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An enhanced path planning method for unmanned surface vehicle based on JPS+ and goalbounding algorithm

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Abstract. The path planning issue in complex environments remains an challenging problem in the field of unmanned surface vehicle (USV) navigation due to its complexity and the nature of nondeterministic polynomial-time hard (NP-hard). Aiming at generating a safe path for the USV within tractable time, this paper proposes an enhanced path planning method via integrating JPS+ algorithm and the goalbounding algorithm. Firstly, principles of the JPS+ and goalbounding algorithms are respectively analysed and investigated in this study. Subsequently, the application platform of the proposed path planning approach for USV is established via combining the YimaEnc electronic chart with WinForm dialog. Finally, the performance of the proposed method is validated through some numerical simulations against some other well-known path planning methods. The simulation results confirm that the proposed method performs superior to the artificial field method and A* algorithm in terms of the computation time and the path safety. Besides, the superiority of the proposed method over the artificial field method and A* algorithm is more significant in the long-distance path planning scenarios as far as the computation time is concerned.

1. Introduction

The Unmanned Surface Vehicle (USV)¹ is a typical type of autonomous planning and navigation marine vehicle which can be widely implemented to execute some crucial unmanned tasks, such as the complex environment of the sea survey, Maritime military operations.² Thanks to its widespread applications both in military and industrial fields, USV has drawn increasing research interests by researchers around the world from the community of unmanned robotics over the last few decades³. A paramount and fundamental problem in USV is the path planning issue, which aims to find a feasible path constructed by sequence points or curves connecting the start point and the end point⁴. To some extent, the path planning problem plays an important role in determining the intelligence of USV⁵.

In virtue of its importance in USV intelligence, the path planning problem of USV has recently turned into one of the most important issues and has been widely investigated. Caccia has designed a USV system with autonomous collision avoidance based on the line-of-sight (OS) planning algorithm⁶.⁷ Using the grid environment model, Song et al. has proposed an improved ant colony algorithm to tackle with the global path planning problem of USV⁸. In order to enhance the performance and accuracy of USV path planner, a Dijkstra algorithm based on distance optimization has been proposed by Jia-yuan Zhang⁹.

Aiming at handling the USV path planning issue within less computation time, this paper proposes an integrated path planning approach through combining JPS+¹⁰ and the goalbounding algorithm¹¹. As a part of development, leveraging the proposed method, this paper also completes the design of an application platform which integrates YimaEnc electronic chart and WinForm dialog to deal with the



path planning issue of USV. The proposed path planning method, namely, the integrated JPS+ and goalbouding algorithm, is used to generate an obstacle-free path for the USV in the given marine map. Lastly, the WinForm dialog displays the main interface of the designed application platform and the generated path. The effectiveness and superiority of the proposed method is validated through several numerical simulations against the artificial field method¹² and A* algorithm¹³. The numerical simulation results confirm that the proposed method dominates its peers with respect to the computation time, especially in the long-distance path planning scenarios. Besides, the proposed method and the A* algorithm outperform the artificial field method in terms of the path safety.

2. Methods and The Path planning platform

2.1. The combination of JPS+ and goalbouding algorithm

In 2012, the JPS+ algorithm^{14, 15} has been developed. As displayed in Fig.1, the JPS+ algorithm tests if T can arrive from the position of J. If yes, J is afterwards determined as a jump point and used to replace S. This implies that the JPS+ algorithm enable eliminate the unnecessary search process during its real-world applications on path planning by using the judgment principle noted above can significantly reduce the computation time of the JPS+ algorithm.

The goalbouding algorithm^{16, 17} belongs to the Gemoetric Containers, which is mainly applied to determine and reduce the search region within a 2D grid. As shown in Fig.2, suppose the starting and ending points are, respectively, denoted by the green and red grids in a search region. The white grid represents the feasible area. The black grid denotes the obstacle. When the search direction is located along the right bottom, the likelihood of finding a high-quality feasible obstacle-free path can be enhanced. Hence, for an action that searches diagonally down and to the right from the starting point, the bounding box is denoted by black dashed box labelled "goal." And the search behaviour located within the grey area labelled by "Pruned" is then forbidden and pruned by the goalbouding algorithm. By adopting this strategy, the goalbouding algorithm is capable of finding a higher-quality path with less computation cost.

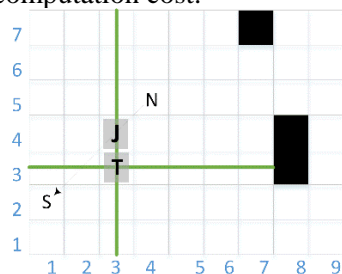


Figure 1. The search behaviour of JPS+

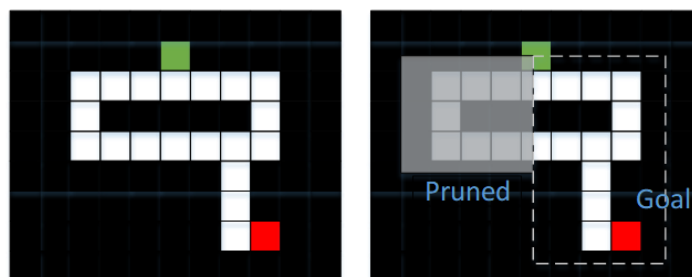


Figure 2. The Example of Bounding Box

In order to generate an obstacle-free path with less computation time, a common way is to combine the JPS+ with the goalbouding algorithm together. Since the goalbouding algorithm pre-processes and prune the entire search space, the obtained possible search area and directions can narrow the search region for in the follow-up path finding process executed by the JPS+ algorithm. Because the search area and directions are pruned, the combined algorithm can significantly reduce the planning time, that is, the computation time

2.2. YimaEnc Electronic Char and Platform design

YimaEnc, which uses the Yimap Core for the application of electronic charting. This software complies with data standard S57 and display standard S52 developed by the International Hydrographic Organization (IHO). It is supportive of the users to the second development through combing this software with radar, AIS and other systems, so that a variety of marine terminal products can be developed.

In this study, YimaEnc electronic charts are mainly used to read and display the required charts, which facilitate subsequent operations such as zooming in, zooming out, and dragging. In addition, one can also mark the starting and ending points on the chart and display the planned path points.

This article implements the path planning and experiments of USV under the Visual Studio 2013 inheritance development environment. The main interface of the established path planning platform is shown in Fig. 3. In the established platform, the marine map is located on the left of the interface. Through clicking the zoom in/out button to zoom in or zoom out the chart, or dragging the chart directly, more marine information of the marine map can be displayed. The display box on the upper right side shows the coordinates of the obstacles detected during the operation. On the bottom of the display box is the algorithm button to be run. The latitude, longitude and enlargement ratio of the initial center point displayed on the chart are on the right bottom.

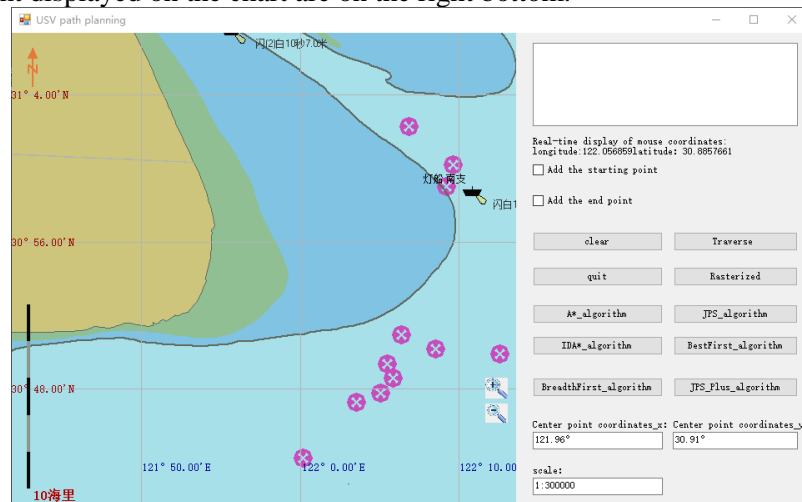


Figure 3. Simulation main interface

3. Design And Experiment

3.1. Chart Rasterization

It is notable that since the considered path planning problem is conducted in a 2-dimensional case, we first need to rasterize the displayed chart. Here, the rasterization of the displayed chart is to convert the latitude and longitude information of the marine map into the grid information which can be detected by the JPS+ and goalbouding algorithms.

As shown in Fig.4, the chart displayed on the screen are divided into different grids in order to release the burden of the calculation. In this paper, the planned grid is 120×100. The algorithmic steps of the rasterization are given as follows:

- Create a 120×100 array.
- Calculate the length and width of each grid. Get the latitude and longitude of the marine map by the function of YimaEnc and convert it to distance, as follows.

$$\begin{aligned}
 & \bullet \quad \text{radLat1} = \frac{(\text{lat1} * \pi)}{180}; \quad \text{radLng1} = \frac{(\text{lng1} * \pi)}{180} \\
 & \bullet \quad \text{radLat2} = \frac{(\text{lat2} * \pi)}{180}; \quad \text{radLng2} = \frac{(\text{lng2} * \pi)}{180} \\
 & \bullet \quad \text{dlat} = \text{radLat1} - \text{radLat2}; \quad \text{dln} = \text{radLng1} - \text{radLng2} \\
 & \bullet \quad a = \left(\sin \left(\frac{\text{dlat}}{2} \right) \right)^2 + \cos(\text{radLat2}) * \cos(\text{radLat1}) * \left(\sin \left(\frac{\text{dln}}{2} \right) \right)^2
 \end{aligned}$$

- $\text{distance} = 2 * \arctan \left(\sqrt{\frac{a}{1-a}} \right) * 6378137$
- Obtain the latitude and longitude of the coordinates of the obstacle on the chart, determine the exact grid that the obstacle is located in and mark the corresponding position in the array as 1, so that the array is divided into 0 and 1, corresponding to the ocean area and obstacles in the map.

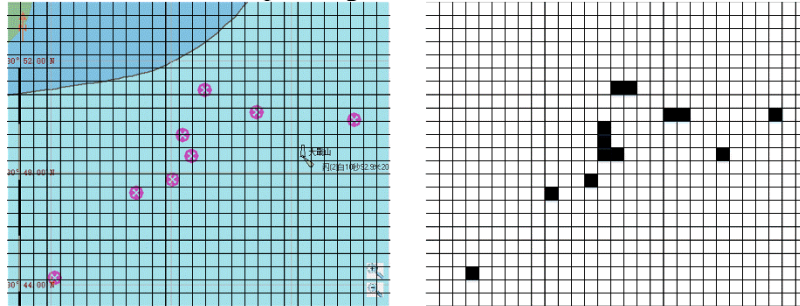


Figure 4. Chart Rasterization

3.2. Path planning

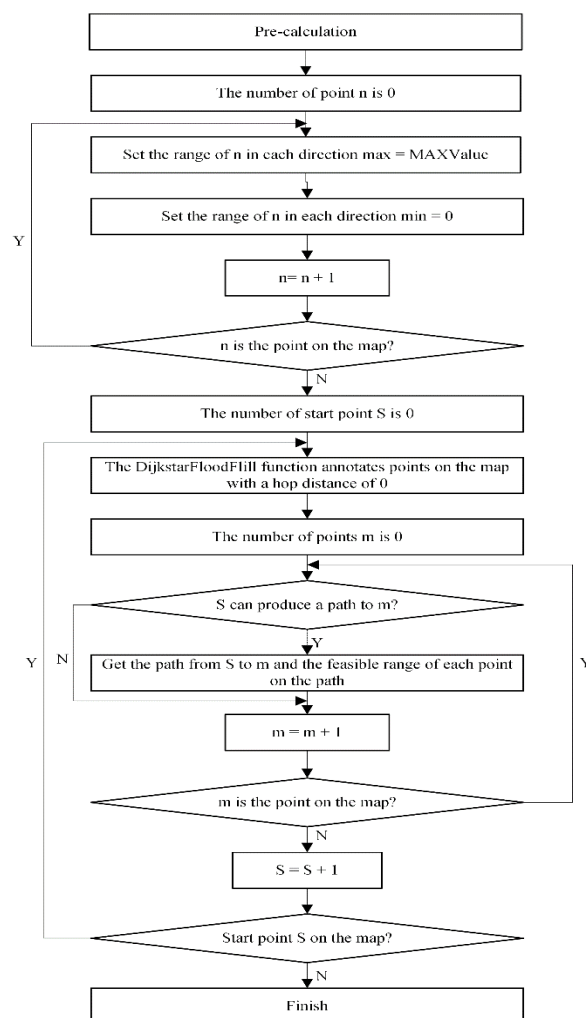


Figure 5. Pre-treatment flow chart

Generating a global path for the USV based on the combined JPS+ and goalbouding algorithm can be divided into two parts: the preprocessing and the path planning parts. The preprocessing is conducted by the goalbouding algorithm, whose flow chart is shown in Fig. 5. The detailed statements and summary corresponding to this flow chart are also provided followed after this flow chart. The path planning part is executed by the JPS+ algorithm.

The summary corresponding to the preprocessing part done by the goalbouding algorithm is given as follows:

- Obtaining the primary jump points and directions. Traverse the rasterized chart and select all the grids labeled by 0. Note that each current grid labelled by 0 means that this grid is feasible. Also, note that any grid is occupied by the obstacle is labelled by 1 and needs to be avoided.
- Obtaining the jump distance. Traverse the chart again, searching for 8 directions for each grid in the marine map. Obtaining the boundary range. Traverse all grids on the chart to obtain a feasible range for each grid.
- After executing the aforementioned three items, the obtained information including the jump distance is recorded and written in to a txt file.

4. Numerical simulations

This section compares the combined path planning algorithm with the artificial potential field method¹⁸ and the A* algorithm¹⁹ to validate the superiority of the combined path planning algorithm in terms of the path safety and the computation time. For extensive comparison, 10 numerical simulations with different starting and ending points in a same marine area are conducted by each tested method. The latitude and longitude of starting and ending points and the straight line distance from starting point to ending point are shown in Table 1. Table 2 compares the computational efficiency and path security of the three algorithms. The time comparison charts are shown in Fig.6 and Fig.7.

Table 1. Three sets of algorithm simulation related data

group	Start Point		End Point		Distance(m)
	longitude(°)	latitude(°)	longitude(°)	latitude(°)	
1	122.2885525	30.2687511	122.2999647	30.2702459	1108.504276
2	122.3001803	30.2647321	122.311915	30.2633309	1137.725036
3	122.3022258	30.2500596	122.3129912	30.2549197	1166.739881
4	122.3956721	30.2777217	122.4034237	30.2692182	1203.404927
5	122.2536718	30.248938	122.2585164	30.2387496	1224.758198
6	122.3592302	30.2847291	122.3514786	30.2757592	1244.536529
7	122.2770334	30.2309907	122.2921053	30.2339821	1485.691591
8	122.2755799	30.2321592	122.2918906	30.2334213	1573.257215
9	122.3353844	30.2350102	122.3589607	30.2434231	2450.440327
10	121.8221292	30.8510122	121.9246046	30.950707	14781.27863

From Table 2 and Figure 6, the following conclusions are drawn:

- In the case of the same starting point and ending point, the calculation time of the JPS+ and goalbouding algorithm is the shortest, the artificial potential field method is the second, and the A* algorithm takes the longest time.
- The artificial potential field method track planning has the lowest security. It can be obvious in the tenth data. Although the calculation time of the artificial potential field method algorithm is the shortest, the planned path is the unsafe path.

- The planning time change of A* algorithm is most obvious in 10 groups data, and the other two algorithms have smaller planning time changes.

Table 2. Experimental Comparison Data of JPS+ and goalbounding Algorithm, Artificial Potential Field Method and A* Algorithm

	group	JPS+ and goalbounding	Artificial Potential Fields	A*
1	time(ms)	5.1778	34	15.3512
	safety	√	√	√
2	time(ms)	6.1475	37	36.5128
	safety	√	√	√
3	time(ms)	5.0992	32	167.2239
	safety	√	√	√
4	time(ms)	5.3531	33	163.8414
	safety	√	√	√
5	time(ms)	7.5273	46	318.6284
	safety	√	√	√
6	time(ms)	5.3656	46	258.0338
	safety	√	√	√
7	time(ms)	6.3072	48	330.586
	safety	√	√	√
8	time(ms)	5.1064	42	191.8893
	safety	√	√	√
9	time(ms)	5.3911	41	341.5311
	safety	√	√	√
10	time(ms)	5.6481	3	382.0156
	safety	√	×	√

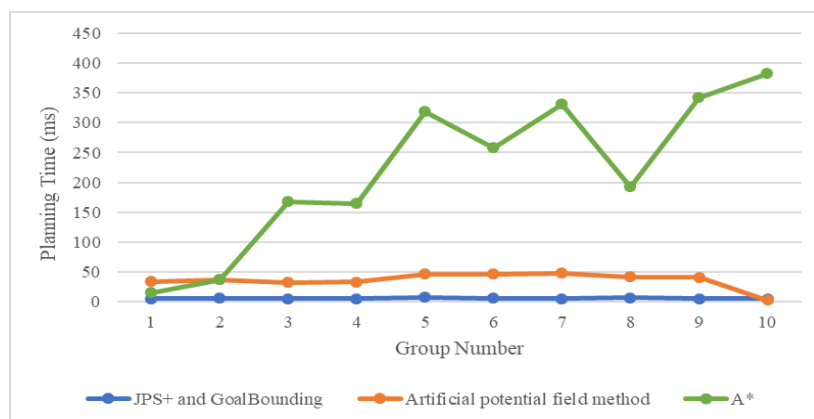


Figure 6. JPS+ and goalbounding algorithm, artificial potential field method and A* algorithm planning time

As can be seen from Fig.7 and Fig.8, As the distance from the start point to the end point increases, the ratio between the artificial potential field method and the JPS+ and goalbounding algorithm increases from 6 to 8 times, and the ratio of the A* algorithm to the JPS+ and goalbounding algorithm

also increases from 3 to 68 times. The longer the straight distance between the start point and the end point, the larger the time ratio is.

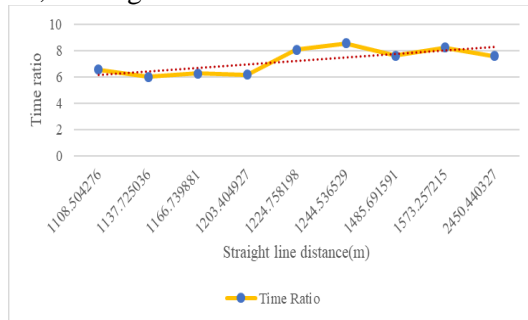


Figure 7. Comparison of planning time between JPS+ and goalbounding algorithm and artificial potential field method

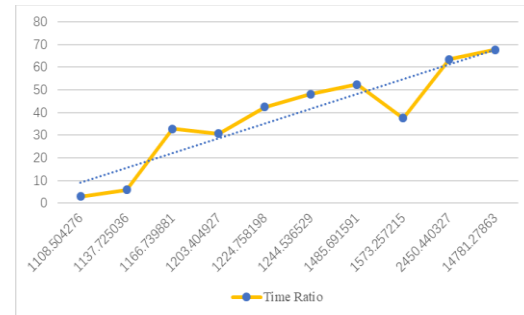
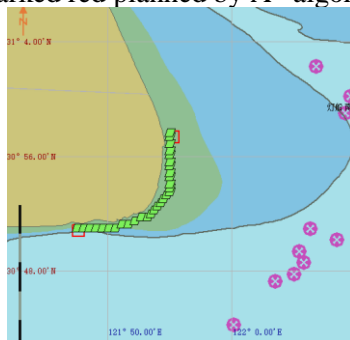


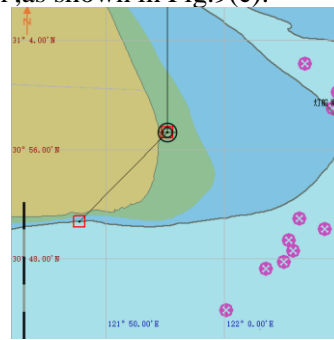
Figure 8. Comparison of planning time between JPS+ and goalbounding algorithm and A* Algorithm

Therefore, It is reasonable to infer that the JPS + and goalbounding algorithms can be applied to the normal path planning of the Yima electronic chart. The computational efficiency is 6-8 times that of the artificial potential field method and 3-68 times that of the A* algorithm. In addition, the larger the range of the planning path and the longer the distance between the start point and the end point, the more obvious the advantages of the JPS+ and goalbounding algorithm in the calculation process.

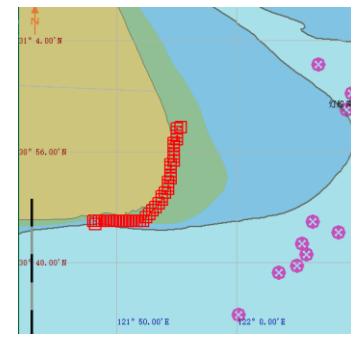
It is obvious in the data of the tenth group: in the case of some line obstacles such as coastlines and large areas of land, the artificial potential field method cannot correctly plan the route, and there will be cases of crossing land blocks, as shown in Fig.9(b). The JPS+ and goalbounding algorithm can easily plan the correct path which is marked green, as shown in Fig.9(a) and the safety path which is marked red planned by A* algorithm, as shown in Fig.9(c).



(a) JPS+ and goalbounding



(b) Artificial Potential Field Method



(c) A*

Figure 9. Tenth group of comparison of path planning between JPS+ and goalbounding, artificial potential field method and the A* algorithm

5. Conclusion

This paper presents USV route planning in the dialog box of WinForm and YimaEnc electronic chart. It is convenient for people to observe the operating status of the USV intuitively, position and monitor it in real time. This article also proposes an algorithm that combines JPS+ algorithm and goalbounding algorithm for USV path planning. The path planning platform proposed in Visual Studio 2013 integrated development environment is used to verify the effectiveness and path safety of the combined algorithm. The combined algorithm can plan safe paths in different marine environments. Compared with the artificial potential field method applied to the same environment, the JPS + and goalbounding algorithm was found to be 6 to 8 times as efficient as the artificial potential field method and 3-68 times as much as the A* algorithm, and the efficiency of planning in the combined algorithm

is more pronounced in planning long-distance paths. JPS+ and goalbounding algorithm greatly reduces unnecessary computational costs, reduces planning time, and improves planning efficiency. Considering the energy consumption of the USV and the requirements of real-time and rapid execution of the work, the algorithm described in this paper is very effective for USV path planning.

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