Path Planning Based on Bi-RRT Algorithm for Redundant Manipulator

Conference Paper · May 2015

DOI: 10.2991/eame-15.2015.51

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Path Planning Based on Bi-RRT Algorithm for Redundant Manipulator

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***Abstract*-For the manipulator which is used to execute maintenance tasks in the Tokamak reactor, solving the problem of collision-free path planning is the premise. This paper introduced the Single-RRT and Bi-RRT algorithms then used Bi-RRT algorithm to make the path planning for the motion of a redundant manipulator in the vacuum chamber, finally made a Matlab simulation analysis. The result shows that RRT algorithm can effectively achieve the purpose of collision-free path planning, and using Bi-RRT can reduce the number of searches and invalid search points compared with Single-RRT. The better path can be obtained and used in the actual control by means of multiple searches and replacements.**

Keywords-redundant manipulator; path planning; RRT algorithm; Tokamak

I. INTRODUCTION

At present, Tokamak is widely used to make magnetic confinement of plasma to control thermonuclear fusion reaction [1]. As shown in fig.1[2], the internal environment of Tokamak is an annular chamber. The plasma is constrained in the annular chamber by the magnetic field. Because the environment characters of the chamber is intense radiation, high magnetic fields, high temperature and vacuum, it's necessary to use manipulators instead of human to execute the maintenance work tasks of the vacuum chamber.

With the needs of a large working space and the high flexibility, many manipulators use redundant structures. When executing maintenance tasks, the redundant manipulator is restricted by the shape and size of the vacuum chamber. So the main target of path planning is collision-free. On the other hand the joint speed and acceleration can't change rapidly in the path. Based on the above demands, this paper made researches on the problem of collision-free path planning for a redundant manipulator in Tokamak vacuum chamber.

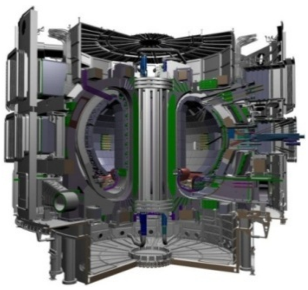

FIGURE I. TOKAMAK REACTOR.

FIGURE II. REDUNDANT MANIPULATOR.

II. TASK DESCRIPTION

As shown in fig.2, the redundant manipulator which is composed of five rotational joints is a 5R planar redundant structure. Before executing maintenance tasks, the manipulator is folded in a rail transport vehicle. As shown in fig.3, when executing tasks, manipulator expands from the initial folded position to a fully deployed position while moving forward with the base on the rail into the vacuum chamber. After entering the vacuum chamber, the base is stationary, and according task requirements, the manipulator will reach different positions without collision.

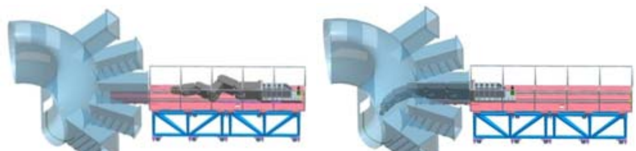

FIGURE III. DEPLOY OF REDUNDANT MANIPULATOR.

Because the computational complexities of traditional sports programming algorithm, image search algorithm, intelligent algorithm are sharply increased by the growth of manipulator's DOF, it's difficult to solve the collision avoidance problem of high-dimensional redundant robot in complex environments by these methods. The random sampling method obtains the collision information by taking collision detections of sampling points in the state space instead of establishing the models of manipulators and obstacle spaces, so it can efficiently solve the path planning problem of high-dimensional space. Therefore, this paper adopts the method of random sampling for path planning.

As a random sampling method, Rapidly-exploring Random Tree (RRT) is particularly suitable for multi-DOF robot path planning problems, which has been widely used in the field of robotics[3, 4].In addition to the advantages of random sampling algorithm, RRT uses a tree structure to store nodes of manipulator configuration obtained by random extension, so the path between adjacent nodes meets requirements of manipulator dynamics, kinematics and collision avoidance, therefore RRT is suitable for nonholonomic redundant motion planning[5].

III. PATH PLANNING ALGORITHM BASED ON RRT

Introduced the Single directional rapidly exploring random tree (Single-RRT) and Bidirectional rapidly exploring random tree (Bi-RRT), and Bi-RRT was used to make the path planning. To make the description more clear, this paper used the definitions as follows.

Working space(W space):the space where the manipulator and obstacles exist.

Joint space(J space):the space where the sets of all θ exist. $\theta=(\theta_1,\theta_2,\theta_3\ldots\theta_5,)^T$ means each joint's rotational angle of the manipulator.

Configuration space(C space): the space where all the possible motion states exist. $C(\theta)$ means the sets of all the possible configuration of the manipulator.

Configuration obstacle space(C_{obs}):the space where there is a collision for $C(\theta)$, written as C_{obs}.

Configuration free space(C_{free}):the space where C space gets rid of C_{obs}. It means there is non-collision to C(θ),written as C_{free}.

As these definitions, RRT about the task can be described as a path planning taking samples in J space and checking in C space, finding a path in C space where the joint angles of manipulator from θ_{start} to θ_{target}. And the target is that all the configurations of manipulator belong to C_{free} [6].

A. Single-RRT Algorithm

Because the redundant manipulator is a 5R planar redundant structure, n=5 in the J space. The initial joint angle $\theta_{start}=(\theta_{s1},\theta_{s2},\theta_{s3},\theta_{s4},\theta_{s5})^T$ and the target joint angle $\theta_{target}=(\theta_{t1},\theta_{t2},\theta_{t3}, \theta_{t4},\theta_{t5})^T$. The Random Tree (RT) is built by random sampling in J space in RRT. The extend step is set up with D_{dis}. The end signs of the search proceeding are that the distance between the node of random tree with θ_{target} is less than the minimum distance D_{min} or the sampled time C_{ount} is biger than the maximum time M_{max}. The steps are as follows and the proceeding of extend is shown in fig.4.

Step1 Define all the parameters, initialize θ_{start} and θ_{target}, add θ_{start} into RT.

Step2 Randomly generate $\theta_{rand}=(\theta_{r1},\theta_{r2},\theta_{r3},\theta_{r4},\theta_{r5})^T$, as the provisional target of RT.

Step3 Judge whether C_{ount} is greater than M_{max}. If $C_{ount}> M_{max}$, the search fails, otherwise continue.

Step4 Use the function Nearest (θ_{rand}, RT,$RTIndex$) to search the nearest node $\theta_{nearest}$ to θ_{rand} in RT. The function calculates distances (the sum of five joint angle) between all nodes in RT and θ_{rand}, and then finds the minimum.

Step5 Use the function $Extend(D_{dis}, \theta_{nearest})$ to find the new node θ_{new}. The function calculates the distance D_{actual} between $\theta_{nearest}$ and θ_{rand}, if $D_{actual} < D_{dis}$, $\theta_{new}=\theta_{rand}$, otherwise use formula (1) to get θ_{new}:

$$\theta_{new} = \theta_{nearest} + (\theta_{rand} - \theta_{nearest})*D_{dis} / D_{actual} \tag{1}$$

Step6 Use the function $Obstacle(\theta_{new})$ to test whether θ_{new} is in C_{free}. If θ_{new} is in C_{free}, go to step 7 otherwise return to step2. The function uses the distance between each joint position and the center of vacuum chamber and the distance between the boundary and center of vacuum chamber to test collision.

Step7 Add θ_{new} into RT and record its' father node.

Step8 If $d(\theta_{new},\theta_{target})<D_{min}$, go to step 9,otherwise return to step2.

Step9 Reverse Search the father node of θ_{new} to get the path.

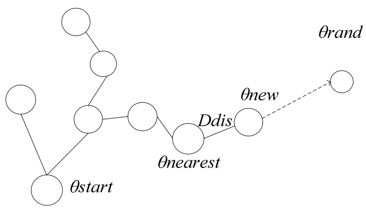

FIGURE IV. THE NODES EXPANSION PROCESS OF SINGLE-RRT.

B. Bi-RRT Algorithm

To improve search efficiency, on the base of Single-RRT, this paper selected Bi-RRT algorithm to search. There are two searching trees at the same time, the direction of the first tree is consistence with the Single-RRT, starting to search from θ_{start}, and the second tree starts to search from θ_{target}. One tree plays a guiding role to the other tree, single tree extends two nodes at the same time, and the directions of the extended nodes are guided by the other tree. In this way, the search speed increases, and Bi-RRT node expansion shown in fig 5.

For either tree, there are two new nodes θ_{new1} and θ_{new2}, θ_{new1} is extended by θ_{rand} while θ_{new2} is extended by the guiding of θ_{new1} of the other tree. The extension stops until the distance between the new nodes of a tree and the nearest node of another tree is less than D_{min}, and the search succeeds. The flow chart of Bi-RRT is shown in fig.6.

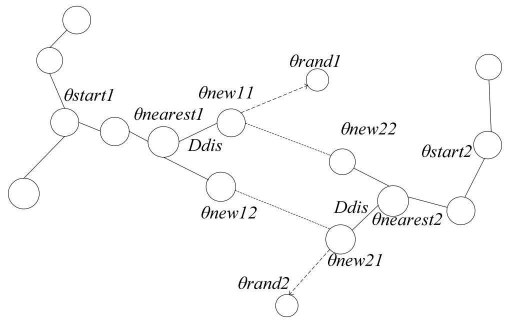

FIGURE V. THE NODES EXPANSION PROCESS OF BI-RRT.

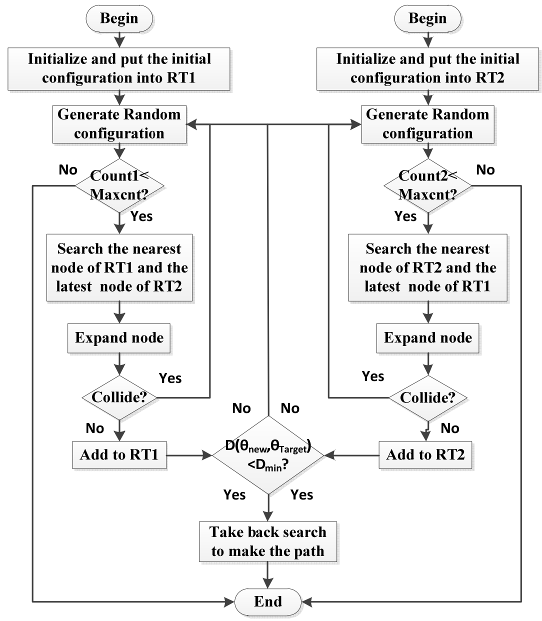

FIGURE VI. THE FLOW CHART OF BI-RRT.

IV. THE SIMULATION OF BI-RRT ALGORITHM

According to the analysis, the algorithm was tested and the motion simulation was built by MATLAB in the condition with θ_{start} (30,30,0, -10, -10) and θ_{target} (45, 50, -65, -65, -40). For a better comparison, Single-RRT was used to make the first search. Then we used Bi-RRT to make researches in the condition with the same θ_{start} and θ_{target}. The statistical results are shown in Table.1.

TABLE I. THE STATISTICAL RESULTS OF SEARCH.

	Search times	Path points
Single-RRT	2642	184
Bi-RRT	165	104

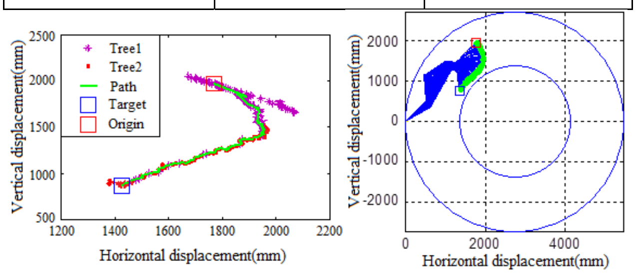

FIGURE VII. THE PATH SEARCHING IN THE VACUUM CHAMBER.

And the search process of Bi-RRT is shown in fig.7, the left picture is the position of manipulator's terminal, and the right picture is the manipulator motion in the vacuum chamber.

According to the results, RRT can meet the requirements of collision-free path planning, and Bi-RRT has much less search times and invalid search point than Single-RRT. On the other hand, because of the impact of randomness, the repeatability of path is weak. Therefore, the better path can be obtained and used in the actual control by means of multiple searches and replacements.

V. CONCLUSION

According to the motion characteristics and environmental characteristics of the redundant manipulator, this paper used Bi-RRT algorithm to make the path planning for a redundant manipulator in the vacuum chamber, the result shows Bi-RRT algorithm is faster and more efficient compared with Single-RRT. Through multiple searches and replacement of paths, the better path can be obtained. Bi-RRT algorithm is suitable for the path planning of redundant manipulator in Tokamak reactor.

ACKNOWLEDGEMENTS

This work was supported by National Magnetic Confinement Fusion Science Program "Multi-purpose Remote Handling System with Large-scale Heavy Load Arm"(2012GB102004)

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