Research Status and Development Trend of Path Planning Algorithm for Unmanned Vehicles

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ABSTRACT\textsuperscript{1}: With the wide application of unmanned ships in the fields of water surface bleaching, sea exploration, water quality monitoring and emergency rescue, unmanned ship technology has attracted more and more people's attention. Due to the navigation environment of unmanned ship is very complex, diverse and changeable, it has become the primary task of unmanned ship technology research to study how to use path planning algorithm to integrate a large number of multi-sensor data, quickly and accurately make navigation strategies and achieve accurate motion control. This paper mainly summarizes the current research status of unmanned ship path planning algorithms, analyzes the differences and advantages of various path planning algorithms in practical applications, and finally points out the research trend of unmanned ship path planning algorithms.

CCS Concepts
• Computing methodologies→ Machine learning.

1. INTRODUCTION
With the deep research on unmanned ships in different countries, the unmanned surface vessel(USV) [1] has become a topic in research due to its wide application prospects in military and civilian applications [2]. Unmanned vessels include fully automatic unmanned vessels: automatic environment sensing, automatic planning of routes, automatic navigation; semi-automatic unmanned vessels: voyages according to manual setup procedures; and remote unmanned vessels. The research content includes path planning, precise identification, precise positioning, and automatic driving. In the aspect
of path planning, applying various path planning algorithms to optimize the navigation path of unmanned ships and improving the safety and reliability of navigation has become a topic of common concern in the academic community.

This paper mainly analyzes and summarizes the current research status of unmanned ship path planning algorithms, and proposes a new idea of applying deep learning to path planning algorithms.

2. UNMANNED SHIP PATH PLANNING

The path planning of the unmanned ship means planning a navigation path [3] that can safely and reliably avoid all obstacles and meet certain evaluation criteria during the unmanned ship's mission from the starting point to the target point in the mission environment where the obstacle exists. According to the unoccupied ship's acquisition of the working environment information, the path planning is divided into global path planning, partial path planning and path planning combined with multiple path planning algorithms [4].

2.1 Global Path Planning Algorithm

The global path planning [5] is to construct an optimal path (such as the shortest path, the shortest time, etc.) that can reach the target point from the starting point in the pre-established environment model when the overall environment map has been discovered. Dijkstra algorithm, A* algorithm, particle swarm optimization algorithm and ant colony algorithm are all commonly used algorithms for exploring global optimal paths.

2.1.1 Dijkstra Algorithm

The Dijkstra algorithm is a classical algorithm for solving the shortest path in a graph search problem, and is used to calculate the shortest path from one vertex to the rest of the vertices in the graph. The basic idea of the algorithm is to use the adjacency matrix storage structure to store the relationship between vertices and vertices, select a vertex as the starting point, and use the breadth-first search strategy to gradually expand from the point to the outside, and calculate the shortest distance from the node to all the other nodes. However, Dijkstra algorithm will search the average direction of each node when searching. When the working environment of the unmanned ship is more complicated [6], the number of nodes searched in the process of planning the shortest path will be very large. Therefore, dijkstra algorithm is less efficient and slower compared with other algorithms.

2.1.2 A* Algorithm

The A* algorithm [7] is a typical heuristic search algorithm in the unmanned ship path planning algorithm. By selecting an appropriate valuation function, the search is guided to the most promising direction to obtain the optimal solution. The A* algorithm can often solve the optimal path faster and more efficiently in static scenes of known environments. However, there are some shortcomings in the A* algorithm. Because the A* algorithm searches for the shortest path, it needs to detect each node at the time and find the node with the least cost. Therefore, the A* algorithm has a large amount of computation when detecting the state of the node and selecting the minimum cost. When the map scene to be planned is large, the A* algorithm often causes problems such as long calculation time and serious memory occupation, so path finding is not efficient.

2.1.3 Particle Swarm Optimization

Particle Swarm Optimization(PSO) was proposed by Dr. Eberhart and Dr. Kennedy in 1995 [8]. It is an optimized search algorithm formed by simulating the behavior of flocks [9]. In the algorithm, in an N-dimensional target search space, the potential solution of each problem to be optimized is represented as a "particle", each "particle" has a fitness value determined by the fitness function, and determines the direction and speed of the particle's movement. Particles not only move at their own speed and direction, but also move towards the current optimal particle direction. Compared with other path-finding algorithms, the particle swarm optimization algorithm has faster convergence speed,
fewer setting parameters and simple implementation [9], but its own local optimization ability and position information update are not accurate enough, which also affects its own computational efficiency and reliability.

2.2 Local Path Planning Algorithm
The local path planning [10] is to use the environmental sensing system carried by the unmanned ship to detect the state information and the surrounding local environment information in an unknown environment, and to make the unmanned ship independently plan an optimal path that satisfies certain evaluation criteria. Commonly used local path planning methods include artificial potential field method, neural network method and dynamic window method.

2.2.1 Artificial Potential Field Method
The artificial potential field method (APF) is a local obstacle avoidance navigation algorithm. The algorithm assumes that the unmanned ship moves in the working area and is affected by the gravitational force of the target point and the repulsive force of the obstacle point. The moving direction of the unmanned ship is the resultant force direction of the two virtual forces. By calculating the combined force of the two virtual forces, the path planning for the unmanned ship can be quickly realized. The artificial potential field method has the advantages of fast response, simple calculation [11] and strong real-time performance, but there is a local minimum value problem, which causes the situation that the unmanned ship cannot escape in time when it encounters obstacles.

2.2.2 Neural Network Method
The neural network method (NN) is a planning algorithm that is constructed by abstracting the structure of the biological neural network and the response mechanism to external stimuli. The neural network consists of a number of interconnected "neurons" (nodes). The processing of a single "neuron" is extremely simple. Only the combined input signal rules and the input signals that combine the inputs are calculated as the excitation rules of the output signal. Each "neuron" only periodically receives signals and sends signals to other "neurons" [12]. When these "neurons" coordinate with each other to form a powerful network, they can perform complex things like the biological nervous system, tasks, and shortest path planning. The neural network method has great advantages in adaptive learning, data parallel processing and fault tolerance, and can solve some path planning tasks in which the unmanned ship working environment is complex and has high real-time requirements. However, if the environmental information detected by the unmanned ship is incomplete, the neural network method cannot be carried out.

2.2.3 Dynamic Window Approach
The Dynamic Window Approach [13] is an autonomous obstacle avoidance algorithm that searches for the optimal control command that maximizes the objective function directly in the control instruction space. The main idea is to take multiple sets of speeds in the speed space (linear velocity and angular velocity), simulate the trajectory of the unmanned ship traveling at the next time interval with these speeds, obtain multiple sets of trajectory data, and select the optimal trajectory to drive unmanned boat’s movements according to the evaluation index.

Compared with other algorithms, the dynamic window method has a smoother path, but it is easy to fall into the local optimal solution and that limits the scope of the algorithm.

2.3 Method For Combining Multiple Path Planning Algorithms
Since there are some problems in the various algorithms of global path planning and local path planning, at present, two methods are combined to make up for their respective shortcomings. For non-global optimal programming algorithms, such as dynamic window method, it can be optimized with A* algorithm; for algorithms that are easy to fall into local optimal solution, such as particle swarm algorithm, artificial potential field method, etc., can be combined with neural network method.
optimization. The specific idea is: after obtaining the complete global path in the global path planning layer, intercepting part of the information from the obtained global path, using the local path planning algorithm to plan and obtain the entire optimal path, thereby overcoming problems of the local minimum value and low efficiency.

Based on the A* algorithm, Chuanqi Cheng [14] designed a key point selection strategy to eliminate redundant path nodes and unnecessary turning points, and constructed an evaluation function that takes into account the global optimal path based on the evaluation function. The dynamic window method performs real-time path planning, thereby improving the local obstacle avoidance ability and obtaining a smoother path while ensuring the global optimality of the planned path. Kun Liu [15] proposed an artificial potential field-ant colony algorithm, which adds the potential field force heuristic information influenced by the artificial potential field method to the heuristic information of the ant colony algorithm, and simultaneously improves the pheromone concentration update rule in the ant colony algorithm. Therefore, the convergence speed of the algorithm is accelerated. In each iteration, the "ant colony" concentrates on searching for the search target in the vicinity of the optimal path, thereby improving the efficiency of the algorithm. Aijun Liu [16] proposed a chaotic simulated annealing particle swarm optimization algorithm, which combines the advantages of random ergodicity of chaotic variables and the fast optimization ability of particle swarm optimization algorithm, and solves the shortcomings of slow convergence and easy to fall into local optimum in particle swarm optimization.

3. APPLICATION PROSPECT OF DEEP LEARNING IN PATH PLANNING

Deep Learning (DL) is the most promising algorithm for achieving simple, reliable path planning goals. In the existing path planning algorithms [17], most of them are from the environment sensing stage to the environment modeling stage, and then the intelligent algorithm and the auxiliary strategy work together to generate the optimal path [18]. In essence, environmental modeling, strategy assistance, and intelligent algorithms are a series of mapping functions. Therefore, each of the above path planning algorithms is a mapping from perception to decision. The deep learning network has strong nonlinear expression ability due to its special structure. It only needs to sense the equipment and then train enough to learn the mapping between input and output, and store the learning results in the connection between the neurons. Therefore, the path learning system based on deep learning can divide the path planning into: from the environment sensing stage to the learning algorithm analysis, and finally output the optimal path. Figure 1 shows a comparison of two path planning systems. The well-trained learning algorithm only needs to perform matrix multiplication and addition calculation in the planning process, and does not need to be iterated, which greatly improves the calculation efficiency and enhances the real-time of path planning.

![Figure 1. A comparison of two path planning systems.](image-url)

Although the well-trained deep learning algorithm has many advantages, the real difficulty in deep learning exists in the design and training of the algorithm. First, it's difficult to choose a suitable deep network structure. Up to now, there have been various structural variants in deep networks. Each structure has its own different advantages and application environments. Choosing the right network structure according to specific application scenarios is very important for the protection of deep learning algorithms. Besides, the depth of the network and the number of neurons in each layer also need to adjust carefully to ensure the stability of the algorithm. Secondly, deep learning requires a great quantity and high quality of samples [19]. It must require that the characteristics of the sample
are obvious, diverse and accurate. Therefore, how to obtain a large number of useful training samples is also a difficult problem. This is one of the important reasons why deep learning path planning technology has not been used in the unmanned ship field. Although the application of deep learning in path planning algorithms has the two above-mentioned main problems, Xuelian Zhang [20] designed the simulation training field and teacher system, and proposed a dynamic path planning algorithm based on LSTM-RNN and simulated it. She successfully solved the above problems, and ensured the feasibility and correctness of the algorithm. This also theoretically confirms the feasibility of applying deep learning to path planning algorithms.

4. CONCLUSION

Based on the above analysis, although the research on unmanned ship path planning algorithm has achieved important progress, some planning algorithms still have limitations. For example, Dijkstra algorithm and A* algorithm have low efficiency and slow speed, and the particle swarm algorithm has less ability of local optimization. The artificial potential field method has problems such as local minimum. In view of the above problems, the commonly used improved algorithms are mainly based on a combination of multiple path planning algorithms. Although they make up for the shortcomings, there are still many development bottlenecks such as increasing algorithm complexity.

From the current requirement of development, the deep learning ability is strong. If it is applied to path planning, it can adapt to complex and unknown environment quickly, and has high computational efficiency, good real-time performance, which is more in line with the requirements of today's era for high efficiency. At present, the selection and training of deep learning network structure requires a lot of resources, but with the deepening of research, it can be optimized to a small amount of sample learning and reduce resource consumption.

In this paper, the principles, advantages and disadvantages of various unmanned ship path planning algorithms are discussed. It is not difficult to see that the existing path planning algorithms still have some improvements. And that is the next destination of the path planning algorithm. In the future, deep learning used in application of path planning will have a great development potential and a broader space for development.

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