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Research and Application of Path Planning for Unmanned Ships

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Abstract

As a new product brought about by technological progress, unmanned ships have shown great potential for application in various fields such as ocean exploration, resource development and utilization, environmental monitoring, and maritime rescue in recent years. Path planning is one of the key technologies for unmanned ships to achieve autonomous navigation, which involves multiple aspects such as environmental modeling, algorithm design, collision avoidance rules, and ship maneuvering characteristics. This article aims to explore the current research status, key technologies, and future development trends of unmanned ship path planning, in order to provide reference for the further development of unmanned ship technology.

Keywords

Unmanned Ship; Path Planning; Environment Modeling.

1. Introduction

In recent years, with the rapid development of intelligent and unmanned ships and the increasing demand for marine resource development by the country, unmanned ships have been widely used in fields such as ocean sampling, environmental monitoring, hydrological measurement, maritime search and rescue, and port surveillance. As a type of unmanned system applied in the ocean, including surface unmanned ships and underwater unmanned boats, unmanned ships have been widely used in military and civilian fields such as monitoring the marine environment, surveying the seabed terrain, maintaining and repairing submarine cables, maritime search and rescue firefighting, and security of ports and coastlines. However, in complex marine environments, how to safely and effectively manipulate USVs to quickly and effectively complete control tasks, and plan a feasible and reliable trajectory based on the environmental conditions, is the key to achieving intelligent navigation for unmanned ships. To achieve autonomous navigation, good motion control performance is a prerequisite for unmanned ships to complete the set navigation tasks without human participation. Generally speaking, unmanned ships mainly solve problems such as environmental information acquisition, path planning, and motion control during autonomous navigation. The research on unmanned ship path planning is of great significance for promoting the further development of unmanned ship technology and expanding the application fields of unmanned ships.

2. Text Research Status of Path Planning for Unmanned Ships

At present, research on unmanned ship path planning mainly focuses on two aspects: global path planning and local path planning[1]. Global path planning is the process of planning a path in a known marine environment based on information such as obstacle positions that remains largely unchanged. The relevant algorithm characteristics are shown in Table 1. Local path planning, on the other hand, involves path planning in a dynamically changing environment, obtaining current environmental information and dynamic obstacle location information through sensors and other device modules[2], and based on this, path planning and obstacle avoidance are carried out.

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Table 1. Comparison of related algorithm characteristics

Algorithm name	Advantage	Disadvantage
A * algorithm	Simple algorithm and high flexibility	Target unreachable, poor real-time performance
Genetic algorithm	Strong convergence and good global performance	Easy to mature early and prone to local optima
Ant colony	Strong robustness and less susceptible to disturbances	Slow convergence and susceptibility to local optima
Particle Swarm Optimization	Simple and easy to implement parameters	Has uncertainty and slow convergence

2.1. Global Path Planning

2.1.1. A * Algorithm

The A * algorithm is a heuristic search algorithm mainly used to find the optimal path from the starting point to the target point in a graph. The core idea is to combine the characteristics of Dijkstra's algorithm and Best First Search algorithm [3], and estimate the total cost from the starting point to the target point through an estimation function f (n) defined as f (n)=g (n)+h (n). The A * algorithm has characteristics such as high efficiency, optimality, flexibility, and scalability.

2.1.2. Genetic Algorithm

Genetic algorithm is an optimization algorithm based on the principles of natural selection and genetics. It simulates the process of biological evolution in nature, and gradually optimizes the optimal solution to the problem through operations such as competition, selection, crossover, and mutation among individuals in the population. Its main feature is to directly operate on structural objects, without limitations on differentiation and function continuity; Having inherent hidden parallelism and better global optimization capability; By using probabilistic optimization methods, the search space for optimization can be automatically obtained and guided without the need for specific rules, and the search direction can be adaptively adjusted.

2.1.3. Ant Colony Algorithm

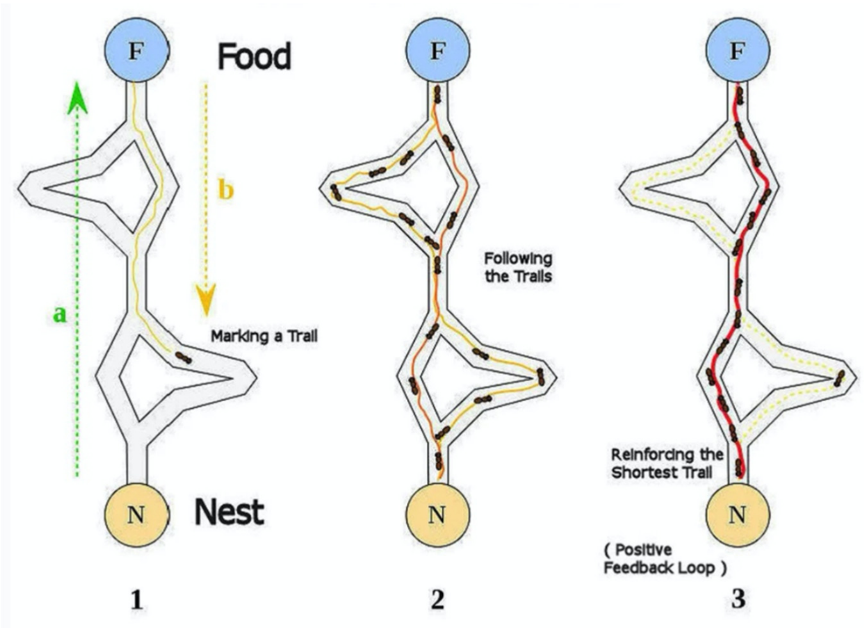

Fig 1. Schematic diagram of ant colony algorithm

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The basic idea of ant colony algorithm is to represent the feasible solution of the optimization problem using the walking paths of ants, and all paths of the entire ant colony constitute the solution space of the optimization problem. Ants with shorter paths release more pheromones, and as time progresses, the accumulated concentration of pheromones on the shorter path gradually increases, and the number of ants choosing this path also increases [4]. In the end, the entire ant will concentrate on the optimal path under the action of positive feedback, which corresponds to the optimal solution of the problem to be optimized, as shown in Fig. 1.

2.1.4. Particle Swarm Optimization Algorithm

Particle swarm optimization algorithm is an evolutionary computing technique developed by J Kennedy and R C. Eberhart was developed in 1995. This algorithm is derived from simulations of simplified social models, inspired by the collective behavior of birds. The algorithm compares the search space for solving the problem to the flight space of birds, abstracting each bird into a particle without mass and volume to represent a possible solution to the problem[5]. The particle swarm algorithm simulates the motion of these particles in the solution space to find the optimal solution to the problem[6]. The particle swarm algorithm has strong global search capabilities, is simple and easy to implement, and has strong adaptability.

2.2. Local Path Planning

2.2.1. Artificial Potential Field Method

The Artificial Potential Field Method, abbreviated as APF, is an algorithm used for path planning of robots (including unmanned ships, etc.). The basic idea of this method is to construct a repulsive potential field around obstacles and a gravitational potential field around the target point, similar to electromagnetic fields in physics[7]. The controlled object (such as a robot or unmanned ship) is subjected to repulsive and attractive forces in a composite field composed of these two potential fields. The combined force of repulsive and attractive forces guides the movement of the controlled object, thereby generating a collision free path. Specifically, the target point exerts an "attraction" on the robot or unmanned ship, causing it to move towards the target point, similar to the effect of magnets attracting iron nails. Obstacles, on the other hand, exert a "repulsive force" on robots or unmanned ships, causing them to move away from obstacles, similar to the effect of magnets of the same polarity pushing apart another magnet. In this way, robots or unmanned ships can autonomously plan safe navigation paths in complex environments.

2.2.2. Dynamic Window Method

The dynamic window method samples the linear velocity and angular velocity in the velocity (v, w) space, and predicts the future trajectory based on the robot's kinematic model. Then, evaluate the trajectories at different speeds and select the optimal speed combination to ensure safety and smoothness. The core of this method is to limit the speed sampling within the dynamic performance range of the robot, that is, to calculate a reasonable speed sampling window based on the current state and dynamic constraints of the robot, and search for the optimal speed within this window.

2.2.3. Dijkstra Algorithm

The Dijkstra algorithm, also known as the Dijkstra algorithm[8], is an algorithm proposed by Dutch computer scientist Dijkstra in 1959 for calculating the shortest path from a single source. This algorithm mainly solves the shortest path problem in weighted graphs, that is, the shortest path from the starting point to the other vertices in the graph. The main feature of Dijkstra's algorithm is that it starts from the starting point and adopts a greedy algorithm strategy. It traverses the adjacent nodes of the nearest and unvisited vertices to the starting point each time, until it extends to the endpoint. During the algorithm execution, an auxiliary array (or vector) D is introduced, where each element D [i] represents the shortest path length found from the starting point to vertex i. The algorithm gradually approaches the final shortest path length by continuously updating the values in the D array.

3. Key Technologies for Path Planning of Unmanned Ships

3.1. Environment Modeling

Environmental modeling is the foundation of unmanned ship path planning, which requires abstracting the physical space of reality into an abstract space that algorithms can handle. The commonly used environmental modeling methods include visual diagram method, Voronoi diagram method, grid method, etc. These methods each have their own advantages and disadvantages. For example, the visualization method can find the global optimal path[9], but the search time complexity is relatively high; Voronoi diagrams have faster computation speed, but there are limitations to the nodes searched; The grid method has limited search performance and can only search in a limited number of directions at a time.

3.2. Algorithm Design

The design principles of unmanned ship algorithms are mainly based on automatic control theory, artificial intelligence [10], big data analysis, and sensor technology to achieve autonomous navigation, intelligent decision-making, environmental perception, and obstacle avoidance functions of unmanned ships. Navigation control system, target positioning system, navigation system, environmental detection system, autonomous decision-making and intelligent control, modular and customized design, etc. The design principle of unmanned ship algorithm is a complex and systematic process that involves knowledge and technology from multiple fields. By comprehensively applying automatic control theory, artificial intelligence, big data analysis, and sensor technology, unmanned ships can achieve autonomous navigation, intelligent decision-making, environmental perception, and obstacle avoidance functions, providing strong support for ocean exploration and resource development and utilization.

3.3. Collision Avoidance Rules

Collision avoidance rules are an important component of unmanned ship path planning, which require unmanned ships to be able to perceive the position and speed information of surrounding obstacles in real time during navigation, and avoid obstacles according to collision avoidance rules. The commonly used collision avoidance rules include collision risk based avoidance rules and collision avoidance rules based on ship domain models.

3.4. Operating Characteristics of Ship

The maneuverability of ships is an essential factor in unmanned ship path planning, which requires full consideration of the ship's dynamic constraints and maneuverability during the path planning process. The speed, steering angle, and path curvature of unmanned ships can all have an impact on path planning.

4. The Future Development Trend of Unmanned Ship Path Planning

4.1. Algorithm Fusion and Optimization

With the continuous expansion of unmanned ship application scenarios, a single algorithm is no longer able to meet the complex and ever-changing demands of marine environments. Therefore, future unmanned ship path planning will pay more attention to the integration and optimization of algorithms to improve their adaptability and stability. High precision positioning and navigation: High precision positioning and navigation are the key to achieving autonomous navigation for unmanned ships. Future unmanned ship path planning will pay more attention to the application of high-precision positioning and navigation technology to improve the navigation accuracy and safety of unmanned ships.

4.2. Intelligence and Autonomy

The intelligence of the unmanned ship is mainly reflected in its ability to automatically perceive and obtain information and data about the ship itself, the marine environment, logistics, ports and other aspects by using sensors, communications, the Internet of Things, the Internet and other technical means. Based on computer technology, automatic control technology, and big data processing and analysis technology, intelligent operation is achieved in ship navigation, management, maintenance, and cargo transportation. The autonomy of unmanned ships refers to the ability of ships to operate independently of human activities to varying degrees. This includes functions such as autonomous navigation, autonomous obstacle avoidance, and autonomous decision-making, enabling ships to safely and efficiently complete navigation tasks without human intervention.

4.3. High Precision Positioning and Navigation

The high-precision navigation technology of unmanned ships mainly relies on advanced algorithms and sensors to achieve functions such as autonomous obstacle avoidance, path planning, and autonomous decision-making. High precision positioning and navigation are the key to achieving autonomous navigation for unmanned ships. Future unmanned ship path planning will pay more attention to the application of high-precision positioning and navigation technology to improve the navigation accuracy and safety of unmanned ships.

4.4. Standardization and Regulatory Construction

With the continuous maturity and popularization of unmanned ship technology, the International Maritime Organization and governments of various countries will accelerate the formulation and standardization of relevant laws and regulations. This will provide strong guarantees for the legal and safe operation of unmanned ships in global waters.

5. Conclusion

Path planning for unmanned ships is one of the key technologies for achieving autonomous navigation of unmanned ships. This article explores the current research status and future development trends of unmanned ship path planning. With the continuous advancement of technology and the expansion of application scenarios, unmanned ship path planning will pay more attention to the development of algorithm integration and optimization, high-precision positioning and navigation, intelligence and autonomy, as well as standardization and regulatory construction. I believe that unmanned ships will play an increasingly important role in future ocean exploration and resource development and utilization.

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