A Fast Path Planning Algorithm Fusing PRM and P-Bi-RRT

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***Abstract*—The path planned by the rapidly expanding random tree (RRT) algorithm is tortuous and the planning speed of RRT algorithm is slow. The path planning failure rate of the probabilistic roadmap (PRM) algorithm is high in complex scenarios. To solve these problems, this paper proposes a fusion algorithm fusing PRM and probability-based bidirectional RRT (P-Bi-RRT), which divides the planning area into two areas on average, and uses the PRM algorithm with faster planning speed for path pre-planning in each area, and then selects a node in each of the two areas to form a pair of optimal matching-points. The optimal matching-points is used to connect the two regional paths with the P-Bi-RRT algorithm or method of barrier-free direct connection. Finally, the planned path is optimized twice, the redundant nodes are trimmed and the path length is shortened. After a large number of simulation experiments, it is shown that the time of path planning is reduced by about 71% to 80%, the number of nodes is reduced by 70% to 80%, and the path length is shortened by 20% to 30% compared with the RRT algorithm.**

Keywords—region segmentation, path optimization, PRM algorithm, RRT algorithm, Bi-RRT algorithm, P-Bi-RRT algorithm, fusion algorithm

I. Introduction

With the development of trade and economic globalization, market competition is intensifying, and people's requirements for efficiency are becoming higher and higher. The problem of vehicle path planning has gradually attracted people's attention, and has become an urgent problem to be solved in the process of artificial intelligence and economic development [1]. Path planning refers to finding a collision-free path from the starting point to the ending point according to certain evaluation criteria, such as the shortest path or the shortest planning time [2]. The PRM algorithm [3-4] is to construct an undirected graph on the map by sampling, and then use a search algorithm such as A [5-6] to find a path on the route map to improve the efficiency of searching. This algorithm can plan a path with relatively few random sampling points in an environment with few obstacles, so the search efficiency of this algorithm is higher, but when there are many obstacles and too few sampling points or unreasonable distribution, the PRM algorithm may fail in the path planning, so the PRM algorithm is incomplete in probability. The rapidly expanding random tree (RRT) [7-9] is a random search algorithm with a fixed search step L_{step} and complete probability. When generating new nodes, the strategy of random expansion leads to a slower path planning speed, tortuous path and a large number of nodes, so when the algorithm is actually applied, it has many limitations. The bidirectional RRT(Bi-RRT) [10-11] algorithm is an improved algorithm based on the RRT algorithm. The algorithm initially generates two RRT trees from the starting point and ending point, and the two RRT trees grows opposite each other, so the Bi-RRT algorithm has a certain improvement in search speed and efficiency compared with the RRT algorithm. In order to further improve the speed of path planning, the work in [12] proposes a Bi-RRT algorithm based on probability. This algorithm extends the new node toward the target point with a fixed offset probability $Prob$, which reduces the randomness of the algorithm, so it accelerates the path planning speed compared with the RRT and Bi-RRT algorithm, but the probability-based bidirectional RRT (P-Bi-RRT) algorithm still uses the inherent strategy of searching while sampling and building a map when expanding new nodes, although there is a certain improvement in planning speed, however, it still has most of the disadvantages of the RRT algorithm, so when it is applied in the field of intelligent vehicles and robots, there are certain limitations.

In order to solve the above problems, this paper proposes a fusion algorithm fusing PRM and P-Bi-RRT. This algorithm fuses the advantages of both PRM and P-Bi-RRT algorithms, discards the disadvantages of the two algorithms, which improves the planning speed. Finally, the path planned by the fusion algorithm is optimized twice to shorten the path length. Through a large number of simulation experiments, it is proved the post-processing fusion algorithm has a significant improvement in terms of planning time, path length and the number of path nodes compared with RRT, Bi-RRT, P-Bi-RRT algorithms.

II. Fusion Algorithm

The main idea of the fusion algorithm in this paper is to divide the planned area into two areas on average, and use the extremely fast PRM algorithm to complete the pre-planning of

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most paths in the two areas, finally we use the P-Bi-RRT algorithm with complete probability or a method of barrier-free direct connection to complete the connection of two regional paths, thus to improve the planning speed and to reduce the number of nodes.

A. Description of fusion algorithm

The steps of fusion algorithm are summarized as follows:

Step1: We divide the planning area into two areas, and then generate an undirected graph composed of several points in each area through the PRM algorithm.

Step2: We search for a node in the two undirected graphs respectively to form a pair of optimal matching-points. The matching-points is used as the starting point and ending point of the path to connect the two regional paths. The strategy for finding the optimal matching-points is as follows:

1) In an undirected graph, the starting point and the nodes connected to the starting point directly or indirectly are divided into a set and perform the same operation in another undirected graph, and then the elements in one set with the elements in another set are matched in pairs one by one, the two nodes after matching are regarded as a pair of matching-points. We suppose these two sets are $set_1=\{x_1,x_2\}, set_2=\{y_1,y_2\}$ respectively, then all matching-points consisting of elements in the two sets are $\{x_1y_1, x_1y_2, x_2y_1, x_2y_2\}$.

2) The Q of all matching-points is calculated according to (1), and the matching-points with the smallest Q is regarded as the optimal matching-points.

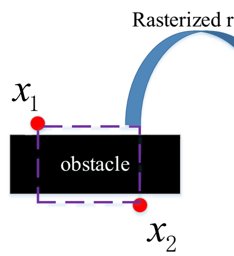
$$Q = w \times (L_{zone1} + L_{zone2}) + L_{connect} \tag{1}$$

Where $w(0<w<1)$ is the weight constant, L_{zone1} and L_{zone2} are the shortest length of regional path from the matching-points to the starting point of the respective area, $L_{connect}$ is the euclidean distance between matching-points. So we can draw such a conclusion that the smaller the sum of L_{zone1} and L_{zone2}, the shorter the planned path and the better the path; The smaller $L_{connect}$, the shorter the distance between matching-points, the smaller the rectangular searching area formed by matching-points, and the faster the planning speed. Since the planned path needs to be optimized twice in the future, the selection of matching-points pays more attention to the speed of path planning, so the weight $w(0<w<1)$ is less than the weight 1 of $L_{connect}$, and when the weight w approaching 0, the faster the path planning speed, conversely, the slower when approaching 1.

Step3: We start the obstacle judgment from the matching-points with the smallest Q. The judgment criterion is: a rectangular area is formed by matching-points and rasterized, we use the number 0 to represent the obstacle area and the number 1 to represent the obstacle-free area, if the rectangle has a row or a column of 0, then it means that it cannot plan a complete path through the matching-points in this rectangular area. As shown in Fig. 1, there is a rectangular area formed by node x_1 and node x_2, and after the rectangular area is rasterized, there is a row of numbers 0 in the rasterized matrix, so the matching-points is discarded, and then select the matching-point with the smallest Q from the remaining matching-points to continue the obstacle judgment. When a matching-points passes the judgment of the obstacle, it stops selecting a new matching-points and regards the matching-points as the optimal matching-points. Since the starting point and the ending point are a pair of matching-points, and this matching-points can pass the judgment of the obstacle, so the fusion algorithm is complete with probability.

Step4: We record the two shortest regional paths corresponding to the optimal matching-points, and connect the optimal matching-points directly, if it collides with the obstacle, it indicates that the path cannot be connected by the method of barrier-free direct connection and then to execute **Step5**, otherwise, directly to connect the matching-points, the whole path planning is completed, and the algorithm ends.

Step5: We use the optimal matching-points to form a rectangular searching area and regard the optimal matching-points as the starting point and ending point of the P-Bi-RRT algorithm to complete the connection of the two regional paths.



x_1	1	1	1	1
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
1	1	1	1	x_2

Fig. 1. Rasterization of rectangular areas

B. Example of fusion algorithm

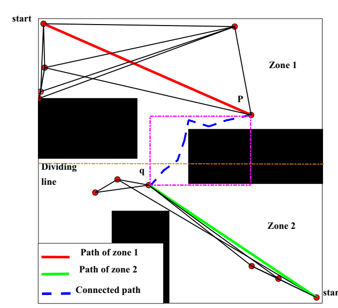


Fig. 2. Schematic diagram of fusion algorithm

As shown in Fig. 2, the path pre-planning is performed by the PRM algorithm in the upper and lower areas, and then we use (1) to calculate the Q of all matching-points and judge whether passing the judgment of obstacle. Finally, among all the matching-points, the Q of the matching-points formed by the node p and the node q is the smallest and this matching-points passes the judgment of the obstacle, so the matching-points formed by the node p and the node q is the optimal matching-points. The whole path is: ①Two regional paths formed by red and green line segments ② The connection path of the two areas formed by blue dotted lines.

III. POST-PROCESSING OPTIMIZATION

Because the algorithm in this paper fuses the PRM algorithm, the number of nodes is less than that of the P-Bi-RRT algorithm alone, but there are still some redundant nodes. To solve this problem, this paper improves the traditional path optimization method, and proposes a quadratic path optimization method, which further shortens the path length and reduces the number of path nodes.

The traditional optimization method starts from the starting point and check whether the connecting line with the subsequent node collides with the obstacle, if not, delete this node, otherwise, use the new node as the starting point to check the connection status of the subsequent node. The diagram of traditional optimization method is shown in Fig. 3.

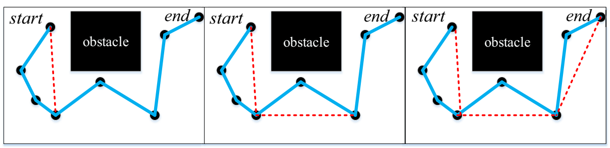


Fig. 3. Schematic diagram of traditional optimization method

A. First optimization for path

This paper improves the traditional optimization method. The schematic diagram of the improved method is shown in Fig. 4.

The first path optimization starts from the starting point and continuously checks whether the connecting line with the subsequent node collides with the obstacle. When a collision occurs, then it searches for a optimal point on the line segment composed of the collision node and the previous node of the collision node, the optimal point is that the line with the starting point happens to not collide with the obstacle, and the optimal node is used as the new starting point to continue to check the connection status with subsequent nodes. As shown in Fig. 3 and Fig. 4, the first optimized path in this paper is shorter than the path optimized by traditional method, but it is not the optimal path and can be further optimized.

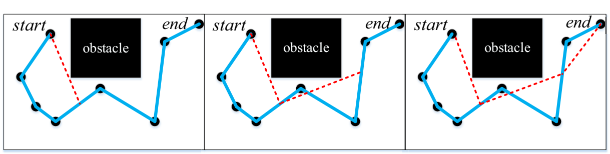


Fig. 4. Schematic diagram of the first path optimization

B. Second optimization for path

The second path optimization is based on the first path optimization. The schematic diagram of the second optimization for path is shown in Fig. 5.

The principle that the sum of the two sides of the triangle is larger than the third side is used for the second path optimization. As shown in Fig. 5, at each corner of the path, a side is used to form a triangle, and this side is considered a part of the new path.

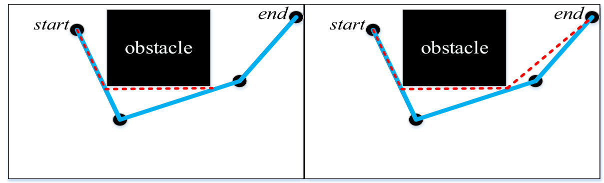


Fig. 5. Schematic diagram of the second path optimization

IV. EXPERIMENTAL RESULTS AND ANALYSIS

In order to prove the superiority of the proposed method in this paper, a series of simulation experiments are carried out. Two complex maps with different obstacle shapes are selected in the simulation, as shown in Fig. 6. The size of map is 500×500 pixels, and the starting point coordinates and the ending point coordinates are (10,10), (490,490) respectively. The black areas in the map are obstacles, and the white areas are obstacle-free areas. The simulation experiments are performed on a computer with a CPU of Intel Core i3-3210M, 2.5GHz, and 8G of memory, and the programming environment is matlab R2016a.

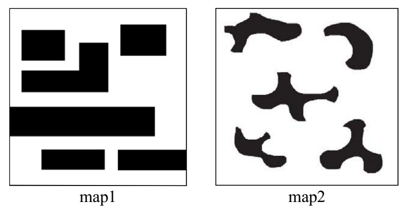


Fig. 6 Simulation map

A. Results and analysis of fusion algorithm

Fig. 7 and Fig. 8 are simulation diagrams of fusion algorithms. During the experiment, the offset probability $Prob$ and the search step of the P-Bi-RRT algorithm is 0.5 and 15 pixels respectively, the number of sampling points of the PRM algorithm is 8, and the weight $w=0.1$.

As shown in Fig. 7 and Fig. 8, two regional paths (solid black lines) are planned by the faster PRM algorithm, and the regional connection paths (black dotted lines) are planed by the P-Bi-RRT algorithm or the method of barrier-free direct connection, which greatly improves the speed of path planning and reduces the number of nodes.

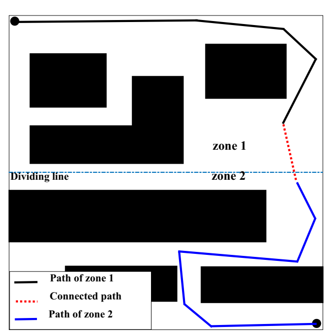


Fig. 7. simulation diagram of fusion algorithm in map 1

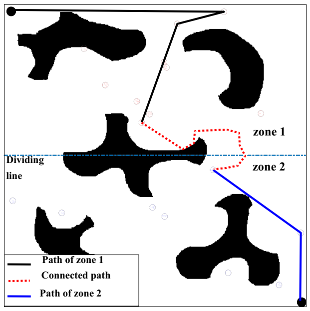


Fig. 8. simulation diagram of fusion algorithm in map 2

B. Results and analysis of quadratic path optimization

Fig. 9 and Fig. 10 are the results of quadratic path optimization on the path planned by the fusion algorithm.

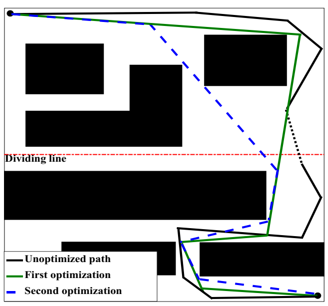


Fig. 9. Simulation diagram of quadratic path optimization in map 1

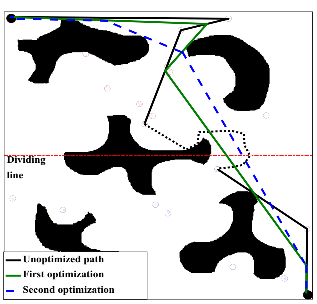


Fig. 10. Simulation diagram of quadratic path optimization in map 2

It can be seen from Fig. 9 and Fig. 10 that the unoptimized path is tortuous and lengthy. After the first optimization, the length of path is shortened and the number of nodes are reduced, but there is still room for optimization, and the path can be further optimized after the second optimization, but a lot of simulation experiments indicate that after the third optimization for path, the shortened path length is very limited, and it increases more time consumption, so in order to achieve the balance of planning time and path length, this article optimizes the path twice.

In order to verify that the quadratic path optimization method proposed in this paper has certain advantages over the traditional method in terms of average path length and number of nodes, the experiments are carried out 50 times based on the map2, and the experimental results are shown in Fig. 11 and Fig. 12, the experimental datas are shown in TABLE I.

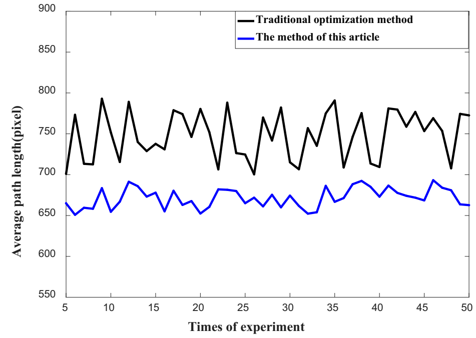


Fig. 11. Comparison of average path length

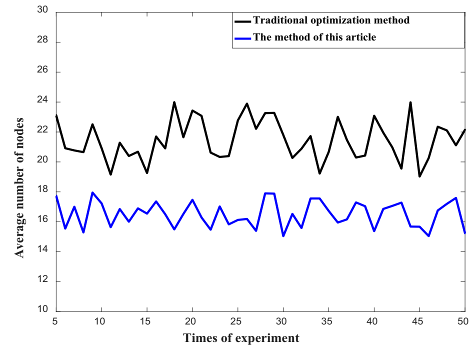


Fig. 12. Comparison of the average number of nodes

TABLE I. COMPARISON OF EXPERIMENT DATAS (THE EXPERIMENTAL DATAS ARE THE AVERAGE OF 50 TIMES)

Optimization methods	Path length(pixel)	Number of nodes
Traditionl method	748.778	22
The method of This article	689.965	17

From the data in TABLE I, in terms of the average length of path and the average number of nodes, compared with the traditional method, this method reduces 7.812% and 22% respectively, which proves the method of quadratic path optimization is more advantageous than the traditional path optimization method.

C. Results and analysis of post-processing fusion algorithm

In order to verify the superiority of the post-processing fusion algorithm in terms of the number of path nodes, planning time and path length, this paper compares the post-processing fusion algorithm with RRT, Bi-RRT and P-Bi-RRT algorithm. The experiments are carried out 50 times. The offset probability $Prob$ of the P-Bi-RRT algorithm is 0.5, the search step L_{step} of RRT, Bi-RRT and P-Bi-RRT algorithm is 15 pixels, the number of sampling points of the PRM algorithm is 8, and the weight $w=0.1$. The simulation diagrams of path are shown in Fig. 13, Fig. 14, Fig. 15 and Fig. 16.

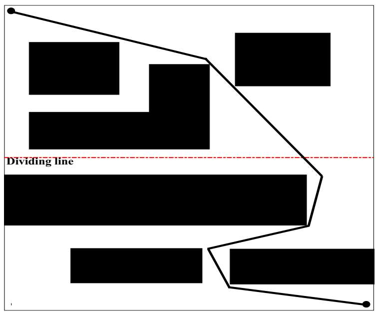


Fig. 13. Simulation diagram of post-processing fusion algorithm

Fig. 14. Simulation diagram of RRT algorithm

Fig. 15. Simulation diagram of Bi-RRT algorithm

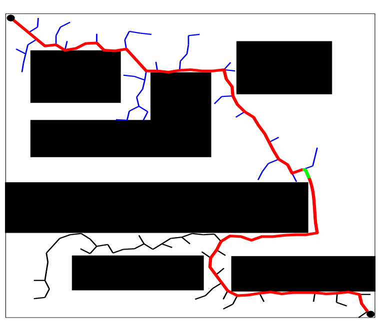


Fig. 16. simulation diagram of P-Bi-RRT algorithm

Analysis diagram of four algorithms are shown in Fig. 17, Fig. 18 and Fig. 19. The experimental datas are shown in TABLE II.

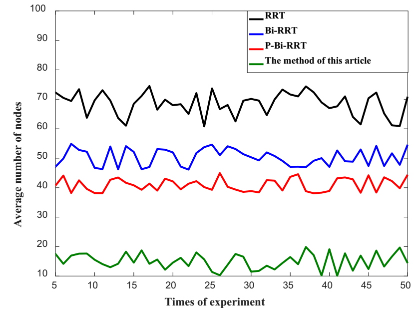


Fig. 17. Comparison of the average number of nodes

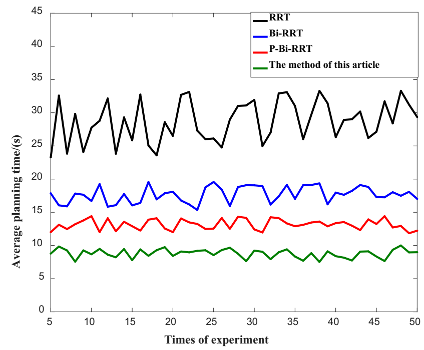


Fig. 18. Comparison of the average planning time

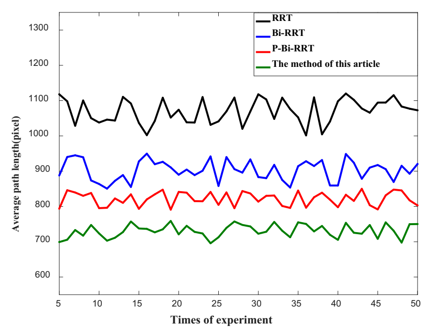


Fig. 19. Comparison of the average path lengths

TABLE II. COMPARISON OF EXPERIMENT DATAS (DATAS ARE THE AVERAGE OF 50 EXPERIMENTS)

Algorithm	Path length(pixel)	Number of nodes	Planning time(s)
RRT	1050.230	69	26.962
Bi-RRT	910.283	51	16.325
P-Bi-RRT	850.693	40	12.836
Post-processing fusion algorithm	790.326	10	8.523

As shown in TABLE II, the post-processing fusion algorithm reduces the average path length by 28.556%, 17.572%, and 11.798%, the average number of nodes reduces by 78.260%, 70.588%, and 62.5%, the planning time reduces by 69.092%, 49.073%, and 33.789% respectively compared with RRT, Bi-RRT, and P-Bi-RRT algorithm. It proves the effectiveness and superiority of post-processing fusion algorithm.

V. Conclusion

In view of the PRM, RRT and its improved Bi-RRT, P-Bi-RRT algorithm have certain limitations in practical application, the following two improvements are made by this article: ① On the basis of region segmentation, a method of fusing PRM and P-Bi-RRT algorithm is proposed to accelerate the speed of path planning and reduce the number of path nodes. ② A quadratic path optimization method is proposed to shorten the path length and further reduce the number of path nodes. A large number of simulation experiments prove that the algorithms proposed in this paper are superior to the RRT, Bi-RRT and P-Bi-RRT algorithm in terms of the number of nodes, planning time and path length, so the post-processing fusion algorithm has broad application prospects in the field of intelligent vehicles and robots.

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