Path Planning for Construction Machinery Based on Improved Potential Field Ant Colony Algorithm

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Abstract. The path planning algorithm of unmanned construction machinery is studied, and the potential field ant colony algorithm is improved to be applied in the field of unmanned construction machinery. Firstly, the raster map modeling was optimized to eliminate the trap grid in the map. At the beginning of algorithm iteration, the heuristic information of artificial potential field method was added and the global pheromone updating model was improve the convergence speed of the algorithm. In addition, the weight coefficient of potential field force and local pheromone updating model were introduced to enhance the development of raster map in the later iteration of ant colony algorithm and reduce the influence of heuristic information of potential field force. Finally, the selection range of parameters such as optimal pheromone heuristic factor and ant colony number is determined by simulation, and it is verified that the algorithm is better than the basic ant colony algorithm.

1. Introduction

With the development of unmanned driving technology, artificial intelligence and other technologies, the research and development of unmanned construction machinery has become a trend of the development of machinery heavy industry. Path planning is an important technical link of unmanned machinery and even unmanned driving technology. In recent years, domestic and foreign scholars conducted extensive research on robot path planning technology, the commonly used method of path planning with grid method, artificial potential field method[1-2]. Grid method is mainly used in the global path planning, to environment around the robot space into the Spaces that don't repeat unit[3], the modeling is relatively simple, but should pay attention to the cell size, when the space increases, the grid method is needed to increase the storage space, influence on the speed of algorithm. In the potential field method, the target point is regarded as the gravity force and the obstacle as the repulsion force, which reasonably determines the forward direction of the construction machinery. Now, there are more and more intelligent algorithms, such as A*Algorithm[4], genetic algorithm[5], ant colony algorithm[6], particle swarm algorithm, etc. The integration of bionic algorithm and intelligent algorithm has become a hot research direction of robot path planning[7]. The randomness and iterative convergence of ant colony algorithm make it suitable for path planning problem, but it has the problem of slow iterative speed in the early stage, which is prone to local optimal, so it needs to improve its performance[8]. This article will combine artificial potential field method of ant colony algorithm is improved, and the ant colony algorithm pheromone update rule redesign, in guarantee the
algorithm's ability to explore work space, reduce the blindness of ant colony search, the ant colony search fast convergence to the optimal path, the simulation experiments verify the new algorithm was applied to the feasibility of the engineering machinery complex construction environment.

2. Environmental Modeling
From the perspective of space, the working environment of construction machinery can be regarded as two-dimensional space in the process of driving and operation. In this paper, the model of environment map is established by grid method. The side length of grid is divided according to the maximum circumferential circle diameter of construction machinery. Among them, the grids without obstacles are feasible grids, and the grids with obstacles are infeasible grids. The grids are numbered from left to right and from top to bottom as 1, 2,..., N, the center point of the feasible grid is the path point of the ant traversal process, and the grid in the upper left corner and lower right corner represent the starting point and target position of the path respectively.

3. Potential Field Ant Colony Algorithm Improvement
The operation area is treated as feasible area in potential field ant colony algorithm iterative optimization, ants arrived in operational areas to traverse the operational areas to transform operation area for the feasible region, the high initial pheromone of feasible region can achieve the goal of ant traversing the feasible region. The artificial potential field algorithm has the following problems in path planning:
(1) When the repulsive force formed by the obstacle is equal in magnitude and opposite in direction to the target attraction, the deadlock phenomenon will be formed and the robot cannot move [9].
(2) When the obstacles are relatively dense, due to the influence of the scope of the repulsive force of the obstacles, the local area is not passable, and even the problem of path planning failure appears[10-11].
(3) When there are more obstacles, the calculation of resultant force is complicated, resulting in the decrease of calculation efficiency.
(4) When the target point obstacles are too dense, there will be no solution.
The conventional path planning algorithm when applied to the path planning of construction machinery, there are obstacles to identify and handle and operational areas, engineering machinery in the operation step and path should be changed according to the operational areas in order to achieve operational areas traversal. Therefore, the traditional path planning algorithm can not meet the path planning of unmanned construction machinery, so the above algorithm needs to be improved.

3.1. Basic Ant Colony Algorithm
In the simulation process of conventional artificial potential field method, if the obstacles around the target point are too dense, there will be no solution, and the target point will become unreachable point. Because the gravitational field near the target point is the weakest, the gravity is small, and too dense obstacles make the robot far away from the target point.
An improved repulsive field strategy is proposed. Let the current position of robot be \( P \) and the position of target point be \( G \). The repulsive field function is as follows:

\[
U'_0(X) = \begin{cases} 
-k_0 \left(1 - \frac{1}{l} \right)^2 \cdot a \cdot d(X, X_E)^2 & l \leq l_0 \\
0 & l > l_0 
\end{cases}
\]  

(1)

Where \( 0 < a < 1 \) is the constant value, \( d(X, X_E)^2 \) is the distance between the current position and the target point.

Under the condition of the new repulsive potential field function, the repulsive force function is:

\[
F'_0(X) = \begin{cases} 
-k_0 \left(1 - \frac{1}{l} \right)^2 \cdot d(X, X_E)^2 \times \frac{\partial l}{\partial X} & l \leq l_0 \\
0 & l > l_0 
\end{cases}
\]  

(2)

At this point, the resultant force of the vehicle in the potential field space is:

\[
F'(X) = F_E(X) + F'_0(X)
\]  

(3)

According to Equation (3), the target point is regarded as the point with the lowest gravity. The closer the vehicle is to the target point, the lower the repulsive force of the corresponding obstacle to the vehicle will be, thus avoiding the unreachable situation of the target.

### 3.2. Pheromone Update Rules Improved

In the basic ant colony algorithm, the pheromone concentration of each node is updated according to the path length traveled by each ant in this iteration and the influence of pheromone volatilization. Therefore, if the ant colony's search for path shows disorder and repetition in the earlier iteration, it will have a great impact on the ant's path selection in the later iteration. Therefore, in order to ensure that the earlier iteration shows a better exploration ability, the pheromone updating rules are improved:

\[
\tau_{ij}(t+1) = (1 - \rho) \tau_{ij}(t) + \rho \Delta \tau_{ij}(t, t+1)
\]

(4)

\[
\Delta \tau_{ij}(t, t+1) = \sum_{k=1}^{m} \Delta \tau_{jk}(t, t+1)
\]

(5)

\[
\Delta \tau_{jk}(t, t+1) = Q / (L_k) \quad L_k \leq L_{bp}
\]

(6)

Where, \( L_{bp} \) is the optimal path reference value, and this pheromone update rule restricts the ant colony to be allowed to release pheromones only if the path length is lower than this value in the iteration. As a result, ants with a longer path are not recorded into this iteration, which improves the development ability of ant colony algorithm and enables it to quickly converge to the optimal solution.

In order to balance the large difference in global pheromone concentration value caused by the optimal ants' pheromone release and improve the global map searching ability of ant colonies, a local pheromone updating model was introduced, whose formula is as follows:

\[
\tau_{ij}(t) = (1 - \gamma) \tau_{ij}(t) + \gamma \Delta \tau_{ij}(t)
\]

(7)

By introducing a local pheromone updating model, the ability of the ant colony to explore the environment map in each iteration can be improved, which can reduce the influence of the path left by
the ants in the previous iteration on the map exploration of the future ant colony. In order to prevent the local pheromone value from being updated too large or too small, leading to premature convergence and local optimal or stagnant state, the maximum $\tau_{\text{max}}$ and minimum $\tau_{\text{min}}$ of local pheromone update are introduced, and the restriction rules are constructed as follows

$$
\tau_{ij}(t) = \begin{cases} 
\tau_{\text{max}} & \tau_{ij}(t) \geq \tau_{\text{max}} \\
\tau_{\text{min}} & \tau_{ij}(t) \leq \tau_{\text{min}}
\end{cases}
$$

(8)

4. Potential Field Ant Colony Algorithm Model

The ant's cue to find the next location consists of two parts. One part is the heuristic information formed by the resultant potential field of the environment, which makes the ants tend to move along the resultant direction; the other part is determined by the distance from the target position of the ants in the conventional ant colony algorithm.

The resultant heuristic information of potential field is constructed as follows:

$$
\eta_{E0}(t) = a F^r
$$

(9)

In this equation, $a > 0$ is constant. Under the influence of the heuristic information, ants tend to choose the grid pointed by the resultant potential field as the next target grid. The heuristic value is helpful to avoid the obstacles of construction machinery, choose the appropriate route and avoid the early disorder of ant colony algorithm.

The other part of heuristic information provides the distance between the ant and the target position, and this part of heuristic information is constructed as follows

$$
\eta_d = \frac{1}{d(i, E)}
$$

(10)

In the initial iteration, the positive feedback effect of the ant colony is weak, and the resultant force of the potential field plays a dominant role. As the iteration progresses, the ant colony gradually fits the optimal route under the guidance of the pheromone. At this time, the influence of the potential field force should be weakened, so an artificial dynamic weight coefficient $\chi$ of the potential field force is introduced, as shown below:

$$
\chi = \frac{N_{\text{max}}}{N}\frac{n-N}{n-N_{\text{max}}}
$$

(11)

In the formula, $N_{\text{max}}$ is the total number of iterations, $N$ is the current number of iterations, and $n$ is a natural number.

The heuristic information for constructing ant colony algorithm of potential field is as follows

$$
\eta_{\text{tot}} = \eta_{E0} \cdot \eta_d = \frac{a d^r}{d(i, E)} \cdot \frac{N_{\text{max}}-N}{N_{\text{max}}}
$$

(12)

It can be seen that even when the resultant force of the potential field $F=0$, that is, when the repulsive force and gravity are balanced, the construction machinery will not stall in the local area, and the ant-colony position heuristic information Equation guides the construction machinery to continue to search the global path.
5. Simulation Experiment Analysis
In order to verify the advantages of the improved ant colony algorithm in path planning, the proposed algorithm was simulated in different raster environment models, and the results were compared with those of the basic ant colony algorithm.

5.1. 20 × 20 Raster Simulation

![Route layout with ant colony algorithm](image1)

![Route layout with potential field ant colony algorithm](image2)

**Figure 2.** Path planning results obtained from two 20 × 20 grid algorithms.

![Comparison of 20 × 20 grid convergence curves](image3)

**Figure 3.** Comparison of 20 × 20 grid convergence curves.

In the 20 × 20 grid, as shown in the figure 2, the final convergent paths of the two algorithms are similar, and the length of the optimal solution is 30.63 in the end. However, the simulation results show that the ant colony algorithm converges to the optimal solution after about 240 iterations, while the potential field ant colony algorithm adopted in this paper converges to the path length of 30.63 after about 30 iterations.
In order to understand the applicability of the algorithm, this paper conducted a simulation experiment on a 30×30 grid map environment.

5.2. 30×30 Raster Simulation

**Figure 4.** Comparison of path traversal nodes of the two algorithms in a 20×20 grid.

**Figure 5.** Motion trajectories of two 30×30 grid algorithms.

**Figure 6.** Comparison of 30×30 grid convergence curves.
As can be seen from figure 6 and figure 7(a), the convergence curve of basic ant colony algorithm in a 30×30 grid is still oscillating when the iteration is up to 300 times, which seriously affects the convergence speed of the algorithm. However, the ant colony algorithm in the potential field proposed in this paper converges to the optimal path length of 47.36 around the 20th iteration.

(a) Node distribution of ant colony algorithm path  
(b) Node distribution of path in potential field ant colony algorithm

Figure 7. Comparison of path traversal nodes of the two algorithms in a 30×30 grid.

6. Conclusion
In this paper, raster map modeling is adopted. Aiming at the deficiency of ant colony algorithm in global static path planning, an improved potential field ant colony algorithm is proposed, which is suitable for complex working conditions of construction machinery. Compared with the ordinary ant colony algorithm, the improved potential field ant colony algorithm converges faster. Meanwhile, this algorithm has good adaptability to the path planning of complex path of mobile robot.
(1) The trap grid in the raster map is processed, and the ant colony algorithm falls into local optimum due to environmental problems, which improves the stability of the algorithm.
(2) The local pheromone updating model is introduced, and the local pheromone concentration value range is determined. Under the premise of not affecting the convergence of the algorithm, the pheromone concentration of each grid node is balanced to improve the algorithm's ability to develop raster maps.
(3) The optimal pheromone release principle is established to make the global pheromone update for the optimal solution and the ant colony in its neighborhood, reduce the traversal of the irrelevant region, and improve the convergence speed of the potential field ant colony algorithm.
(4) The heuristic information obtained by the artificial potential field method is used to improve the distance heuristic factor of the ant colony algorithm. The improved algorithm can effectively avoid the algorithm falling into local optimum in the iteration, and the disorder search of the ant colony algorithm is changed into directional search.

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