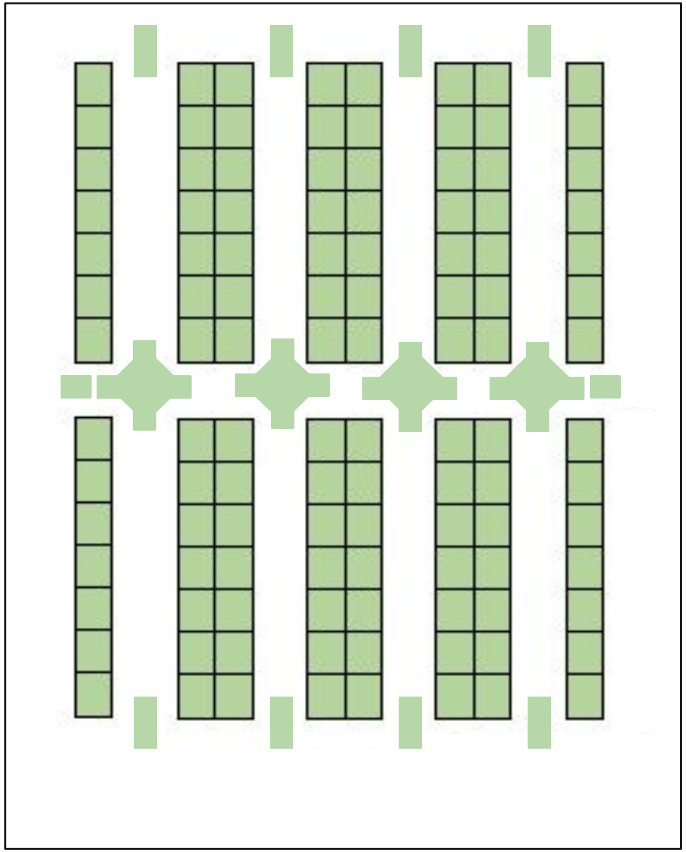

Figure 33

Confined space planner:

- Narrow space between open spaces
- Obtains allowable poses to enter and exit the narrow space
- Creates confined window during obstacles avoidance
- Best suited for warehouse navigation with narrow aisles
- Multiple junctions can be generated, connected by a graph

Milestones

Milestones to complete:

- Minimum Viable:
  - Framework: Implement controller, localization, ROS wrapper and some common utility functions
  - Modify and implement state-of-the-art approaches for the ROBILE platform in simulation and reality
  - Evaluated and compare (soundness, completeness and complexity) the outputs for multiple established scenarios

- Expected:
  - Develop and implement an online geometric planner for the same scenarios
  - Evaluated and compare with state-of-the-art approaches

- Desired:
  - Test in complex and dynamic (moving obstacles) environment to find where is fails
  - Integrate into a framework which handles different spaces

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Thank You