Path planning method of smart mobile robot based on genetic algorithm

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Abstract. Robot path planning is an important topic in the field of robots. Unlike previous methods which consider the smoothness of paths in the process of genetic algorithm, this paper presents a new method of robot path planning that separates the genetic algorithm process from the path smoothing process. First, a simple genetic algorithm with variable length encoding is designed to generate a better polyline path, and then a new type of spiral with shape parameters is introduced to smooth it to smooth a larger corner. Throughout the path planning process, only obstacle coordinates are input to select parameters adaptively to generate the robot's walking path. The simulation results show that separating the genetic algorithm process from the path smoothing process reduces the complexity of the genetic algorithm itself, so the designed smoothing operation not only improves the smoothness of the path, but also reduces the length of the path.

Keywords: Mobile robot, Genetic algorithm, Rotary spiral, Smooth operation, Route Planning.

1. Introduction
Robot path planning is an important topic in the field of robots. It is actually a complex non-linear planning problem. It mainly solves the problem of finding a non-touch walking path for a robot in an environment with obstacles, which should meet the criteria of short length, less usage time and high smoothness. Robot path planning method plays an important role in the safety and efficiency of the robot. At present, there are many methods for robot path planning, such as graphic search, Dijkstra algorithm [1], artificial potential field method, and so on. These algorithms have their own advantages, but in general, there are still some problems such as low adaptability, complex algorithm and so on. As one of the optimization algorithms, the genetic algorithm [2] shows good robustness in complex nonlinear optimization problems such as robot path planning, and has been widely used. Although this algorithm defines genetic operations such as smoothing and truncation, can adjust the corner of the robot's walking path locally, and effectively considers the smoothness of the path, it increases the complexity of the genetic algorithm itself to varying degrees. Therefore, by introducing a spiral loop, the genetic process is separated from the smoothing operation to improve the smoothness and shorten the path length, and to reduce the complexity of the genetic algorithm itself.
2. Cyclotron spiral related problems

2.1. Cyclotron spiral

Gyrospiral [3] is a plane curve constructed by Fresnel integral, whose curvature is proportional to the arc length. A generalized Fresnel integral with shape parameter \( \lambda (0 \leq \lambda \leq 1) \) is introduced here. The gyrospiral constructed by this integral becomes the standard gyrospiral when \( \lambda = 0.5 \).

Definition 1 curve

\[
\gamma (\theta; \lambda) = (x(\theta), y(\theta)) = \alpha (C(\theta; \lambda), S(\theta; \lambda))
\]

Called generalized spiral, referred to as spiral, where the scale factor \( \alpha \) is a positive number, shape factor \( \lambda \) is less than 1, \( \theta \) indicates that the tangent angle is getting worse, \( C(\theta; \lambda) \) and \( S(\theta; \lambda) \) is with shape parameter \( \lambda \) The generalized Fresnel integral:

\[
C(\theta; \lambda) = \frac{1}{\sqrt{2 \pi}} \int_0^\theta \frac{\cos \mu}{\mu} d\mu, S(\theta; \lambda) = \frac{1}{\sqrt{2 \pi}} \int_0^\theta \frac{\sin \mu}{\mu} d\mu
\]

2.2. Cyclotron spiral couple [3]

Definition 2 a cyclotron helix couple consists of two cyclotron helices

\[
\gamma (\theta; \lambda) = P_i + \alpha_i C(\theta; \lambda) T_i + \alpha_i S(\theta; \lambda) N_i, \quad 0 \leq \theta \leq \theta_i, \quad i = 0,1
\]

Combined, where \( P_i (i = 0,1) \) is their starting point, \( \alpha_i \) is the scale factor at the starting point, \( T_i \) is the unit tangent vector at the starting point, and \( N_i \) is the unit normal vector at the starting point. It is required that the two spirals be \( G^2 \) continuous, that is, their endpoints are coincident, and the tangent vectors at the endpoints are parallel and the unsigned curvatures are equal.

3. A new robot path planning algorithm based on genetic algorithm and cyclotron helix

In order to improve the path smoothness of a robot, most of the traditional genetic algorithms adopt the methods of overwriting the fitness function or increasing the genetic operation. To reduce the complexity of the genetic algorithm itself and adjust the routes'corners flexibly, the method of separating the smoothing process from the genetic algorithm process is proposed, which is discussed in detail below.

3.1. Genetic algorithm description

The robot is simplified as a particle, and the obstacle is assumed to be a convex polygon. Expand each boundary of the obstacle outward by a certain safe distance to form a new obstacle. In this way, even if the path coincides with a vertex of the new obstacle, there is actually a safe distance from the original obstacle.

3.1.1. Coding mode. The so-called coding refers to the process of transforming the solution space of the problem into the genetic coding space. Coding has a great impact on the population diversification and search ability of the algorithm. For the robot path planning problem, this paper adopts the floating point variable length coding method, and the chromosome [4] is composed of the Cartesian coordinate sequence of the path node. The connection of a series of points constitutes a chromosome, indicating a feasible or infeasible path.

3.1.2. Population Initialization. There are many kinds of population initialization processes in genetic algorithm. When studying this algorithm, initialization population is usually generated randomly. The advantage of this method is that it can be applied to any problem, does not depend on a specific problem, the disadvantage is that it cannot ensure the rationality of the population, and the efficiency of the algorithm cannot be determined. The purpose of this paper is to add a heuristic method based on the
random generation of the initial population, which can improve the efficiency of path generation and more scientifically reflect the information of solution space.

Initial population generation steps:
Step1 The number of intermediate points (including coordinates) contained by an individual of a chromosome is randomly generated.
Step2 Knows the start and end points of the path, and it is the shortest and smoothest path without obstacles. With this information, other intermediate points in the individual can be heuristically generated to improve the search efficiency of the algorithm.

3.1.3. Fitness function [5]. A safe distance has been extended outward from the barrier boundary in the convex polygon environment representation before the barrier, and a cyclotron spiral pair is introduced to smooth the path, so the fitness function only needs to include the length of the path and whether or not it touches the barrier. The fitness function is:

$$F = N - \left( \alpha_1 \sum_{i=1}^{n} d_i + \alpha_2 \times m \right)$$  \hspace{1cm} (4)

Where $\alpha_1$ and $\alpha_2$ are the scaling coefficient, $d_i$ is the length of the i-th small path, $\sum_{i=1}^{n} d_i$ is the total path length, $m$ is the number of obstacles traversed by the path, $N$ is a large integer, and the greater fitness $F$ is, the better individual performance.

3.1.4. Genetic Operation. 1) Selection operator: Roulette method is used to achieve the selection operation.
2) Crossover operator: single-point crossover method is used. Because they are variable-length codes, the two chromosomes can cross at different locations. If the newly generated individual exceeds the upper limit of chromosome length, it is discarded.
3) Variant operator: Individuals vary by a certain probability over the entire space to increase population diversity.

3.1.5. Termination Conditions of Genetic Algorithms. 1) The algorithm terminates when the fitness function has the largest fitness individual as the output of the optimal solution during the evolution process.
2) When the fitness of the population and the fitness of the optimal individual no longer increase, the algorithm terminates.
3) When the number of iterations reaches the preset algebra, the preset algebra is generally set between 100 and 500 generations, then the algorithm terminates.

3.2. Smoothing Operation Based on Cyclotron Helix
To ensure the safety of the robot when turning, a genetic operator [6] for smoothness of the path is added to the fitness function. If the sum of the corners of all nodes in a path is large, the fitness of all nodes in the path will be reduced, which makes the path easier to be eliminated. This method effectively considers the smoothness of routes and generates a better collision-free polyline route with higher efficiency.

A generalized spiral with shape parameters is now introduced to smooth the resulting non-collision polyline paths. The final smooth path is generated by adaptively selecting the shape parameters. The smoothing operation by introducing a cyclotron at a single node is introduced first, and then the smoothing operation at multiple nodes is introduced.

In order to simplify the genetic algorithm and obtain a better collision-free polyline path with higher efficiency, the smoothness of the path is temporarily omitted from the genetic process described above, where the path may have a larger corner, as shown in Figure 1. $\alpha$ and $\beta$. According to the specific situation of the robot, a safety angle is preset, and the size of the corner at each node on the path is
determined in turn. When the preset safety angle is exceeded, the extended spiral pair is introduced to smooth the robot.

![Figure 1. Large Turn in Folded Path](image1)

Suppose that the Angle $\alpha$ at point $P_i$ exceeds the safe Angle, and smooth operation is needed at this point. As shown in Figure 2, midpoints $A$ and $B$ are selected on the line between $P_i$ and its two adjacent nodes. $A$, $P_i$, $B$ and other three points are regarded as the control vertex, and the shape parameter $\lambda$ is selected to generate a gyrospiral pair as a new path to replace the original polyline path. In this way, the goal of smoothing the corner is achieved and the length of the path is shortened.

![Figure 2. Smoothing at large corners](image2)

If the generated gyrospiral couple collides with an obstacle, it needs to be adjusted. Due to the limitation of $\lambda=0.5$, the obstacle can be avoided by moving the control points. No need to move any control points. Only the value of the shape parameter $\lambda$ can be increased to make the gyrospiral pair closer to the control polygon, so as to control it to avoid the obstacle. It should be noted that the larger the shape parameter $\lambda$ is, the closer the gyrospiral is to the original broken path, which is not good for the turning safety of the robot. From this point of view, the shape parameter $\lambda$ should be as small as possible, and the path length will be shortened. However, when $\lambda$ gets too small, the gyrospiral couple moves away from the control polygon and is likely to collide with obstacles. Therefore, the value of $\lambda$ is set to start from the initial value of 0.1 and increase by the step size of 0.1, and the value of the shape parameter $\lambda$ is adaptively selected to satisfy the condition of definition 1 and the minimum value of the path generated without collision with obstacles.

When the path contains several large corners, each corner is smoothed in turn. As shown in Figure 3, it is recommended to set the angles at $P_i$ and $P_{i+1}$ to exceed the safety Angle, and smooth them respectively. The smoothing operation at $P_i$ is the same as above, and the following smoothing operation is performed on $P_{i+2}$. Midpoint $C$ is selected on the line $P_{i+1}$ and $P_{i+2}$, and a gyrohelix pair is generated with $B$, $P_{i+1}$ and $C$ as the control points to replace the original broken line path at $P_{i+1}$.  

![Figure 3. Smoothing of multiple corners](image3)
As a transition curve between a circular arc and an arc, a straight line and a straight line, or a circular arc and a straight line, the spline curve generated by the combination of a cyclotron spiral pair and a control polygon can be $G^2$ continuous. Therefore, the cyclotron spiral pair can be well embedded in the polyline paths obtained by the genetic algorithm, so that the newly generated paths can maintain high continuity. At the same time, the smoothing operation at each corner is independent, that is, their shape parameters can be independently evaluated, which can adjust the shape of the path locally through the shape parameters, making it flexible and convenient. This smoothing operation can effectively improve the safety of the robot when turning, and also shorten the length of the original polyline path [7].

4. Simulation experiment and result analysis

4.1. Simulation experiments in different environments

The path planning method designed in this paper can obtain the final smooth path adaptively by simply entering the environment coordinates. To verify the effectiveness of the algorithm, three groups of simulation experiments are performed in the environment of special obstacles, regular obstacles and irregular multiple obstacles.

Special obstacle environments are shown in Figure 4. Among them, three long bars are obstacles. The robot starts from (0,50) and ends at (100,50). Although there are few obstacles, the obstacles are large and uniquely distributed. Fig. 5 is a regular multi-obstacle environment, in which the ordered small squares are arranged as one obstacle. The robot starts from (0, 30) and ends at (100, 80). The obstacles are distributed evenly but in large numbers. Figure 6 shows an irregular multi-obstacle environment in which the scattered polygon is an obstacle with a robot starting from (0, 0) and ending at (100, 100). The obstacles in this environment are irregular in shape, scattered and numerous.

![Special multi obstacle environment map](image1.png)

**Figure 4.** Special multi obstacle environment map

![Regular multi-obstacle environment](image2.png)

**Figure 5.** Regular multi-obstacle environment
Simulation experiment in special obstacle environment. Because of the particularity of obstacles, the traditional path planning method based solely on genetic algorithm inevitably has a large Angle. The broken line in Figure 7, is the obstacle avoidance walking path of the robot obtained in the genetic algorithm part of this paper, including nodes P1, P2, P3, P4 and P5. The angles of P2, P3 and P4 all exceed the preset safety Angle of 90 degrees, so smooth operation should be performed for them. As shown in Figure 8, take the midpoint A of P1 and P2, the midpoint B of P2 and P3, the midpoint C of P3 and P4, the midpoint D of P4 and P5, take A, P2 and B as the control point of P2, take B, P3 and C as the control point of P3, and take C, P4, D is the control point at P4, and shape parameters are selected adaptively for each point. \( \lambda (0 \leq \lambda \leq 1) \) starts from 0.1 and increases by step size 0.1. It is calculated that when the shape parameters of the three nodes are set as \( \lambda = 0.7 \), \( \lambda = 0.5 \) and \( \lambda = 0.3 \), they are the minimum shape parameters satisfying the condition of generating gyrohelix pair in definition 1 for the first time. The curve in Figure 8, is the gyrospiral pair generated for the first time at each node, and the dashed line is the control polygon, that is, the original broken line path.
After calculation, it is found that the gyrospiral pair first generated at points P₂ and P₃ can avoid obstacles, so the value of its shape parameter is no longer increased. When λ=0.3 at point P₄, although the generating condition of gyrohelix pair is met, the path generated will collide with obstacles, and the value of λ should be increased continuously. After calculation, until λ=0.5, the generated gyrospiral couple does not collide with obstacles, as shown in Figure 9. Therefore, the shape parameter of P₄ is finally taken as λ=0.5.

![Figure 9. Final smooth path](image)

In the second group, the path planning simulation experiment is carried out in the rule-based multi-obstacle environment. The simulation experiment process is the same as that in the first group. As shown in Figure 10, the broken line is the path obtained by the genetic algorithm, including nodes P₁, P₂ and P₃. The curve is the gyrospiral generated after smoothing the P₂ point, and its control point is P₂, the midpoint A of P₁P₂ and the midpoint B of P₂P₃. Finally, the shape parameter λ=0.4 of P₄ is selected adaptively.

![Figure 10. Final smooth path in regular multi-obstacle environment](image)

Similarly, the simulation experiment process in the third group of irregular multi-obstacle environment is the same as the first two groups. As shown in Figure 11, the final shape parameter of P₄ is selected as λ=0.6.
Figure 11. Final smooth path in irregular multi-obstacle environment

From the above simulation results, it can be clearly seen that, in three different obstacle environments, after smoothing polyline paths with cyclotron spiral pairs, the effect of smoothing the path is achieved, and the total length of the path is reduced to a certain extent. Especially in the case of special obstacle distribution in the first group of simulation results, the problem of large turning angle in traditional genetic algorithm is overcome. It also reduces the complexity of the genetic algorithm itself.

4.2. Comparison with Dijkstra algorithm

The method of separating the genetic algorithm process from the path smoothing process proposed in this paper is compared with the Dijkstra-based route planning method. The experimental results in three different environments show that the optimal path length obtained by the proposed route planning method is smaller than that obtained by the Dijkstra-based algorithm. The average search path time used is less than the average search path time based on the Dijkstra algorithm, which can save at least 5% of the search time.

Through the comparison above, it is found that the method of separating the genetic algorithm process from the route smoothing process is better than the Dijkstra algorithm in time complexity and has certain advantages in solving the route planning problem.

Concluding remarks

In order to improve the smoothness of a robot's path, most of the traditional genetic algorithms adopt the methods of overwriting the fitness function or increasing the genetic operation. In this paper, the genetic algorithm process is separated from the path smoothing process. A new cyclotron spiral pair with shape parameters is introduced to smooth the better path generated by the genetic algorithm. The whole route planning process requires only input of obstacle coordinates to generate a smooth path by selecting parameters adaptively, and the coordinate distance between the path and the obstacle can be adjusted flexibly by changing the shape parameters. The simulation results show that the method of separating the genetic process from the smoothing operation by introducing a spiral can improve the smoothness and shorten the path length, and also reduce the complexity of the genetic algorithm itself.

References

[1] Sun Ziguang, Li Chungui, Wang Qin.Automation and instrumentation, 2009,24 (6) : 5-7.
[2] Li Liangxian.Research on Path Planning and Obstacle Avoidance Strategy of Autonomous Soccer Robot [D]. Jiaozuo: Henan Polytechnic University, 2011.
[3] Hao Bo, Qin Lijuan, Jiang Mingyang.Research on path planning method of mobile robot based on improved genetic algorithm [J]. Computer engineering and science, 2010,32 (7) : 104-107.
[4] Shi Tiefeng.Application of improved genetic algorithm in path planning of mobile robot [J]. Computer simulation, 2011,28 (4) : 193-195.
[5] Liao Weiqiang, Li Zhenyu.Path planning of soccer robot based on genetic potential field method [J]. Journal of jimei university (natural science), 2009,14 (2) : 179-184.
[6] Puding Chao.Research on Path Planning of Mobile Robot Based on Genetic Algorithm [D]. Hefei:
Hefei University of Technology, 2010.

[7] Li Gang, Yu Jianxin, GUO Daotong, et al. Robot Path Planning and Simulation Based on Improved Genetic Algorithm [J]. Computing Technology and Automation, 2015 (2) : 24-27.