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Research on Path Planning of Manipulator Based on Improved Bi-RRT Algorithm

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***Abstract*—Aiming at the problems that the bidirectional rapidly expanding random tree algorithm (Bi-RRT) generates many redundant nodes and the generated path has many large-angle turning points in the robot path planning, the path selection, node screening and path smoothing are analyzed from three perspectives. The traditional algorithm is optimized so that the manipulator can reach the target point with the shortest path on the basis of avoiding obstacles. At the same time, the angle changes of 6 joints are smoothed, and the broken line part in the path is eliminated, so that the manipulator can run smoothly and safely. Simulation experiments show that the improved algorithm shortens the original path length by 35% on average.**

***Keywords*—Manipulator, Bidirectional Rapidly Expanding Random Tree, Path Shortening, Smoothing**

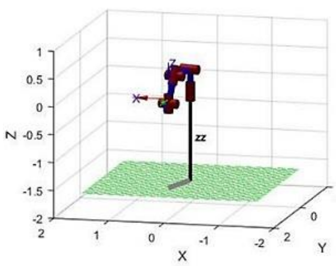
I. INTRODUCTION

With the development of science and technology and the concept of "Made in China 2025" and "Industry 4.0", the manufacturing industry is constantly moving towards automation and intelligence [1]. Industrial robots play an extremely important role in the development of the manufacturing industry. Role, we can see manipulators flexibly and quickly assemble parts in industrial sites to complete tasks in complex environments. People's demand for high-precision and high-intelligence robots continues to increase, and obstacle avoidance path planning has also become a research hotspot in the field of robotics.

The path planning of the manipulator refers to planning a collision-free path based on the known starting point, target point and the position of the obstacle in the workspace [2]. The traditional path planning algorithm can be divided into: traditional algorithm and intelligent algorithm according to the development time. algorithm. The traditional algorithms mainly include: artificial potential field method (APF), in which the APF method is easy to fall into local minima due to lack of global information when performing path planning [3]. The A* algorithm requires a lot of space to store environmental information, and the path planning efficiency is low [4]. Intelligent algorithms mainly include: ant colony algorithm [5], ant colony algorithm has better effect in low-dimensional path planning, but in the path planning of high-dimensional 6-DOF manipulators, due to more joints, the path planning will be more difficult to compare. complex. Genetic algorithm, genetic algorithm [6] can obtain approximate optimal path but it is difficult to control the rate of evolution. Rapid Search Random Tree (RRT) [7-8] is a widely used algorithm for high-dimensional path planning. It was proposed by LaValle in 1998. It finds a collision-free path by continuously sampling randomly in space. It has probabilistic completeness. When the number of iterations is infinite, the probability of the algorithm planning a path is 1. The defects of the RRT algorithm are also obvious. Due to the large randomness of sampling, the expansion of the tree is not guided and the efficiency of the algorithm is low [9]. Therefore, many scholars at home and abroad have improved the algorithm. Combining the artificial potential field method and the fast expanding random tree method not only overcomes the problem that the artificial potential field method is easy to fall into a local minimum, but also solves the problem that the expansion of the RRT algorithm is not guided [10]; The weight introduced by the node is to gradually approach the target node and accelerate the convergence speed [11]; Liu Yaqiu added the expansion point selection strategy and the adaptive step size strategy on the basis of the traditional RRT algorithm, thereby improving the planning efficiency [12]. Liu Aobo proposed a target-biased bidirectional RRT* algorithm, in which the two trees are expanded toward their respective target points with a certain probability at the same time, and the path is pruned and smoothed at the same time, and a better path can be obtained [13] .

II. KINEMATIC MODELING OF MANIPULATOR

In this paper, a 6-DOF serial manipulator as shown in Figure 1(a) is used as the research object, which consists of 6 independent joints, each of which has a certain rotation angle [14], as shown in Figure 1(b), the model diagram of the connecting rod coordinate system between adjacent axes of the manipulator. Table 1 is the D-H(Denavit-Hartenberg) parameter table of the manipulator.



(a)model of manipulator

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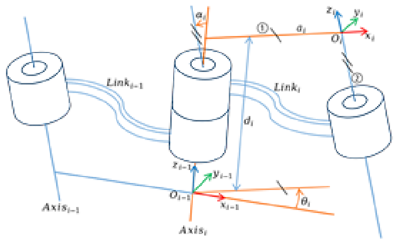

(b) The coordinate system of the manipulator link

Fig. 1. Kinematic Modeling of Manipulator

Table 1: DH parameters of each link

Link i	d_i	a_{i-1}	α_{i-1}	θ_i
1	0	0	0°	90°
2	d_2	0	-90°	0°
3	0	a_2	0°	-90°
4	d_4	a_3	-90°	0°
5	0	0	90°	0°
6	d_6	0	-90°	0°

The meaning of the 4 DH parameters: a_i represents the length of the connecting rod, that is, the distance from z_i to z_{i+1} translation along the x_i direction; α_i represents the connecting rod angle between z_i and z_{i+1}; d_i represents the link offset, that is, x_{i-1} translates the distance d_i along the z_{i-1} axis to make it collinear with x_i;θ_i represents the joint angle of the i-th joint , that is, after rotating the z_{i-1} axis by an angle of θ_i, x_{i-1} is parallel to x_i. These four parameters determine the state space description between adjacent links. According to the forward and inverse kinematics solutions of the six-degree-of-freedom manipulator, the world coordinates in the free space where the manipulator is located can be related to the relative motion of each joint of the manipulator, The rotation degrees are converted to each other using matrix functions [11].

The general formula for the homogeneous transformation between coordinate system i and coordinate system i-1 is as follow:

$$ {}^{i-1}_{i}T = \begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & a_{i-1} \\ \sin\theta_i\cos\alpha_{i-1} & \cos\theta_i\cos\alpha_{i-1} & -\sin\alpha_{i-1} & -d_i\sin\alpha_{i-1} \\ \sin\theta_i\sin\alpha_{i-1} & \cos\theta_i\sin\alpha_{i-1} & \cos\alpha_{i-1} & d_i\cos\alpha_{i-1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

According to the above formula, the second transformation matrix of the coordinate system of the end of the manipulator relative to the base coordinate system can be obtained through the forward kinematics solution as in(2):

$$ {}^{0}_{6}T = {}^{0}_{1}T\,{}^{1}_{2}T\,{}^{2}_{3}T\,{}^{3}_{4}T\,{}^{4}_{5}T\,{}^{5}_{6}T = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

The 3*3 matrix in the upper left corner represents the joint pose of the manipulator, and P represents the three-dimensional coordinates of the manipulator.

III. Basic Principles of Traditional RRT Algorithms

RRT algorithm is a high-dimensional search algorithm based on random sampling proposed by LaValle.Create a collision-free path from the starting point x_{init} to the target point x_{goal}. The schematic is as in figure(2):

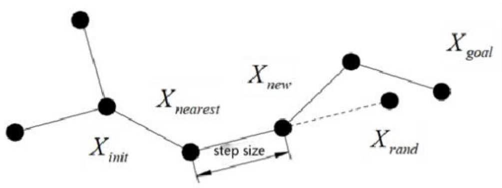

Fig. 2. Schematic of RRT algorithm

Step1. Initialize the workspace and limit it. There is only one starting point x_{init} and one target point x_{goal} in the entire workspace.

Step2. A random node x_{goal} is generated in the space defined by step 1 using a random distribution function.

Step3. Find the node $x_{nearest}$ closest to the random node x_{rand} by traversing all existing nodes, expand from $x_{nearest}$ to x_{rand} with a fixed step size λ , and generate a new node x_{new}.

Step4. Perform collision detection on the newly generated node x_{new} and between $x_{nearest}$ and x_{new}, if it passes the collision detection, it will be added to the random tree, if not, it will be discarded, and random sampling will be performed again [15].

Step5. Determine whether x_{new} has reached the target point x_{goal}, or meet the requirements, the algorithm ends, otherwise go to 2nd step for the next iteration until the target point is found.

Although the RRT algorithm is a better global planning algorithm, compared with local search algorithms such as the Artificial Potential Field method, it has the advantage that the system is not easy to fall into the minimum value, but the RRT algorithm also has some disadvantages:

- Nodes are more random. Since the RRT algorithm determines the nodes through a random distribution function, the searched path will be blind and unguided.
- Convergence is slower. Since the traditional RRT algorithm is extended with a fixed step size, it also takes a lot of time in a space with few obstacles. When the distance between the newly generated node and the target point is less than the step size, the algorithm will not move to the target. Click to expand directly.
- The resulting path is poor. Since the nodes are randomly generated, a large number of redundant nodes will be generated, the path cost is high, and the generated path has a large-angle jitter phenomenon, which will cause damage to the motor of the manipulator.

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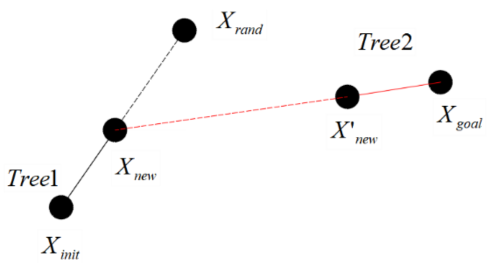
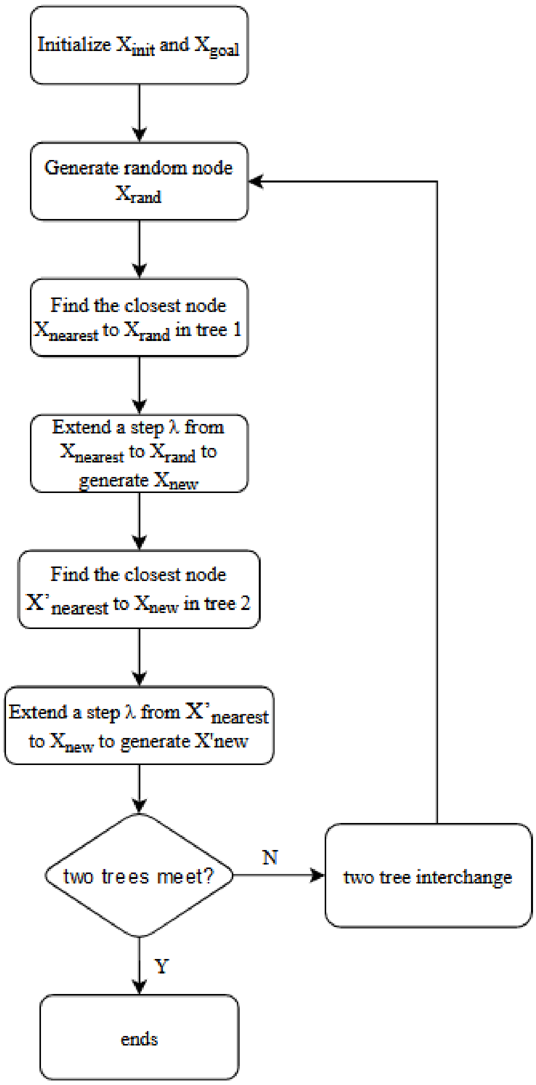
IV. IMPROVED BI-RRT ALGORITHM

A. *Bi-RRT algorithm*

The Bi-RRT algorithm takes the starting point x_{init} and the end point x_{goal} as the root nodes, respectively, to construct two rapidly expanding random trees, and the two trees grow alternately until they meet [16]. Compared with the original RRT, the improved algorithm builds a second tree in the target point area for expansion. In each iteration, the starting step is the same as the original RRT algorithm, which is to sample random points and then expand. Then, after expanding the new node of the first tree, take this new target point as the direction of the second tree expansion, and extend a step in this direction [17]. Then judge whether the two trees meet, and if they do not meet, exchange the two trees and repeat the above process until the two random trees meet, that is, the algorithm end. The schematic is shown in figure 3(a). The following figure 3(b) shows the flow chart of Bi-RRT algorithm:



(a) The schematic of Bi-RRT



(b) the flow chart of Bi-RRT

Fig. 3. Schematic and flow chart of Bi-RRT

B. *Path shortening process*

Through the Bi-RRT algorithm, a collision-free path can be generated, but some redundant nodes far from the target point will also be randomly generated, causing the path to have a large-angle deflection. The mutation of these paths will make the path distance longer. Therefore, delete these redundant nodes. The schematic diagram is shown in figure 4.

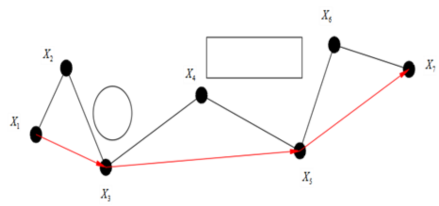


Fig. 4. Schematic of Path shortening process

Step1. Number all nodes that have initially formed a path $X_1, X_2, \dots\dots X_i, X_n$.

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Step2. Start from the first node and connect with subsequent nodes accordingly and perform collision detection.

Step3. If the connection between the current node X_i and the first node cannot pass the collision detection, then connect the previous node X_{i-1} with the initial node as a new connection, and connect the initial node to X_{i-1} Nodes in between are deleted.

Step4. Starting from the X_{i-1} node, it connects with the following nodes in turn and judges it until it reaches the target point, and obtains the path L_1. Through such a pruning operation, the redundant nodes of the initial path can be eliminated, so that the path length can be effectively shortened.

C. *Path smoothing*

After the above steps, the algorithm has generated a path with a short distance, but the generated path is formed by several line segments connected at the node, so there is still a turning point at the node, and the angle at the turning point changes too much. The nodes are in a jagged shape, and when the manipulator encounters this state during operation, it may have a bad influence on parts such as motors, and even cause damage to the manipulator. At present, the methods used to smooth the robot path include Bezier spline method, B-spline method, NURBS method, etc. Among them, the B-spline method has higher accuracy after processing, and the path is continuous and smooth, but the amount of calculation is large, and the Bezier spline method It is simpler to construct than other algorithms, and the interpolation efficiency is also higher [18], so this paper uses Bezier splines to smooth the path.. The expression of the n-th degree Bezier spline is shown in the following Eq.(1)：

$$P(t)=\sum_{i=0}^{n} P_i B_i, n(t) \tag{3}$$

where t represents the time variable, P_i is the control point of the Bezier curve, and in Eq.(2) $B_{i,n}(t)$ is the n-th Bezier basis function.

$$B_{i,n}(t)=C_n^i t^i (1-t)^{n-1} \tag{4}$$

The smoothing of cubic Bezier splines is shown in figure 5 below：

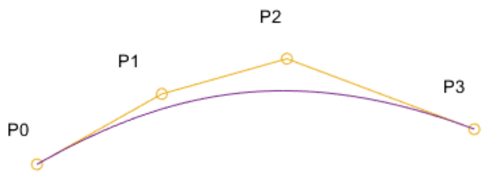
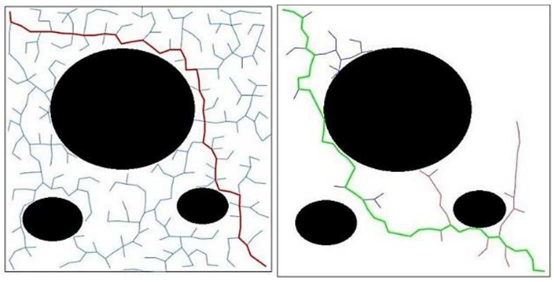


Fig. 5. Path smoothing effect drawing

V. SIMULATION

A. *2D space simulation experiment*

First, perform path planning in two-dimensional space in a 500x500 map. The coordinates of the initial point are (10, 10), the coordinates of the end point are (490, 490), the step size is set to 20, and the maximum number of iterations is set to 1000 times, respectively. The RRT algorithm and Bi-RRT algorithm are used for simulation, and the simulation results are shown in Figure 5. The final generated paths are marked in red and green.



(a) RRT algorithm (b)Bi-RRT

Fig. 5. 2D simulation diagram of the algorithm

From the comparison in Figure 5, it can be seen that the RRT algorithm generates a large number of redundant nodes during sampling, and generates many inflection points of the path, the direction changes greatly, and the path planning efficiency is low. The redundant nodes generated by the Bi-RRT algorithm are compared with the RRT. There are few algorithms, and the comparison results obtained by taking the average after ten experimental simulations are shown in Table 2 below:

Table 2: Comparison of simulation results

	time	path length	number of nodes
RRT	8.95	944.81	40
Bi-RRT	4.03	914.77	43

According to Table 2, it can be seen that the time consumed by the Bi-RRT algorithm is 54% less than that of the RRT algorithm, but the generated path length and the number of path nodes are not much different. Therefore, the Bi-RRT algorithm is optimized according to the pruning strategy. The optimized path The simulation is shown in Figure 6:

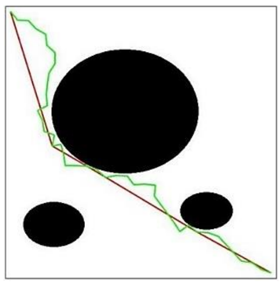


Fig. 6. Path after pruning policy processing

It can be seen from figure 6 that the algorithm after node optimization eliminates all redundant nodes, and the generated path is better than the traditional algorithm in terms of node and path length. Table 3 is the comparison of the simulation results.

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Table 3: Comparison of simulation results

	time	path length	number of nodes
RRT	8.95	944.81	40
Bi-RRT	5.03	914.77	43
Improved	5.78	723.15	5

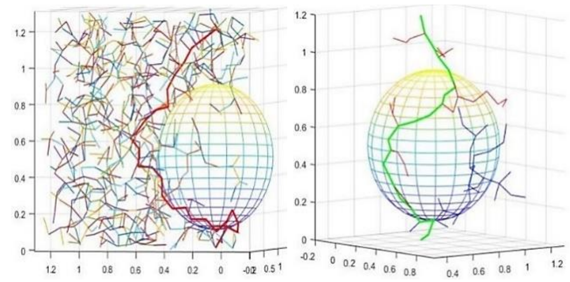
B. Manipulator Simulation Experiment

The three-dimensional simulation experiment of the manipulator is carried out in the robot toolbox of matlab. In order to simplify the scene obstacles are set to spheres, and the simulation parameters are set as shown in Table 4:

Table 4: parameter settings

Start	(0.2,0.8,1.2)
Goal	(0.1,0.5,0)
Location of obstacles	(0.2,0.9,0.5)
Radius of obstacles	0.4
Step size	0.1

The trajectory of the obstacle avoidance path of the end of the manipulator in the RRT algorithm and the Bi-RRT algorithm is shown in figure 7:



(a) RRT algorithm (b)Bi-RRT

Fig. 7. 3D simulation diagram of the algorithm

It can be seen from Figure 7 that the expansion of the RRT algorithm from two-dimensional to three-dimensional generates a large number of redundant nodes, and the total number of nodes has reached more than 800. The total number of nodes generated by the Bi-RRT algorithm extended to three-dimensional is significantly less than that of the RRT algorithm. There are less than 80 nodes in 10 simulations. Table 5 below is a comparison of the results of the two algorithms in three-dimensional space:

Table 5: Comparison of simulation results in three-dimensional space

	time	path length	number of nodes
RRT	35.3	2.71	28
Bi-RRT	3.06	2.29	24

It can be seen from Table 8 that the Bi-RRT algorithm has much better convergence speed than the RRT algorithm in three-dimensional space. Basically, a path is planned within 4 seconds. The average of 10 simulations is 3.06 seconds. Next, the algorithm in this paper is used for simulation. the result is shown in Figure 8:

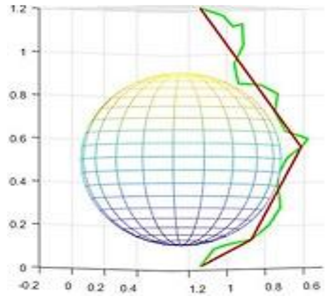


Fig. 8. Simulation results of the improved algorithm

Compared with the RRT algorithm and the Bi-RRT algorithm, the paths planned by the algorithm in this paper are much less than the RRT algorithm and the Bi-RRT algorithm. The planned path nodes are kept within 5, and the path length is within 2. Figure 8 shows 4 path nodes. The path length is 1.48, which greatly reduces the path length.

Next, the manipulator is visualized for obstacle avoidance planning simulation. The simulation scene of the manipulator is shown in Figure 9 below:

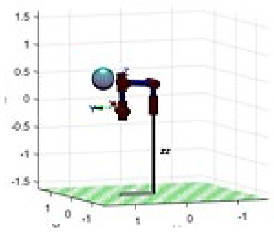
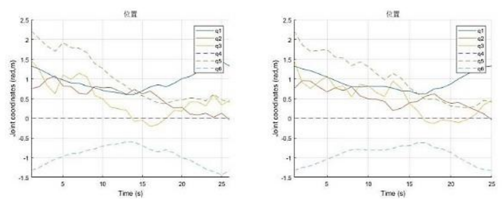


Fig. 9. Manipulator and Obstacle Visualization

Figure 10 shows the changes of each joint angle when using RRT and Bi-RRT path planning to simulate the obstacle avoidance of the manipulator. The mutation of the joint angle causes a large mutation in the joint angle, which is easy to cause damage to the motor of the manipulator joint.



(a) RRT algorithm (b)Bi-RRT

Fig. 10. The change of the joint angle of the manipulator using the traditional algorithm

The improved algorithm is used to simulate the manipulator, and the changes of each joint are obtained. As shown in Figure 11, after the algorithm is improved, the angle of each joint will not have a large angular mutation, and the inflection point of the path is less than the above two algorithms. It takes a lot less time than the above two algorithms, and is more friendly to the joint motor of the manipulator. It can be seen from Table 6 that the algorithm in this paper is better than other algorithms in terms of time and path length.

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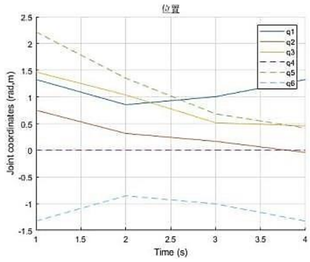

Fig. 11. The change of the joint angle of the manipulator using improved algorithm

Table 6: Comparison of simulation results in manipulator space

	time	Path length
RRT	25.2	2.71
Bi-RRT	25.0	2.29
improved	4.0	1.48

As shown in Figure 11, smoothing is carried out on the sudden change of angle in the joints of the manipulator, specifically in the second and third seconds. In order to reduce the calculation, 3 times Bezier spline interpolation is used for smoothing. After the final smoothing the angle changes of each joint are shown in Figure 12. The joint angle changes after interpolation and smoothing are relatively smooth, which can make the manipulator complete obstacle avoidance in a better state.

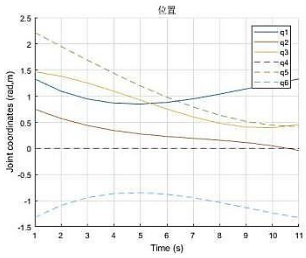

Fig. 12. Joint angle changes after smoothing

VI. CONCLUSION

This paper improves the Bi-RRT algorithm and introduces a pruning algorithm for shortening the path, which greatly reduces the number of redundant nodes. After pruning, the length of the path is shortened and the number of nodes on the path is greatly reduced, making obstacle avoidance possible. Paths are more efficient and secure. After initially planning a collision-free path, three times of Bezier interpolation is used to optimize the path, so that the changes of the joints of the final manipulator are smoother and more stable. The method in this paper is suitable for static obstacle environments, and further research is needed for dynamic obstacle avoidance..

REFERENCES

[1] ZHENG Yongjia. Research on strategic choice of SYL Intelligent Company[D]. East China University of Science and Technology,2018.

[2] Xu Da,Xia Xiang. Obstacle avodance path planning of ammunition loading robot based on w-working space[J]. Manufacturing Automation, 2013,35(01):9-11+25.

[3] LI Yuqi. 3D Obstacle Avoidance Path Planning for Manipulator Based on A* Mixed with Potential Field Metho[J]. Agricultural Equipment & Vehicle Engineering, 2018,56(12):62-66.

[4] HUANG Pu.Research on Indoor Path Planning Based on Improved A* Algorithm. North China Electric Power University,2019.

[5] ZHAO Huadong,LEI Chaofan. Path Planning of Six Degrees of Freedom Manipulator Based on Improved Ant Colony Algorithm[J]. Journal of Zhengzhou University(Natural Science Edition), 2020,52(01):120-126.

[6] HAN Tao,WU Huaiyu. Research on path planning for manipulator to avoid real-time obstacle based on genetic algorithms[J]. Application Research of Computers, 2013,30(05):1373-1376.

[7] LaValle S M. Rapidly-exploring random trees: A new tool for path planning. Technical Report[R]. : Ames, IO, USA: Iowa State University, 1998.

[8] Aguinaga I , D B orro, Matey L . Parallel RRT-based path planning for selective disassembly planning[J]. International Journal of Advanced Manufacturing Technology, 2008, 36(11-12):1221-1233.

[9] LIU Enhai,GAO Wenbin. Improved RRT path planning algorithm[J]. Computer Engineering and Design, 2019,40(08):2253-2258.

[10] LI Ji,SHI Chenfa.Path Planning of 6-Dof Robot Based on Improved RRT Algorithm[J]. Computer Applications and Software, 2020,37(09):221-226.

[11] LIU Yaqiu,ZHAO Hanchen. An Improved RTT Based Obstacle Avoidance Path Planning Algorithm for Industrial Robot[J]. Information and Control, 2021,50(02):235-246+256.

[12] LIU Aobo,YUAN jie. Robot Path Planning Based on Goal Biased Bidirectional RRT* Algorithm[J]. Computer Engineering and Applications: 1-8[2021-06-10].

[13] ZHANG Yusong.6-Dof Manipulator Trajectory Planning Methods Research[D]. Harbin Engineering University,2014.

[14] SHI Yanglin,YANG Jiafu.Research on intelligent vehicle path planning based on improved bidirectional random tree, 2020,42(07):1287-1293.

[15] XIANG Jinlin,WANG Hongdong. Algorithm of Local Path Planning for Unmanned Surface Vehicles Based on Improved Bi-RRT[J]. Shipbuilding of China, 2020,61(01):157-166.

[16] HU Huihuan. An Improved Path Planning Algorithm With Variable Probability Bidirectional RRT[J]. Electronic Science and Technology, 2019,(6):16-21.

[17] XU Yi. Research and Implementation of Cooperative Motion Control Technology for Industrial Robots[D]. Huazhong University of Science and Technology,2019.

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