Path Planning Method in Multi-obstacle Marine Environment

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Abstract. In this paper, an improved algorithm for particle swarm optimization is proposed for the application of underwater robot in the complex marine environment. Not only did consider to avoid obstacles when path planning, but also considered the current direction and the size effect on the performance of the robot dynamics. The algorithm uses the trunk binary tree structure to construct the path search space and A * heuristic search method is used in the search space to find a evaluation standard path. Then the particle swarm algorithm to optimize the path by adjusting evaluation function, which makes the underwater robot in the current navigation easier to control, and consume less energy.

1. Introduction
Path planning is one of the most important tasks in underwater robot navigation, and it represents a degree of intelligence on underwater robots. The overall path planning consists of three parts: 1. Model the environmental information of the robot in relation to the environment. 2. Get a search space that contains environmental information. 3. Search in the search space using the corresponding search algorithm [1]. Before the underwater robot path planning, it must first model environment, described the underwater robot activity space by the external environment of the original form through a series of processing into a suitable planning model of the algorithm. A reasonable environment is conducive to reducing the amount of search in the plan and the overhead of space and time [2]. Path search algorithm search the feasible space of the path from the environment model, while the path generated from search to the path of the feasible to generate a feasible path in the space. Path optimization is considering basis dynamic characteristics of the intelligent underwater robot, in order to let more conducive to the implementation of underwater robot path for a smooth path [3].

2. Environmental Expression
Obstacles such as islands and reefs in the Marine environment are more irregular. Obstacles are constructed as a relatively neat polygon to facilitate the mathematical representation of obstacles in the planning algorithm. Because of the convex polygons are more concise and convenient in the point of tangency, intersection and judgment of whether the obstacles are in the polygons or not and so on environment planning algorithm expression into a convex polygon obstacle. The principle of constructing obstacles into convex polygon in planning algorithm is that giving priority to fill a vacancy if it does not pose a threat to the precision of path planning for the case [4, 5]. If obstacles in the depth of the underwater robot work area are large and filling a vacancy of convex polygon will have an impact on the precision of path planning then using split method. The expansion is based on the size, navigation error and safety factor of the underwater robot. The path planning of a large
voyage will not affect the accuracy of the plan. In the planning system, the convex polygons have been reformulated or separated and expanded such as Figure 1.

In order to verify the planning ability of the underwater robot's path planning algorithm in the ocean current, the numerical simulation simulates the current field. A series of uniform flows and a point vortex overlay are used to simulate the current of ocean. According to the theory of potential flow, the velocity potential of the flow field is obtained by solving the Laplace equation, and the velocity distribution of the flow field is obtained by the velocity potential.

According to the characteristics of velocity potential can be stacked, the complex flow velocity potential \( \psi \) under polar coordinates can be calculated as follows:

\[
\psi = \sum_{p=1}^{p=m} v_p r \cos \theta - \sum_{q=1}^{q=n} \Gamma_q \frac{\ln r}{2\pi}
\]  

Where m, n are the number of uniform flow and vortices at a certain point, \( r \) is the distance from current position to the centre of the vortex, \( \theta \) is the angle between compound velocity and uniform flow velocity. \( v_p \) is the pth speed of uniform flow and \( \Gamma_q \) is the velocity of the vortex at that point. The velocity distribution is obtained through the relationship of velocity and velocity distribution:

\[
v_r = \frac{\delta \psi}{\delta r} = \sum_{p=1}^{p=m} v_p \cos \theta
\]

\[
v_\theta = \frac{1}{r} \frac{\delta \psi}{\delta \theta} = -\sum_{p=1}^{p=m} v_p \sin \theta - \sum_{q=1}^{q=n} \Gamma_q \frac{\ln r}{2\pi}
\]

The upper part of the formula is calculated to get the current vector at the center of the grid, and the grid only records the information about the flow of the sea without any information about the obstacles. Each grid's current information is based on the centre of the grid. The size of the grid is only related to the complexity of the current instead of the dimensions of obstacles and underwater robot [6].

Current flow around obstacles can produce change. Due to the planning used obstruction information after expansion, the current changes around the obstacles do not take into account in the path planning.

3. Path searching
Use the A* heuristic search method to find a path that meets the criteria in the search space. Because of the presence of the current, it is not appropriate to use the shortest path as a path planning criterion. The algorithm uses the minimum energy consumption as the criterion of the path planning. The evaluation function is defined as

\[
f(n) = g(\text{start}, n) + h(n, \text{goal})
\]

\( g(\text{start}, n) \) denotes the path cost from initial node s to node n; \( h(n, \text{goal}) \) denotes estimate cost from node n to goal node G; \( h(n, \text{goal}) \) rely on information that is relevant to the problem, which is called heuristic function. \( g(\text{start}, n) \) consist of path cost L, current cost C and diversion cost T [7,8].

\[
g(\text{start}, n) = L(\text{start}, n) + C(\text{start}, n) + T(n)
\]

\[
L(\text{start}, n) = \sum_{i=\text{start}, j=i+1} L_{ij} + \sum_{i=\text{start}, j=i+1} C_{ij} + \sum_{i=\text{start}+1}^{n-1} T_i
\]

\[
h(n, \text{goal}) = L(n, \text{goal}) + C(n, \text{goal}) + O(n, \text{goal})
\]

\[
= L_{n, \text{goal}} + C_{n, \text{goal}} + \sum_{i=1}^{n} O_i
\]

The different steps of the A* algorithm can be summarized as follows:

Establish the backbone structure between the start node and the end node. Get the boy and girl point from the first obstacle among starting node and terminating node.
Calculate boy’s and girl’s evaluation function and set the lesser one as expanding node. Create a backbone structure between the current extension node and the end node and get the boy and girl points of the next layer of tree structure. Keep repeating the above steps until there is no barrier between the extension node and the terminated node.

4. Path optimization by Particle Swarm Optimization
The problem of path planning for underwater robots is the problem of constraint optimization, which can be described as follow:

\[
\text{Min}(F) \tag{7}
\]
\[
\text{s.t. } P_i^w \notin \text{obstacle} \tag{8}
\]

Where F denotes the fitness function, which is also called target function. \(P_i^w\) denotes location of the ith dimension of the wth particle. The constraint is that \(P_i^w\) can not be located within obstacles. There are two types of particles that do not meet the constraints of an obstacle: 1. The position of particle is outside of the obstacle, but the path of particle passes through the barrier. 2. The position of a particle is in the obstacle [9]. Both situations need to be adjusted. Move along its own velocity direction to the adjusted position until it is visible to the previous and the next dimension. After calibration, the particle satisfies the constraint, but this processing changes the search process of the particle group. Due to the adjusted position is not clear the relationship between the global best position and their own best position, the adjustment speed is set to zero, waiting for its own best location and the global best position to guide.

The PSO algorithm path optimization implementation steps are as follows [10,11]:

- Initialize the velocity and position of the particle in the search space. The optimal location of the individual, pBest, is its current location. The optimum position of all particles is determined by the fitness function, which is called gBest [12].
- Update the flight speed of each particle. When the particles fly into an obstacle, the two criteria that are generated by random particle encoding are used to adjust the position of the particle.
- Calculate the fitness of each particle. If the current fitness of particle is less than the fitness value of the individual’s optimal location, update pBest by current position. If the fitness of individual location is less than the fitness value of gBest, update gBest by the exact particle’s position.
- Keep repeating the above steps until the maximum iteration number is reached.

5. Implementation
Simulation experiments were conducted in two simulated multi-obstacle Marine environments. Set the area of the complex current to be size (3500*2500). The number of particles is 20. Particle groups use the von neumann structure. The nonlinear adjustment inertia coefficient is set to 1.45. Search width is set to 200. In order to ensure the adjustment of the sea current, the minimum dimension is set to 5. And the maximum value of the dimension is set to 10 for the convergence of the particle swarm optimization algorithm.
Figure 2. Path optimization in the first environment.

Figure 3. Optimization convergence in the first environment.

Figure 4. Path optimization in the second environment.
In Figure 2 and Figure 4, the black convex polygon represents the obstacle, and the arrow indicates the direction of the current. The cables represent the path before and after the optimization. In Figure 3 and Figure 5, the curve shows the change trend of fitness function as the number of iterations increases.

6. Conclusions & Future work
From the optimized path diagram (Figure 2, Figure 4) can be seen that the optimized path reduces the influence of lateral flow as far as possible, which can greatly reduce the energy consumption of the underwater robot in the current. As you can see from the fitness convergence diagram (Figure 3, Figure 5) that the fitness has been plummeted. So the search speed is getting faster and the energy consumption is getting smaller. Because of this path segmentation optimization method considering the current environment without the obstacles, the dimension of the particle swarm will be reduced. Particle swarm optimization algorithm’s convergence speed is faster than the particle swarm path planning algorithm and easier to converge.

The simulation results show that the environmental modeling using binary tree structure is simple, and A * algorithm search path is effective and feasible. Particle swarm optimization is more suitable for sailing in the current environment. The influence coefficient of marine current on the underwater robot are obtained by experience and simulation experiment. As future work, the influence of different number needs further experiment.

7. References
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