A Dynamic Path Planning Method considering Sea Area Division for Off-shore Wind Farm Maintenance

Wenrui Ouyang
School of Data Science & Engineering
South China Normal University
Shanwei, Guangdong, China
20228131051@m.scnu.edu.cn

Wentian Xu
School of Data Science & Engineering
South China Normal University
Shanwei, Guangdong, China
20218132022@m.scnu.edu.cn

Qi Xi*
School of Data Science & Engineering
South China Normal University
Shanwei, Guangdong, China
xiqi@m.scnu.edu.cn

Jing Wang
School of Data Science & Engineering
South China Normal University
Shanwei, Guangdong, China
wangjingscnu@m.scnu.edu.cn

Abstract

With the development of the wind power industry, the development of resource-rich offshore wind farms has become an industry trend. However, due to the distance from the coast and the more complicated sea conditions, the maintenance of wind farms faces great challenges. This paper proposes a dynamic path planning model based on the division of nearshore and offshore areas. The model considers the basic geographic information of the round-trip path between the port and the wind farm, and divides the sea area along the way. Based on the characteristics of the nearshore and offshore areas, different path planning algorithms are selected to determine the optimal round-trip path. In round-trip path planning, the nearest neighbor algorithm is first used to divide the sea area, and the nearshore and offshore areas are divided according to the characteristics and distribution of obstacles in the sea area. Then, the D* algorithm is used in the nearshore part, and the improved artificial potential field algorithm is used in the offshore part for path planning in the nearshore and offshore areas. Finally, experiments are conducted based on the virtual sea area simulated by the simulation, and the experimental results show that the proposed path planning model can adapt to the complex sea area and plan the optimal round-trip path for wind farm maintenance.

CCS Concepts

• **Computing methodologies** → Artificial intelligence; Planning and scheduling.

Keywords

Dynamic path planning, Sea area division, K-Nearest Neighbors Algorithhm, D* Algorithm, Artificial Potential Field Algorithm

*Corresponding author.

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1 Introduction

With the growing global energy demand and increasing pressure on environmental protection, the development and utilization of wind energy has become an important part of countries' energy strategies [1]. However, the operation and maintenance of wind farms present numerous challenges. Due to the distance from shore and the complex sea conditions, maintenance operations are difficult and costly. Therefore, efficiently managing the operation and maintenance of wind farms has become crucial for enhancing their economic benefits and competitiveness.

In order to efficiently operate and maintain wind farms, optimizing the schedule of maintenance activities and the path of maintenance vessels can significantly reduce the costs incurred in this process [2] Most researchers start from the perspective of optimizing ship paths to improve the efficiency of wind farm maintenance. The improved model mainly considers path planning and scheduling within the wind farm [3],[4]. However, for offshore wind farms, the offshore geography is more complex due to the distance from the port, which greatly increases the uncertainty and risk of ship maintenance. Therefore, it becomes crucial to consider the navigational geography during the ship's round trip and implement the corresponding dynamic planning. Path planning in front of the field can be summarized as the maritime ship path planning problem with known start and end points, and the existing path planning algorithms have been relatively mature, and many researchers have improved the traditional path planning algorithms in the maritime path planning problem by considering the impact of complex sea conditions on the ship. P. Zhou and D. Gao designed a path planning strategy based on the improved A* algorithm, which is based on the dynamic obstacle location and its area, selecting different degrees of navigation and controlling the ship's speed for effective obstacle avoidance [5]. W. Li et al. improved the artificial potential field algorithm to solve the maritime path multi-solution

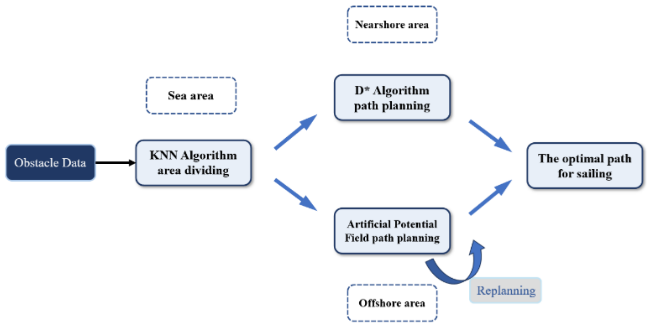

Figure 1: Structure of Path Planning Model

problem [6]. For complex sea conditions, X. Fang et al. used the particle swarm algorithm to optimize the global optimal path planning by considering factors such as waves, gusty winds, and other navigating ships [7]. Based on the maritime meteorological big data, two researchers, Y. Zhang and Y. Shi, combined the weather forecast model with the D* algorithm to plan a safe and shortest route under the constantly changing threat conditions [8].

When studying the path planning problem in front of wind farms, not only the dynamic environment of the ocean should be considered, the hydrographic information such as wind speed and wave height is unstable in the offshore area [9], with diffusion effect, which affects not only the geographical location where it is generated, but also its surrounding area. The static obstacles in the ocean are also not to be ignored, and in the nearshore, obstacles such as shallow reefs, reefs, and floats will have a greater impact on ship navigation [10], [11].

In summary, combined with the characteristics of the nearshore and offshore environment, this paper proposes a dynamic path planning model based on the division of nearshore and offshore regions. Through the regional division, the global optimal path can be obtained by finding the optimal path in different regions [12]. In the sea area division, the model adopts the nearest neighbor algorithm [13], which divides the sea area into the nearshore and offshore areas according to the distance index and obstacle type.

In the nearshore part, facing obstacles such as reefs, sea floats, etc., and considering that their positions may change, the D* dynamic path planning algorithm, which is improved based on the A* algorithm, is used. In the offshore part, since the waves and gusty winds have a certain range of action on the ship, which can be analogized to a potential field, the artificial potential field method is considered here for dynamic path planning. However, the waves will change with time and need to be constantly replanned according to the position of the waves, so that real-time obstacle avoidance can be realized according to the environmental changes.

2 Proposed Method

The path planning model proposed in this paper mainly consists of two parts, the sea area dividing and the path planning, as shown in Figure 1.

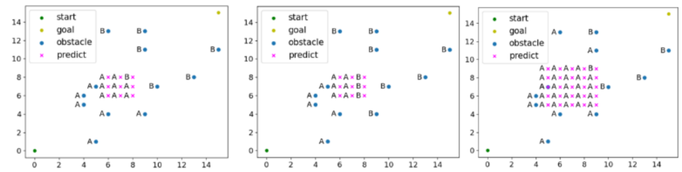

Figure 2: KNN Computational Process.

2.1 The sea area dividing

In the solving process, the K-Nearest Neighbor algorithm is used to divide the nearshore and offshore sea.

According to the starting and ending points set in this model, the midpoint between the two points is selected as m_0 to be the initial sample point in order to ensure that the entire path can be the shortest. Meanwhile, a given number of sample points around it are selected as $n_i(i \in (0, 2^l - 1), l \geq 3, l \in N)$. In particular, when l is taken as 3, it is not possible to differentiate between the near and far points, and then the value of l is increased until it can be differentiated.

The K-nearest neighbor algorithm is used to classify the region. Initially the coordinates of the reef, the wind speed and wave height are obtained, which are used as data samples for classification. Then the KNN algorithm is used to calculate the Euclidean distance between the stated midpoint m_0 and its sampling points and the data samples based on the selected K_0. At the same time, the values of distance are ranked and each sampling point is classified into the category with the higher number of species as the final category for that sampling site. Finally, m_0 and its sampling points are categorized into two categories labeled as nearshore and offshore sea respectively, so as to obtain the demarcation line of the sample points, and define the sample point $n_j(j \in (0, i])$ whose demarcation line belongs to offshore sea as the starting point of the offshore planning, and as the end point of the nearshore planning. As shown in the following Figure 2.
where (a), (b) denotes the KNN computation process, and (c) denotes the case of increasing l when it is not possible to distinguish between near and far points.

2.2 The path planning

The D* algorithm is used in nearshore path planning. The length of the planned path as well as the start and end points are recorded as $d_{1,k}(k \in (0, j])$. For offshore path planning, the Artificial Potential Field (APF) algorithm is employed, with criteria for selecting wind speed and wave height obstacles based on sea research. These criteria vary by season, sea area, and vessel type, with no universal threshold specified [14].

The algorithm proceeds as follows: the KNN-derived point is selected as the starting point, and the wind farm as the endpoint. After setting the coordinates for the start, end, and obstacles, the combined potential at the current position is calculated with the gravitational and repulsive potential formulas. The resulting combined force determines the acceleration of ship, and its displacement is computed based on this acceleration and the set time interval. The position of ship is updated, and this process repeats until the endpoint is reached.

Table 1: Coordinate Display

Obstacles	Coordinate
Origin coordinate	(0,0)
Terminal coordinates	(50,50)
Nearshore obstacle coordinates(reef)	(4,7),(10,10),(17,5.5),(16,9),(7,15),(3,25),(18,20),(25,15),(20,15)
Offshore obstacle coordinates (effective wave height)	(20,35),(25,35),(35,32),(35,35),(35,45), (45,40)(50,30),(37,20)

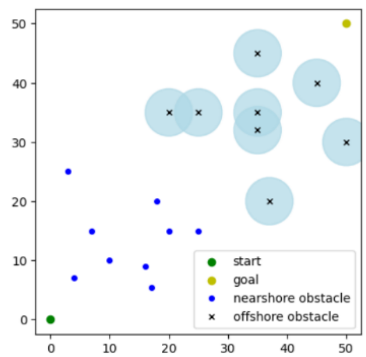

Figure 3: Virtual Ocean.

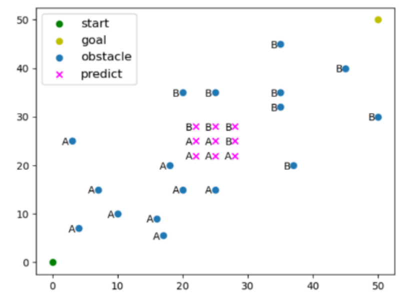

Figure 4: KNN Dividing the Sea Area.

The first step of planning is to compute the path lengths $d_{2,k}$, sum them with the offshore part, and select the shortest combined path at point $n_{\min\{k\}}$. During navigation, wave height changes are monitored in real-time, enabling path replanning as needed until the vessel reaches the wind farm. This planning calculation process is as follows: $d_{final} = d_1 + d_2$, where $d_1 = d_{1,\min\{k\}}$ and $d_2 = \sum_{i=1}^{times} d_{rep_i}$.

3 Simulation Experiment

3.1 Description of Dataset

In order to better demonstrate the universality of the algorithm, the paper constructed a virtual ocean for vessel path planning at sea as in Figure 3. The starting point and the end point were located at the two ends of the diagonal of the sea area range, and at the same time, another diagonal was used as the approximate sea area segmentation line, and obstacles were randomly generated in the nearshore and offshore. The coordinates of the specific points were shown in the following Table 1.

3.2 K-Nearest Neighbor Algorithm Sea Area Division

Firstly, the coordinates of reefs and effective wave heights are obtained as data for classification. K-Nearest Neighbor algorithm is used to classify the said data source by obtaining the demarcation line of the selected sample points. Also define the sample point $n_j (j \in (0, i])$ where the demarcation line belongs to the offshore as the starting point of the offshore planning and as the end point of the nearshore planning. As shown in Figure 4.

where point A indicates nearshore obstacles and point B indicates offshore obstacles.

3.3 D* path planning

After completing the boundary differentiation of KNN algorithm for nearshore and offshore sea in the above steps, the D* algorithm is used to plan the nearshore portion of the path. In the following figure, the blue dots mark the obstacles in the navigation, the yellow dots are the endpoints of the nearshore planning portion, while the red dots denote the candidate endpoints. Observed from the Figure 5, different paths and their lengths can be obtained depending on the choice of the endpoints. The calculated path lengths are stored and combined with the subsequent nearshore planning to complete the distance calculation and comparison of the complete paths, from which the algorithm selects the optimal result, i.e., the shortest path.

3.4 Artificial potential field path planning

The artificial potential field algorithm is used for the offshore sea part of the path planning, in the Figure 6 for the point difference marked for the wind speed and wave height anomalies and for the impact on the ship navigation area (wave height (37, 20) is not shown because of the small impact on the ship in the figure). The green point is the end point of the near-field planning part and the starting point of the offshore planning part; the yellow point is the end point of the offshore planning part. Based on the actual trajectory maps of the four diagrams, it can be observed that depending on the starting point, the potential field generated by the obstacle affects the navigation of the vessel to a different extent and actually acts on the planning of the path. According to the selection of nodes at the decomposition zone, four sets of nearshore and offshore path combinations are obtained, and the summing

Table 2: Planning Path Determined By D* And KNN

Path	Different decision points			
	(a)	(b)	(c)	(d)
KNN Division Point	(22,28)	(25,28)	(28,25)	(28,28)
$D*$ Path Distance (km)	35.70	36.94	36.94	38.77
APF	36.50	34.27	32.74	35.50
Total distance	72.2	71.21	72.44	71.51

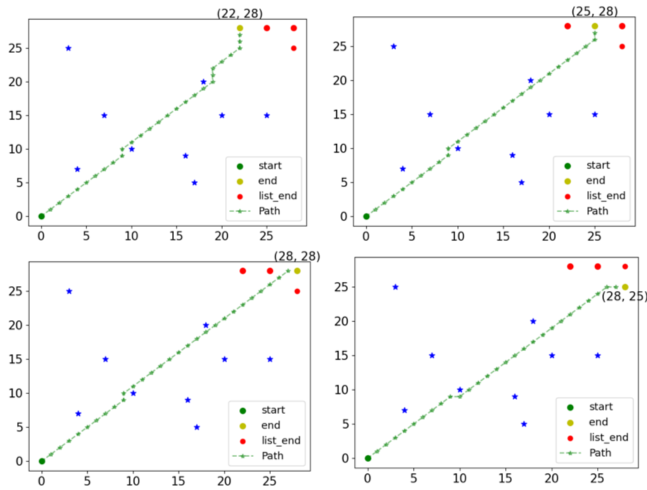

Figure 5: D* path planning.

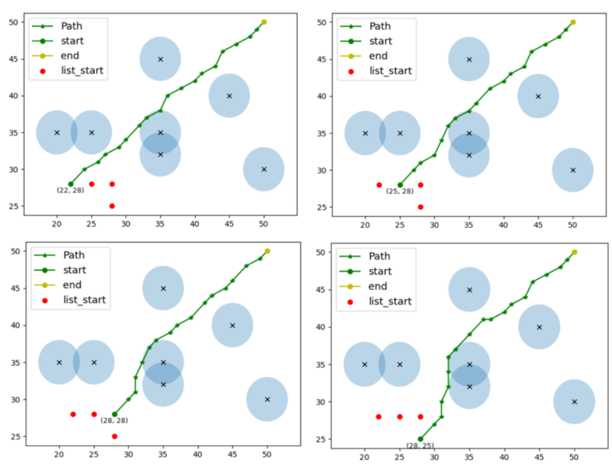

Figure 6: Artificial potential field path planning.

operation is used to obtain the complete paths. The optimal path is obtained through comparison.

The following Table 2 shows the paths based on the two path plans and the choice of demarcation points. The complete path planning and path distances for the section are obtained by using summation of the obtained path distances.

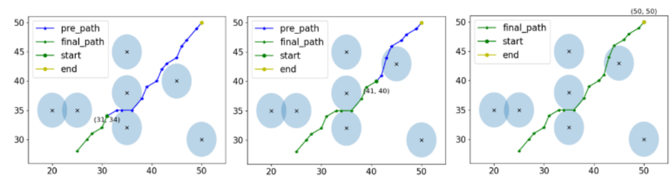

Figure 7: Artificial potential field replanning process.

After the comparison of the total distance traveled, (25, 28) is chosen as the final point of differentiation.

3.5 Path Replanning

Since the obstacle selected for the artificial potential field method is the wind speed and wave height, and the hydrological information of this object is highly susceptible to change, so the dynamic artificial potential field method is used in this part which replan the paths according to the change of the obstacle at a fixed time interval. The subsequent data and figures show in Table 3 and Figure 7.

The pre-field dynamic path planning is completed. Since the solution process of the return line is similar to the above process. In this paper, we do not describe too much.

4 Conclusions

In this paper, a dynamic route planning model based on sea area partitioning is proposed. This model focuses on the detailed path planning from the harbor to the wind farm area. Specifically, the KNN algorithm is used to segment the nearshore and offshore area for round-trip voyage, the D* algorithm is used to plan the path for the nearshore point set, and the improved artificial potential field method is used for the path planning for the offshore point set, which is dynamically adjusted based on the real-time geographic information.

According to the results of simulation experiments, the model is universal and can be applied to more random and complex sea conditions. Additionally, there are potential research directions that could enhance the practicality of this model. For instance, since different wind and wave conditions vary in intensity and thus affect vessel navigation to different degrees, it would be beneficial to improve the artificial potential field algorithm by incorporating obstacle grading.

Table 3: Obstacle Coordinates In The offshore

Ship coordinates	Coordinates
Beginning (25,28)	(20,35),(25,35),(35,32),(35,35),(35,45),(45,40),(50,30), (37,20) (This point is omitted from the diagram)
The 1st update (31,34)	(20,35),(25,35),(35,32),(35,38),(35,45),(45,40),(50,30), (37,20)(This point is omitted from the diagram)
The 2nd update (41,40)	(20,35),(25,35),(35,32),(35,38),(35,45),(45,43),(50,30), (37,20) (This point is omitted from the diagram)

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