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Research and Application of Path Planning Algorithm for Unmanned Craft

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Abstract

In order to better research the unmanned boat path planning algorithm and application, respectively from the global path planning based on static obstacle and local path planning based on dynamic two angles of the existing path planning algorithm planning summary, respectively from the algorithm principle, characteristics, advantages and disadvantages and development status, for better development of the unmanned boat path planning algorithm, for the future unmanned boat path technology research has certain reference value.

Keywords

Unmanned Boat; Path Planning; Intelligent Bionic.

1. Introduction

With the extensive application of surface unmanned craft (Unmanned Surface Vessels, USV) in future modern naval warfare, this paper mainly introduces the latest methods of USV path planning and obstacle avoidance. Furthermore, the aim of this paper is to provide a comprehensive overview of recent progress and new breakthroughs and to discuss some future directions worth to study in the field. The focus of this paper is on these pathway planning algorithms that handle the constraints and properties of the USV and the impact of the marine environment. We divide the USV path planning approach into two categories: global path planning with known static barriers, and local path planning with unknown and dynamic barriers.

2. Global Path Planning

Global path planning algorithm is based on the map environment information is known, through the environment using graphic perspective modeling way, the realistic physical space algorithm abstraction, make the two can form a mapping, has sought a optimal path from the starting point to the target, the path length is usually the key to USV path planning optimization target. Under this goal, how to plan quickly and efficiently out the optimal path is crucial to promote the development of USV. There are many global path planning algorithms, and their trials and ranges vary according to their own advantages and disadvantages. According to the research on the global path planning algorithm commonly used in various fields, it includes A* algorithm, ant colony algorithm, genetic algorithm and particle swarm algorithm. Commonly used local path planning methods include RRT, artificial potential field, fast travel method, etc.

2.1 A* Algorithm

Because the A* algorithm combines heuristic search and search based on the shortest path, the A* algorithm is the most effective direct search algorithm in a static environment. In A* algorithm, the search area is generally divided into small blocks, each small block represents node, the idea is on the basis of the breadth of first introduced an evaluation function: $f(n) = g(n) + h(n)$, $g(n)$ is the actual cost function, it represents the actual cost from the starting node to node n, $h(n)$ is the minimum distance from the node to the target node, often using the Manhattan distance of two nodes, $f(n)$is the starting node The estimated cost to the target node in Fig. .The A* algorithm finally finds the target node by constantly calculating the value of the surrounding nodes and selecting the minimum cost $f(n)$as the next traversal node. However, the traditional A* algorithm adopts the eight-neighborhood node expansion method, resulting in the planned paths are mostly "zigzag", so it does not conform to the large inertial motion characteristics of USV.

Based on this, research scholars have proposed various improved A* algorithms. To reduce the computational time and redundancy of the A* method, unnecessary adjacent nodes avoiding unnecessary anterior and posterior movements are proposed by Yan[1]. Daniel[2] proposed A method based on the A* square The Theta * method of the method is used to smooth the path generated by the A* method. Singh[3] proposed a revised A* algorithm, called the "constrained A* algorithm", which can generate safer planning paths in the Marine environment considering the effects of tailwind and headwinds. In addition, Xie proposed a multidirectional A* algorithm based on APF to generate safer and shorter navigation trajectories within wind farm waters.

In short, in order to make USV better adapt to path planning, A* algorithm by improving the inspired function or child the extension of the nodes, when A* algorithm search the next node, it must calculate $f(n)$ and choose the cost minimum node, because $f(n)$its basic idea is greedy calculate all nodes in the map, which makes the map larger search area, planning path speed is very slow.

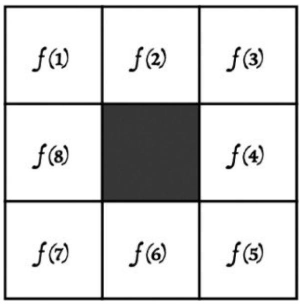

Fig. 1 A* algorithm Search scope

2.2 Genetic Algorithm

Inspired by natural selection and natural evolution, genetic algorithms have been proposed and widely used to solve various optimization problems. The working principle of genetic algorithm is to initialize the population randomly, select the better individuals as candidate solutions according to the specific index, and select, cross and variant them. Repeat this process to update the next generation population until a certain convergence index is met. Limited by genetic algorithms, researchers usually modify the algorithm in terms of genetic operators, evaluation factors or individual selection in the population to accommodate the characteristics of USV.A fuzzy controller optimized using genetic algorithms to ensure proper navigation along the intended path of the USV was proposed by Chen et al. In a study by Niu[4], combining genetic algorithms with a Voronoi roadmap to generate energy efficient paths for USV in a complex geographic map of ocean currents. Xin junfeng [5] future customer service unmanned ship in the path planning of traditional genetic algorithm population precocious and slow convergence,put forward to use multi-domain inversion to increase the number of offspring strategy, by optimizing the chromosome to improve the traditional genetic algorithm, effectively improve the local search ability, has a shorter path, faster convergence rate and better robustness.

Genetic algorithm has been successfully applied to USV path planning in the environment of known static obstacles. Its biggest advantage is that it does not need to know how to find the optimal solution before the planning. Due to its high robustness, the algorithm is widely used in the path solving problem in complex environment. However, its disadvantage is that if the parameters of the algorithm are not adjusted properly, there are problems such as slow convergence rate or individual peaks.

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2.3 Ant Group Algorithm

Ant colony algorithm is a heuristic optimization method proposed to simulate the foraging behavior of ant colonies in nature. The idea is that each ant when foraging on the road after a certain concentration of pheromone, in the same time the shortest path due to the number of ants through and pheromone concentration is high in Fig. , plus later ants in choosing road will choose pheromone concentration as the basis, played a positive feedback effect, so the pheromone concentration high shortest path was soon found. The colony algorithm uses the behavior of individual ants to represent a feasible solution to the path optimization problem, and the behavior of the whole colony constitutes the solution space of the problem.

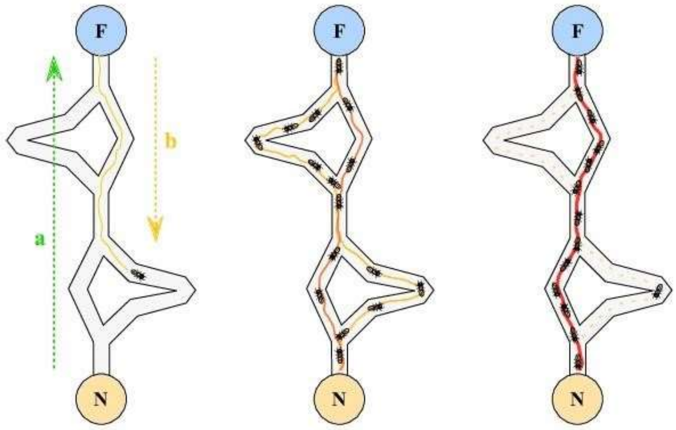

Fig. 2 Schematic diagram of ant colony algorithm

Chen Lijia [6]. Based on electronic chart in multiple constraints (wind and waves, depth, speed, sailing costs, etc.) the lowest cost of the optimal route generation algorithm, based on route network diagram, the algorithm using improved ant colony algorithm to find the optimal path, the algorithm improves the search efficiency, can be faster to find the best path. Xin junfeng [7]. improved the traditional particle swarm algorithm by random grouping inversion, linear descent inertial weight method, and adaptive particle swarm optimization algorithm. Zhang used hydrodynamic simulation to calculate the aerodynamic resistance of unmanned ships in different directions and wind speed, and then used the ant colony optimization algorithm to plan the path of unmanned ships with the rotation performance, wind and wave resistance and the influence of sea current. In Lazarowska [8] to a new method based on a group of optimized dynamic environment path planning to solve the problem of sea collision avoidance, through the use of actual navigation input data simulation test and evaluate the actual efficiency of the direction, prove that the method can be applied to the decision support system and intelligent obstacle detection and collision avoidance system.

Ant colony algorithm compared with other algorithm has strong robustness and wide applicability, especially in other algorithms to solve the problem of path planning can make significant progress and breakthrough, but its convergence is slow, easily into local optimal problems also need researchers to consider improvement when applied.

2.4 Particle Population Algorithm

Particle swarm optimization is a computational technique based on random population evolution derived from the study of bird foraging behavior. When birds look for food, they do not know exactly where it is, but only where they are now and the distance from it. Through the coordination of birds, the sharing of information, and the transmission of their own search state, other birds can compare to determine whether they are the optimal solution. The flight process of a particle is a search process whose flight speed can be dynamically adjusted by the global optimal position and the individual historical optimal position. Each particle has two properties: speed and position, where the speed represents the speed the particle moves and the position represents the direction the particle moves. In the algorithm, the position of each particle is continuously updated according to the historical and global optimal location until it converges to the optimal solution.

For example, an improved PSO is proposed to address the shortest and safest paths for multi-target robots. The modified PSO was applied to the multiobjective path planning with the shortest distance and the most smooth path by Mac [9]. Wu [10] combines the PSO algorithm to study the collaborative path planning and target strike of unmanned aerial water vehicle and autonomous underwater vehicle. Multi-target linear summation UAV path planning based on an improved PSO was proposed by Shao [11]. Das proposed a modified PSO and gravity search algorithm for robotic path planning.

Compared to other natural heuristic algorithms, the PSO is characterized by memory, and each individual can learn from themselves and others to optimize their performance. Due to few parameters, fast convergence speed and convenient calculation, it is widely used in optimization problems and achieves good results. However, the particle population is not sensitive to the population size and lacks the dynamic regulation of the particle velocity, and the particle population optimization is easy to fall into the local optima.

3. Local Path Planning

3.1 Artificial Potential Field Method

The artificial potential field method was first a real-time path planning algorithm proposed by Khatib, which has been widely used in local path planning problems. It is by establishing a virtual potential field, by imitating the object affected by gravity and repulsion of the movement, between the moving object and the target point is gravity, between the object and the obstacle is the repulsion force, and then establish the gravitational field repulsion field function to guide the object target point to move. Due to its low cost, simple mathematical calculation and convenient real-time observation, artificial potential fields are widely used in the path planning of autonomous mobile robots. However, if the resultant force is zero, then the robot cannot find a path or make a closed-loop motion. To address this problem and make it applicable to USV path planning. Zhang Guodong [12]. analyzed the heading jitter problem of artificial potential field method and introduced the method of filtering the heading planned by artificial potential field method to reduce the amplitude of the output heading Angle jitter and avoid the trajectory jitter of unmanned boats caused by heading jitter. Yiyang [13] improves the flow function method separated from the local minimum area along the edge of the obstacle. This method overcomes the local minimum problem and makes the unmanned boat can successfully escape from the minimum position. Due to the smooth obstacle avoidance trajectory planned by the flow function method, the problem of obstacle avoidance trajectory jitter is well avoided. Li Ye needle [14] of unmanned boat using traditional artificial potential field obstacle avoidance because expected obstacle avoidance Angle is too large and local tiny cause the unmanned boat course change sharply, designed the obstacle compensation method, the expected heading Angle, avoid jitter amplitude is too large, solved the traditional artificial potential field method generate expected heading Angle mutation, jitter, get obstacle avoidance trajectory light shun, improve the unmanned boat obstacle avoidance performance.

The artificial potential field method has a great advantage in avoiding unknown obstacles. Because the unmanned boat in close to the obstacles by the repulsion and repulsion direction will change rapidly, the unmanned boat turning radius is too large, which can lead to the movement of the unmanned boat will produce large swing, causing problems such as unmanned boat horizontal drift or tail, should consider the local minimum problem, avoid the limited force lead to USV instability, bring greater losses to equipment or environment.

3.2 Fast Marching Method

FMM is a numerical method created by James Sethian to solve the boundary value problem of the Eikonal equation. It builds the potential field by simulating the propagation of an electromagnetic wave, which originates from the beginning and continues to propagate until it reaches the end point [15]. The value of the potential field represents the distance to the origin, and the farther from the start, the higher the value. Thus, the potential field has only one global minimum point at the starting point, and no other local minimum points exist within the region of interest. Therefore, FMM overcomes the local minimum problem, which is the main drawback of the APF method. Moreover, the path is taken by using gradient descent, with good smoothness and continuity, more suitable for unmanned boat tracking. Meanwhile, FMM responds fast, which further facilitates its application in real-time navigation of USV in complex dynamic environments.

In order to better adapt to the Marine environment, Garrido S[16].proposed a fast moving solution based on the particularity of the Marine environment. By adding vector fields to the fast moving planning space, collision avoidance and optimal planning under multiple conditions. Xu[17] introduced the risk function ζ to describe the impact of obstacles on the safety of generated paths. Combined with the description of the external flow disturbance based on the laws of physics, the path planning problem in a realistic environment is formulated as a forward propagation according to the extended Eikonal equation. This makes the solution of the equation without any simplification or introducing additional complexity. The proposed method has higher efficiency and robustness compared to the classical fast marching based methods in anisotropic environments. An improved fast travel method completing the application of unmanned surface craft for path planning in imprecise local static environments was proposed by Xu [18] This method has the capability of path replanning, which can largely maintain existing paths and efficiently replan new pathways.

Fast moving method is characterized by easy to implement, fast calculation speed and safe path generation, and has been widely used in USV path planning.

3.3 Quickly Expand the Random Tree Method

The basic idea of rapidly expanding the stochastic tree method is to randomly spread some points in the search space, and then connect them into the motion path of the robot by calculation. The collision detection at random sampling points in the state space expands the random nodes to the undetected open regions to effectively find the collision-free path from the starting node to the target node. Feng Nan adopts the target-biased search strategy to make the search tree easy to grow towards the target point, while using the two-way search strategy, which significantly improves the convergence speed of RRT algorithm[19]. Zhuang Jiayuan define a suppressor related to an obstacle for each growing node. The suppressor acts together with the distance between the node to the obstacle to determine the growth point of the random tree, so as to accelerate the growth rate of the touch-free path and reduce the growth of unnecessary nodes. In addition, the modified RRT algorithm proposed by Liu Xiang [20] also imposes the maximum rotation angle constraint on each extended node to improve the path smoothness. In view of the problem of dynamic collision avoidance, Lee [21] proposed a "grafting RRT algorithm", which detects the collision avoidance through the speed obstacle method and calculates the grafting Angle, and then generates and inserts the grafting point to successfully realize the dynamic collision avoidance of USV. Ouyang Zi Road [22] also applied the RRT algorithm to the USV formation path planning problem, and proposed a non-strict conformal correction vector and non-strict conformal control circle region in the node growth link. The former allows the search tree to grow towards strictly conformal coordinate points, while the latter is used to control the formation conformal accuracy and adjust the computation. The study shows that the algorithm is less time consuming, strong stability and high conformal accuracy.

4. Conclusion

The path planning method of USV is mainly divided into two categories: global path planning of known static obstacles and local path planning of unknown dynamic obstacles. When there is a global map of all things, including obstacles, before the planning path, such as the position and profile of static obstacles can be measured or obtained, USV can use this information to find the collision-free path between the starting point and the target with the global path planning method. The global path planning of USV mainly includes an A algorithm, genetic algorithm, particle swarm optimization algorithm and ant colony optimization algorithm. A A This algorithm is suitable for simple, small-scale Marine environments, because a large number of nodes need to be calculated in large-scale environments, resulting in low search efficiency. AUV pathway planning for genetic algorithms requires large storage space and powerful computational systems due to numerous evolutionary operations. Ant colony optimization algorithm and particle swarm optimization algorithm can adapt to the environment in less time. The particle swarm optimization algorithm has few parameters and has certain memory function, which greatly reduces the search time.

In dynamic and uncertain underwater environments, local path planning methods are required to avoid unknown and dynamic obstacles by obtaining local environment information in real time through sensors above the planning path of the global path planner. Commonly used local path planning methods include RRT, artificial potential field, fast travel method, etc. The real-time performance of RRT is not high compared to other methods. The artificial potential field plays an important role in real-time obstacle avoidance in USV. Pathway planning has been an important branch of research to improve USV autonomy and has attracted much attention from researchers worldwide over the past decades. Although many path planning algorithms have been proposed and implemented on USV, there are still many potential problems for USV path planning to be further explored, especially considering the characteristics and constraints of USV and its working environment.

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References

[1] Liu Wenxia, Wang Rongjie, Gao Huaitong, etc. Unmanned surface craft path planning based on quantum particle swarm algorithm [J]. Journal of Jimei University (Natural Science Edition), 2023,28(01):34-40.

[2] Tongtong S,Jinchao X,Junfeng X, et al.Path Planning Method of Unmanned Surface Vehicles Formation Based on Improved A* Algorithm[J].Journal of Marine Science and Engineering,2023,11(1).

[3] Lanyong Z,Yu H,Bo J.Research on Path Planning Method of Unmanned Boat Based on Improved DWA Algorithm[J].Journal of Sensors,2022,2022.

[4] Chen Jiyang. Research on global path planning and motor control of unmanned craft [D]. Shanghai Ocean University, 2022.

[5] Shi Pengsheng. Research on the full coverage path planning algorithm and shore-based supervision system [D]. And Hainan University, 2022.

[6] Yu Jiahui, Luan Meng. Improving the ant colony algorithm in unmanned craft path planning [J]. Control engineering, and 2022,29(03):413-418.

[7] Ma Siyuan, Huang Dazhi, Xu Huili and so on. Overview of path planning algorithms for water surface drones [J]. Automated Expo, 2021,38 (11): 68-71.

[8] Jiabao Z,Boyang L,Shixin L, et al.Particle swarm optimization with orientation angle-based grouping for practical unmanned surface vehicle path planning[J].Applied Ocean Research,2021,111.

[9] Ao Bang Qian, Yang Sha, Ye Zhenhuan. Improved ant colony algorithm for surface drone smooth path planning [J]. Control theory and Application, 2021,38 (07): 1006-1014.

[10] Liu Jia, Wang Jie. Overview of the unmanned surface craft [J]. Computer Application and Software, 2020,37 (08): 1-10 + 20.

[11] Ouyang Zi Road, Wang Hongdong, Huang Yi. Based on the improved RRT algorithm [J]. Chinese Ship Research, 2020,15(03):18-24.

[12] Cheng Jie, Chen Yao Jie, Liu Zhifeng. Pway planning of unmanned surface craft based on A~ * algorithm optimization [J]. Science, Technology and Engineering, 2019,19 (29): 201-206.

[13] Ocean Research; Findings from Department of Mechanical Engineering Reveals New Findings on Ocean Research (Smoothed A* Algorithm for Practical Unmanned Surface Vehicle Path Planning)[J].Ecology Environment & Conservation,2019.

[14] Song R,Liu Y,Bucknall R.Smoothed A* algorithm for practical unmanned surface vehicle path planning[J]. Applied Ocean Research,2019,83.

[15] Junfeng X,Jiabao Z,Jinlu S, et al.IMPROVED GENETIC ALGORITHMS BASED ON DATA-DRIVEN OPERATORS FOR PATH PLANNING OF UNMANNED SURFACE VEHICLE[J].International Journal of Robotics and Automation,2019,34(6).

[16] Luo Daichao. Search strategy of multi-surface unmanned craft [D]. Harbin Engineering University, 2019.

[17] Algorithms; Studies from University College Yield New Data on Algorithms (Efficient multi-task allocation and path planning for unmanned surface vehicle in support of ocean operations)[J].Journal of Robotics & Machine Learning,2018.

[18] Tao L,Zaopeng D,Hongwang D, et al.Path Following Control of the Underactuated USV Based On the Improved Line-of-Sight Guidance Algorithm[J].Polish Maritime Research,2017,24(1).

[19] Xiang Zuquan, Jin Chao, Du Kaijun and so on. Stratified local path planning for surface drones based on particle swarm optimization algorithm [J]. Journal of Wuhan University of Technology, 2015,37 (07): 38-45.

[20] Zhuang Jiayuan, Zhang Lei, Sun Hanbing, etc. Local path planning of unmanned craft applying an improved stochastic tree algorithm [J]. Journal of Harbin Institute of Technology, 2015,47 (01): 112-117.

[21] Kim H,Kim D,Shin J, et al.Angular rate-constrained path planning algorithm for unmanned surface vehicles[J].Ocean Engineering,2014,84.

[22] Phanthong T,Maki T,Ura T, et al.Application of A* algorithm for real-time path re-planning of an unmanned surface vehicle avoiding underwater obstacles[J].Journal of Marine Science and Application, 2014,13(1).