Improved Bi-Directional RRT* using Artificial Field Potential

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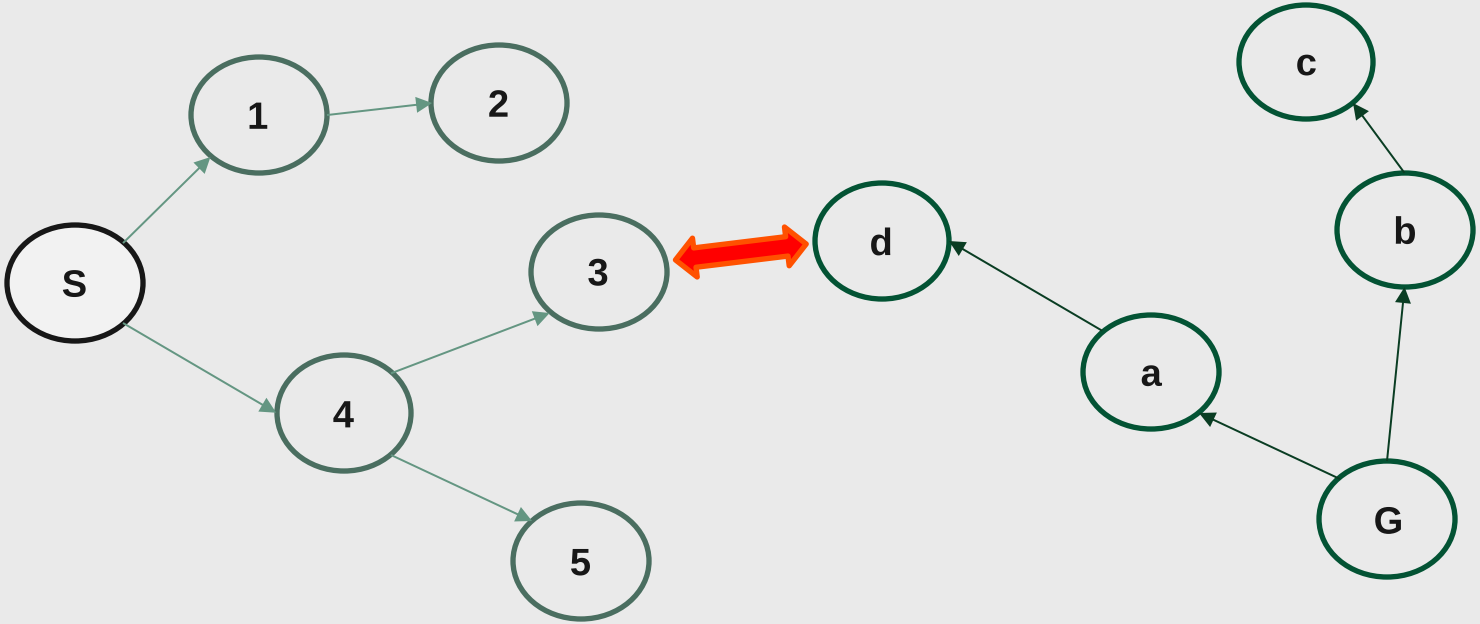
CONTENTS

Bi-Directional RRT*

- When using a single random tree to search the whole space, the search efficiency is low. Using the RRT* algorithm to expand the random tree at both the start and goal sides can improve search efficiency.

- When two trees are connected or when two trees are within a certain distance from each other, the search is completed.

Bi-Directional RRT*



Path: S → 4 → 3 → d → a → G

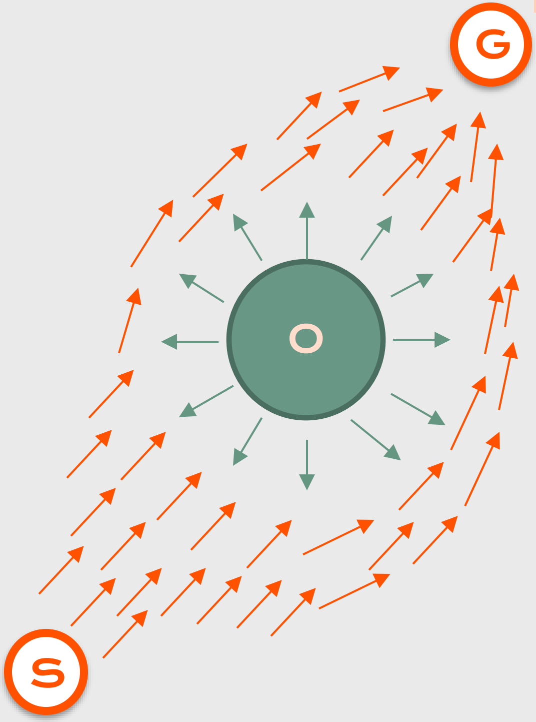
What is Artificial Potential Field?

- The fundamental idea behind APF is to treat the robot as a particle moving in an artificial force field generated by the goal and obstacles in the environment.

- The force field consists of attractive forces that guide the robot towards the goal and repulsive forces that steer the robot away from obstacles.

- The robot's movement is determined by the combined effect of these forces, which are mathematically represented as potential fields.

Components:
1. Attractive Potential Field
2. Repulsive Potential Field



Attractive Potential Field

- The attractive potential field is designed to guide the robot towards its goal. It is typically modeled as a quadratic function, which generates a force proportional to the distance between the robot's current position and the goal position. The attractive potential field is defined as:

$$U_{att} = \frac{1}{2} c \rho^2 (P, P_{goal})$$

where,

- c is a positive constant that determines the strength of the attractive force
- $\rho(P, P_{goal})$ is the Euclidian distance between the robot’s current configuration P and goal configuration P_{goal}

Repulsive Potential Field

- The repulsive potential field is designed to prevent the robot from colliding with obstacles. It is typically modeled as an inverse quadratic function, which generates a force that increases as the robot gets closer to an obstacle. The repulsive potential field is defined as:

$$U_{rep} = \begin{cases} \frac{1}{2}\mu\left(\frac{1}{\rho(P, P_{0bs})} - \frac{1}{\rho_0}\right)^2, & \rho(P, P_{0bs}) \le \rho_0 \\ 0, & \rho(P, P_{0bs}) > \rho_0 \end{cases}$$

where,

- μ is a positive constant that determines the strength of the repulsive force
- $\rho(P, P_{0bs})$ is the Euclidian distance between the robot's current configuration P and nearest obstacle configuration P_{0bs}
- ρ_0 is the distance threshold for the influence of the repulsive potential field

Total Potential Field and Robot Motion

- The total potential field is the sum of the attractive and repulsive potential fields:

$$U = U_{att} + U_{rep}$$

- The robot's motion is determined by the gradient of the total potential field, which represents the force acting on the robot:

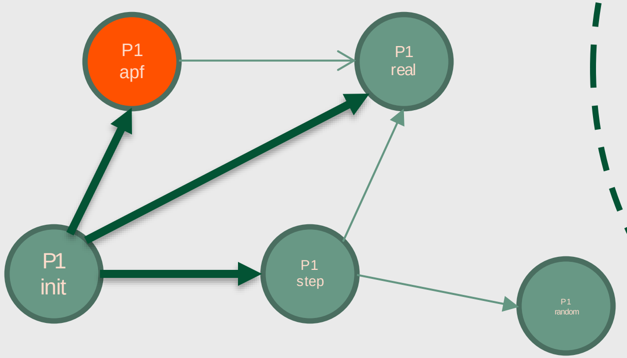
$$F_{total} = -\nabla U_{total}$$

- The robot moves in the direction of the force vector F_{total}, which is derived from the total potential field. This enables the robot to navigate towards the goal while avoiding obstacles.

Search Method

- $P1_{init}$: Current node
- $P1_{APF}$: Artificial potential field method's bias of the current node
- $P1_{step}$: Node extended by one step
- $P1_{real}$: Actual extended node.
- $P1_{rand}$: Randomly sampled node

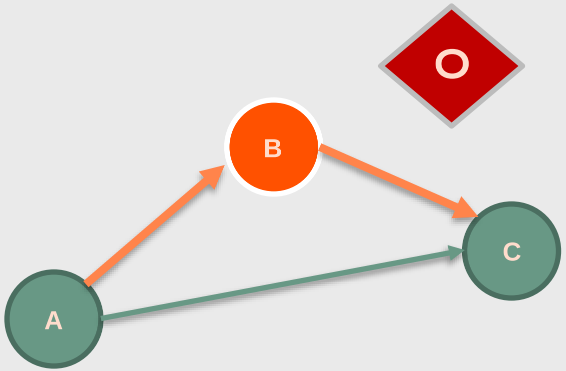
- The artificial potential field method is first used to improve the sampling points; then, the nodes in the path are re-selected as parents to further optimize the path.



Path Optimization

The line between points A and C does not pass through the obstacle, in which case point B is the redundant node.
At this time, the path planned by the improved bidirectional RRT* algorithm is optimized to extract key nodes and eliminate redundant nodes. The specific steps of the process are as follows:

1. Put all the nodes into the set $\{P_1, P_2, P_3 \ldots P_n\}$ in order.
2. Connect the nodes in the set one by one from the starting node Pt until the connection between the node with P_{t+1} passes the obstacle and P_t is the key point in the set. At this point, starting from P_t, connect the remaining nodes in turn until all the key points are found.
3. Connect the key points and target points in sequence from the starting point to plan the new path.
4. We use Euclidian distance to calculate the length of the path.



Detailed Pseudocode

Initialize constants:

- K: Attractive force constant
- MU: Repulsive force constant
- RHO: Obstacle radius of influence
- clearance: Clearance distance from obstacles

Define helper functions:

- line_points: Generates points along a line between two given points
- steer: Computes the next point along a line between two points considering the potential forces
- costs: Computes Euclidean distance between two points
- path_cost: Computes the total cost of a path by summing the distance between consecutive points
- calculate_repulsive_force: Calculates the repulsive force from obstacles for a given point
- calculate_potential_force: Calculates the total potential force (attractive + repulsive) for a given point
- Trees: Class to manage the R-tree data structure for vertices and edges
- BiDirectionalRRTStarAPF: Class for bi-directional RRT* with artificial potential field algorithm

Detailed Pseudocode

Initialize the BiDirectionalRRTStarAPF class with the following parameters:

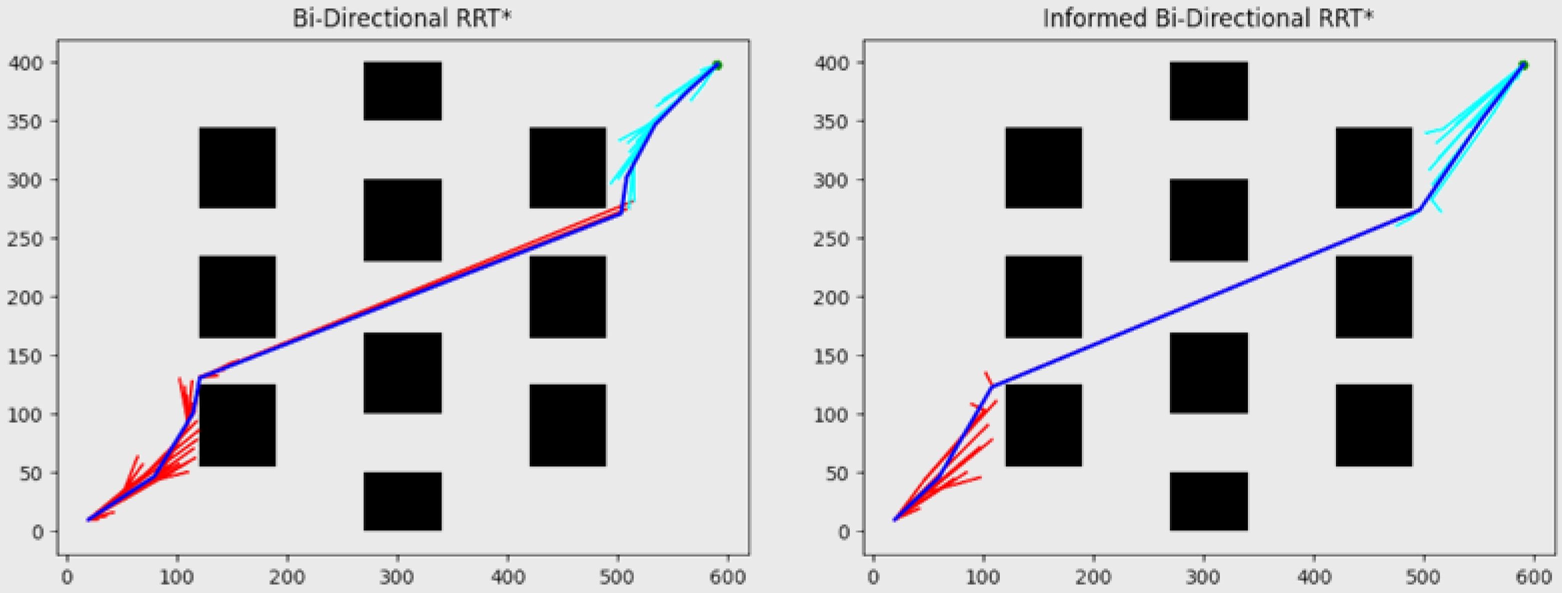
- dlen: Length of the dimensions
- Q: Array of steering parameters
- start: Start point
- goal: Goal point
- max_samples: Maximum number of samples
- r: Radius for rewiring
- obstacles: List of obstacle coordinates
- prob: Probability of random connection
- rcount: Number of vertices to consider for rewiring

Implement the bidirectional RRT* algorithm with artificial potential field:

- Initialize the two trees with the start and goal points
- While not reached maximum samples:
  - For each steering parameter in Q:
    1. Generate a random point in the configuration space and connect it to the nearest vertex in tree 0
    2. Rewire the tree 0 considering the new point
    3. Check if the new point can be connected to tree 1, if so, update the best path
    4. With a certain probability, switch the roles of tree 0 and tree 1
- If a path is found, return the best path, otherwise return None

Plot the results (obstacles, path, trees, starting point, and goal point)

Comparision



Samples Checked: 169

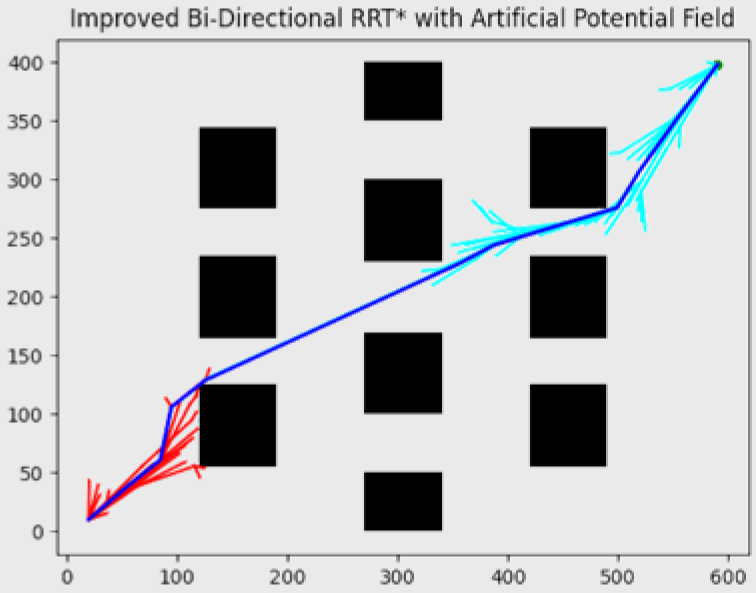
Samples Checked: 76

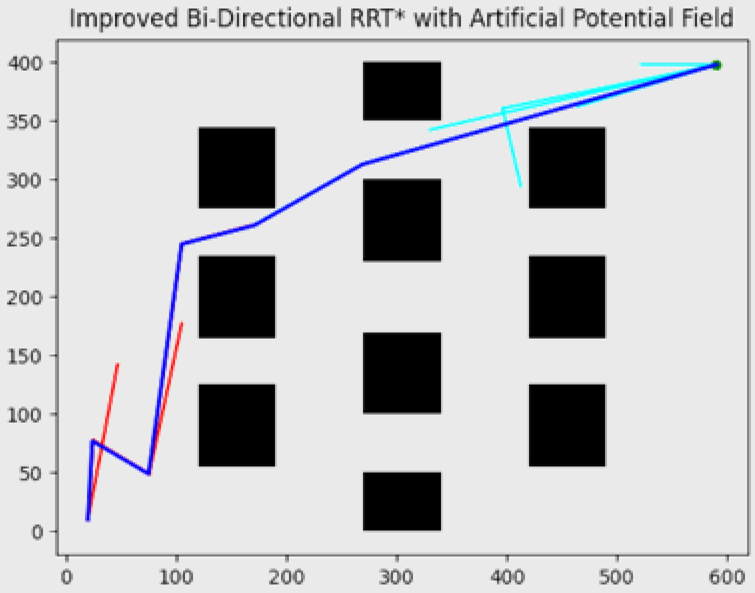
Comparision with Informed RRT*

Informed RRT* is another variant of the RRT* algorithm that uses a heuristic, such as the Euclidean distance, to guide the sampling process.
By restricting the sampling region, informed RRT* can find better solutions more quickly compared to the basic RRT* algorithm. However, when compared to the integrated Bidirectional RRT* and APF approach, informed RRT* has some limitations:

- The heuristic used in informed RRT* may not always be the best choice for all environments or problems
- Informed RRT* does not explicitly consider obstacle avoidance, which can lead to a higher number of explored nodes and increased computational time
- The integrated approach combines the advantages of both Bidirectional RRT* and APF, leading to improved exploration efficiency and faster convergence

Paths with Different Values





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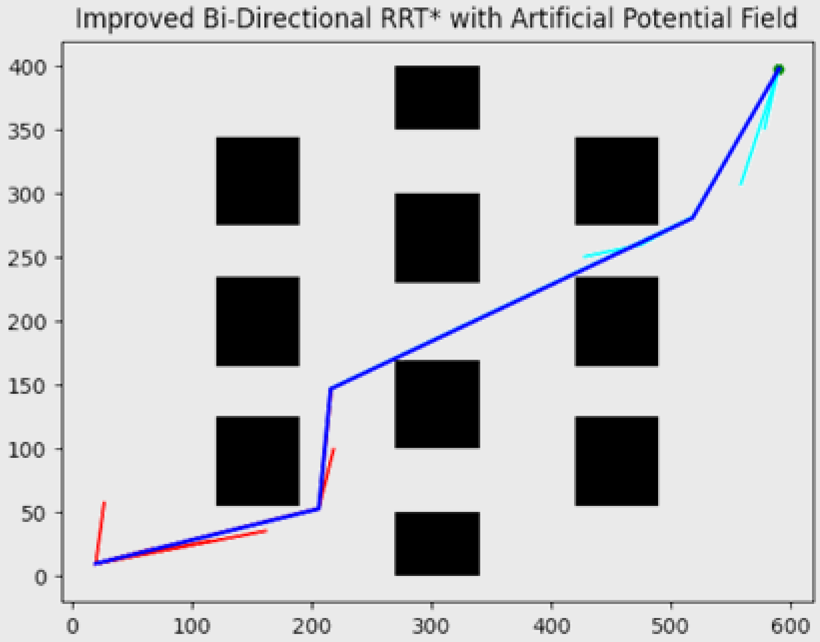
Unoptimized Path



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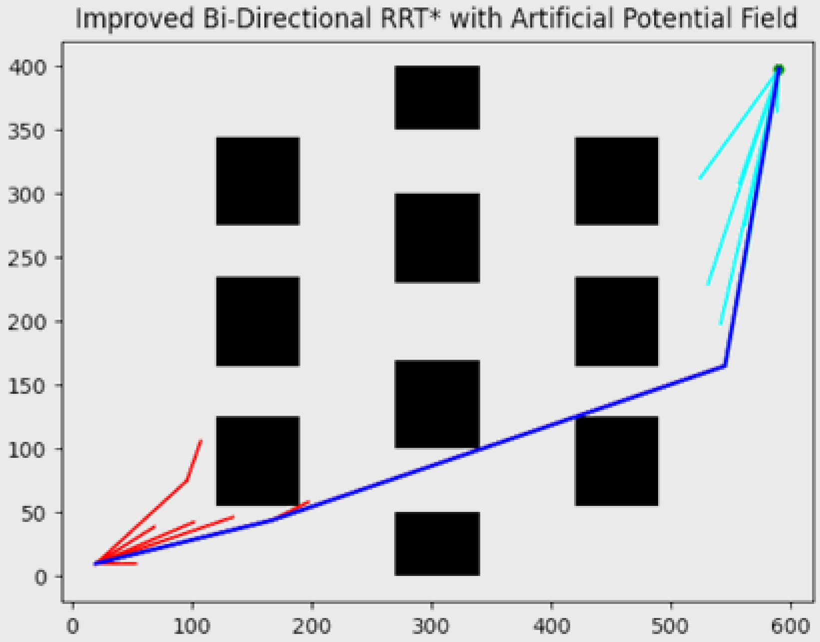
Best Path



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Potential Limitations

LOCAL MINIMA

The robot can get trapped in local minima of the potential field, which occurs when the attractive and repulsive forces cancel each other out.

PARAMETER TUNING

The performance of APF is sensitive to the choice of parameters (k_{attr}, k_{repr}, and $dist_{thresh}$), which may require manual tuning for different environments.

OSCILLATIONS

The robot may oscillate between two or more points in the presence of narrow passages or closely-spaced obstacles.

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Thank You