Guide Circle-based Improved Ant Colony Algorithm

Chen Huang¹, Zhengzhong Gao*, Junjun Chen¹, Luyao Zhou¹, Zhanming Lu², and Qifei Qu³

¹College of Electrical Engineering and Automation, Shandong University of Science and Technology, Qingdao, Shandong 266590, China
²Nantun Electric Power Branch of Yancong Group Co., Ltd.
³Liaocheng branch of Shandong Special Equipment Inspection Institute Co., Ltd.
*Corresponding author’s e-mail: skdgzz@163.com

Abstract. In order to solve the path planning problem of autonomous mobile robots in an unknown environment, the traditional ant colony algorithm and the guide circle algorithm were combined, and an improved ant colony algorithm based on the guide circle was proposed. In terms of local path planning, the guide circle algorithm is used to avoid obstacles, which effectively solved the problem of unstable path planning ability in narrow spaces. In the aspect of global path planning, the concept of safety index circle is introduced according to the length between robot and obstacle, and partial heuristic information of ant colony algorithm is improved, so as to avoid the traditional ant colony algorithm falling into local optimal. It is verified by simulation experiments that the improved algorithm has a stronger global search capability, faster convergence speed, and enhanced path planning capability.

1. Introduction

In the path planning of autonomous mobile robots, several relevant factors, such as time and distance, must be considered. Based on these factors, an optimal movement criterion is formulated. So that the robot can find the best path between the starting point and the target point to meet the most optimizing performance indicators[1]. Representative path planning intelligent algorithms include ant colony algorithm, particle swarm algorithm[2], A*algorithm[3], dynamic window method[4], and force field method[5]. Inspired by the foraging behavior characteristics of ant populations in nature, Italian scholar M. Dorigo designed an intelligent bionic optimization algorithm named Ant System[6]. The traditional ant colony algorithm still has several problems, for instance, slow convergence speed, easy to fall into local optimum, lack of initial pheromone, and improper selection of algorithm parameters although the ant colony algorithm shows good results in path optimization.

To deal with the problem that the ant colony algorithm is easy to fall into the local optimal, Zhang rubo et al. proposed a method based on the rule of pheromone adjustment among ant colonies, which can limit the number of pheromones remaining in each path to a certain range [7]. Ren Yan et al. combined the ant colony algorithm with the artificial potential field method included virtual traction and fast function and introduced force field resultant force as part of heuristic information of ant search path points[8]. The above algorithms can effectively solve the problem that the ant colony algorithm is easy to fall into the local optimal problem, but it is prone to instability problem to a certain extent in the narrow space path planning. For the problem of poor stability of path planning in
narrow spaces, Seunghwan Park et al. applied the guide circle algorithm to the obstacle avoidance selection decision of remotely operated robots[9]. Do-Hyung Kim et al. proposed a method of obstacle avoidance for remotely operated robots with double expanded guide circles[10]. These two algorithms effectively figure out the problem of unstable robot path planning in narrow spaces, but only for remote control of robots.

Combining the traditional ant colony algorithm and the guide circle algorithm, a new path planning strategy is proposed. The guide circle strategy is used to avoid obstacles in the local path planning, which availably solves the problem of instability in narrow spaces. Then the concept of safety index circle is introduced into the global path planning to modify the heuristic function of the ant colony algorithm, which effectively avoids the ant colony algorithm falling into the local optimum.

2. Configuration of the autonomous robot system model

The autonomous mobile robot (Hereinafter referred to as robot) is equipped with the radar sensor as shown in Figure 1. The radar sensor is set at the center of a circle with a radius of \( d_{\text{robot}} \). The robot travels at a constant speed in the environment at a rate \( v \).

\[
d_{\text{robot}} = \left( \frac{w^2}{4} + \frac{d^2}{4} \right)^{1/2}
\]

Where \( w \) is the width of the autonomous robot, and \( d \) is the length of autonomous robot.

![Figure 1 System model of autonomous mobile robot](image1)

3. Guide Circle Algorithm

3.1. The Safety Index Circle

According to the distance between the autonomous mobile robot and obstacle, the safety index circle can be defined, as shown in Figure 2.

![Figure 2 The definition of safety index circle](image2)
Where \( d_{\text{safe}} \) is the safe stopping distance of the robot, \( r_{\text{max}} \) is the safe value for the robot to successfully avoid obstacles, \( R \) is the length of the radar detection range, and \( L_m \) is the distance between the robot and the obstacle.

According to the definition of the safety index circle, the surrounding range of the robot can be divided into three parts, which are unsafe, conditionally safe, and safe regions.

1) Safe regions \( (r_{\text{max}} < L_m) \): If \( r_{\text{max}} < L_m \), it indicates that the mobile robot can avoid obstacles.

2) Conditionally safe regions \( (d_{\text{robot}} < L_m < r_{\text{max}}) \): If \( d_{\text{robot}} < L_m < r_{\text{max}} \), it indicates that the mobile robot is less likely to avoid obstacles safely.

3) Unsafe regions \( (L_m < d_{\text{robot}}) \): If \( L_m < d_{\text{robot}} \), it indicates that the robot will not safely avoid obstacles.

### 3.2. Guide circle obstacle avoidance strategy

#### 3.2.1. The Initial Guide Circle

When the robot moves in the original direction at a constant rate \( v \), the intersection \( P_{\text{IGC}} \) of the robot and the circle with a radius of \( d_{\text{robot}} \) can be predicted as shown in Figure 3. Then this intersection is taken as the center to detect the surrounding environment information until encountering obstacles.

\( R_{\text{IGC}} \) is defined as the radius of the initial guide circle. \( P_{\text{im}} \) is the scanning distance from the robot to the obstacle. If \( ||P_{\text{im}} - P_{\text{IGC}}|| > r_{\text{max}} \), the scanning is stopped and \( R_{\text{IGC}} = r_{\text{max}} \). In this case, the direction of original path is feasible, and the robot moves in this direction. If \( ||P_{\text{im}} - P_{\text{IGC}}|| < r_{\text{max}} \), \( R_{\text{IGC}} = ||P_{\text{im}} - P_{\text{IGC}}|| \). This situation demonstrates that the robot may not be able to avoid obstacles and then the auxiliary guide circle will be introduced.

#### 3.2.2. The Auxiliary Guide Circle

As shown in Figure 4, there are two intersections between the initial guide circle and the circle with radius \( d_{\text{robot}} \). The intersection on the direction that can avoid obstacles is taken as the center of the auxiliary guide circle and defined as \( P_{\text{AGC}} \). If \( ||P'_{\text{im}} - P_{\text{AGC}}|| > r_{\text{max}} \), the scanning is stopped and \( R_{\text{AGC}} = r_{\text{max}} \). In this case, the direction of this path is feasible, and the robot moves towards the point \( P_{\text{AGC}} \). If \( ||P'_{\text{im}} - P_{\text{AGC}}|| < r_{\text{max}} \), \( R_{\text{AGC}} = ||P'_{\text{im}} - P_{\text{AGC}}|| \). The auxiliary guide circle is redefined in the direction of avoiding obstacles.

![Figure 3 Definition of initial guide circle](image1.png)

![Figure 4 Definition of auxiliary guide circle](image2.png)

### 4. Improved Ant Colony Algorithm

To deal with the problem that the ant colony algorithm is prone to fall into local optimality, the concept of safety index circle is introduced into the ant colony algorithm and the heuristic function of the ant colony algorithm is redefined.

At any time, the radar located in the center of the robot can detect the surrounding environment information. The maximum detection length of the radar is \( R \), where \( R = d_{\text{robot}} + r_{\text{max}} \).
\[ L'_m = \begin{cases} 
L_m < d_{\text{robot}}, & L_m = L_m \\
 d_{\text{robot}} < L_m < r_{\text{max}}, & L'_m = d_{\text{robot}} \\
r_{\text{max}} < L_m, & L'_m = r_{\text{max}} 
\end{cases} \] (2)

Where \( L_m \) is the length between the robot and the obstacle and the parameter \( L'_m \) is introduced into the heuristic function of the ant colony algorithm.

\[
p^k_{ij}(t) = \begin{cases} 
\sum_{\text{allowed}} \left[ \tau^n_{ij}(t) \right]^2 \cdot \left[ \eta^n_{ij}(L_m) \right]^\beta, & \text{if } S \in \text{allowed}_k \\
0, & \text{others} 
\end{cases} \] (3)

\[
\eta_{ij}(L_m) = \frac{L'_m}{r_{\text{max}}} \] (4)

Where \( \eta_{ij}(L'_m) \) is the desired degree of transition from the current position \( i \) of the robot to the next position \( j \). The value of \( L'_m \) is larger, the value of \( \eta_{ij}(L'_m) \) is larger. So the probability of the robot to choose the path is greater[11].

5. Experiment Results
Firstly we rasterized the environment map and then with the help of MATLAB to perform simulation experiment[12]. As shown in Figure 5, 6, the path planning of the improved ant colony algorithm is more stable and the route is better in a narrow space. As shown in Table 1, the improved ant colony algorithm has a faster convergence speed and takes less time to search for the optimal path.

![Figure 5](image1.png)  
**Figure 5** Path planning comparison between two ant colony algorithms.

![Figure 6](image2.png)  
**Figure 6** Comparison of path convergence curves of two algorithms.

| Table 1 Comparison of path length and motion time between two ant colony algorithms. |
|---------------------------------|-----------------|----------------|
|                                | Optimal path length | Average number of iterations | Time(s) |
| Traditional Ant Colony Algorithm | 29.213            | 25                          | 24      |
| The improved Ant Colony Algorithm | 28.926            | 18                          | 22      |
As shown in Figure 7, during the driving process, the robot found an obstacle in the initial guide circle, then it used $P_{AGC}$ as the auxiliary guide circle center to search the surrounding environment information. Then the robot found that there is no obstacle in the search range, then it moved to the direction of the point $P_{AGC}$ to avoid the obstacle successfully.

Figure 7 Simulation of obstacle avoidance process.

6. Conclusions
In order to resolve the problem mentioned in this paper, an improved ant colony algorithm based on the guide circle is proposed. The initial guide circle and the auxiliary guide circle are introduced to avoid the obstacle based on the distance between the robot and the obstacles, which realized the local path planning and availably solved the problem of unstable path planning ability in narrow space. At the same time, the concept of safety index circle is introduced into the ant colony algorithm, and the heuristic function of the ant colony algorithm is modified. It effectively solved the problem that the ant colony algorithm is easy to fall into local optimum. The improved ant colony algorithm has a faster convergence speed and better path planning ability.

Reference
[1] Goldman, J. A., (1994) Path Planning Problems and Solutions. Proceedings of National Aerospace and Electronics Conference. (NAECON94)., pp. 105-108.
[2] Mac, T.T., Copot, C., Tran, D.T., Keyser, R.D. (2017) A Hierarchical Global Path Planning Approach for Mobile Robots Based on Multi-Objective Particle Swarm Optimization. Applied Soft Computing., vol. 59, pp. 68-76.
[3] S, R., Liu, Y.C., Bucknall, R. (2019) Smoothed A* Algorithm for Practical Unmanned Surface Vehicle Path Planning. J. Applied Ocean Research., vol. 83 , pp. 9-20.
[4] Fox, D., Burgard, W., Thrun, S. (1997) The Dynamic Window Approach to Collision Avoidance. IEEE Robotics & Automation Magazine., vol. 4, no. 1, pp. 23-33.
[5] Matoui, F., Boussaid, B., Abdelkrim, M.N., (2019) Distributed Path Planning of a Multi-Robot System Based on the Neighborhood Artificial Potential Field Approach: Simulation., vol. 95, no. 7, pp. 637-657.
[6] Dorigo, M., Maniezzo, V., Colomni, A., (1991) The Ant System: An Autocatalytic Optimizing Process. In: Proceedings of the First European Conference on Artificial Life. Paris, France.
[7] Zhang, R.B., Li, J.J., Yang, Y., (2015) AUV route planning study for obstacle avoidance task based on improved ant colony algorithm. J. Huazhong Univ. of Sci. & Tech. (Natural Science Edition)., 43(S1):428-430.
[8] Ren, Y., Zhao, H.B., Xiao, Y.J., (2019) Robot obstacle avoidance and path planning based on improved potential field ant colony method. J. Electronics Optics & Control., 26(11): 75-79.
[9] Park, S., Kim,G.K., (2014) Expanded Guide Circle-Based Obstacle Avoidance for the Remotely Operated Mobile Robot. Journal of Electrical Engineering & Technology., vol. 9, no. 3, pp. 1034-1042.
[10] Kim, D.H., Kim, G.W., (2017) Dual Expanded Guide Circle (Dual-EGC) Algorithm for Obstacle Avoidance of Remotely Operated Mobile Robot. In: 2017 14th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI), pp. 226-227.

[11] Liang, K., Mao J.L., (2020) Dynamic path planning of robot based on improved ant colony algorithm. Electronic measurement technology., 43(07):56-60.

[12] Xiao, Y.F., Zhang, C., Luo, J., Yang, C., Liu, C., (2020) Integrating the radiation source position into a grid map of the environment using a mobile robot. Nuclear Inst. and Methods in Physics Research., A.976.