# Study on Path Planning for Family Service Robot based on Improved Genetic Algorithm

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**Abstract.** An approach to obstacle avoidance and navigation for mobile robot based on structured environment is proposed. In this approach, the IGA is integrated with the graph theory, and is applied to finding the appropriate path; meanwhile, by application of the niche algorithm, the diversity of population after the initial population generated can be maintained. The simulated annealing algorithm is employed to IGA so as to optimize the result and to avoid the large increase of individuals. The simulation results indicate that this method is successfully applied in large scale with less iteration and the convergence rate is improved.

**Keywords:** Path Planning, Graph Theory, Genetic Algorithm, Simulated Annealing Algorithm, Niche Algorithm.

## 1 Introduction

Robot technology has been in-depth development, not only in the industrial field, but also in the service. It has a wide range of applications. At the same time, automatic path planning has great significance to the autonomous movement and route optimization of home service robot, which according to the known geographic information data to find a safe and shortest path from one point to another in complex environment. The navigation technology has been applied to many methods, such as simulated annealing algorithm, neural network algorithm, artificial potential field algorithm [1], particle swarm optimization algorithm, ant colony algorithm and graph search method. Compared with other search methods, ge-

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netic algorithm adopts multi-point search, which has stronger global search ability and higher search efficiency, so it is more likely to find the global optimal solution. The strong robustness and flexibility make it widely used in path planning of mobile robot [2].

The problem of traditional genetic algorithm is that the evolution speed is difficult to control and the premature convergence often occurs. At the same time, there are too many empirical parameters to meet the real-time needs, which is not conducive to automatic processing. Especially in a complex environment, if a better initial solution can't be given, it is usually difficult to find a feasible path through hybrid mutation and other operations. Genetic algorithm usually produces redundant search, which affects the convergence rate of the algorithm makes the algorithm need a long time to calculate. In this paper, combine the niche technology, simulated annealing algorithm with genetic algorithm to ensure that individuals can be dispersed in the global scope, and to avoid the function falling into local optimization. What's more, the new individual is adjusted to form a new solution, and the objective function is calculated to determine whether or not to receive the new solution, so as to obtain a better adaptive solution, to ensure the quasi-certainty of the evolutionary direction, and to prevent the degradation [3]. Thus the optimal path is obtained. The feasibility and effectiveness of the method are verified by simulation experiments.

## 2 Establishment of Environmental Model

In this paper, the location information of obstacles is obtained by laser radar Rplidar-A2, and using the improved ICP algorithm to match the data of different positions to get the entire map [4].

The environment used in this paper is the laboratory, just as Fig. 1 shown, through the laser radar Rplidar-A2 continuously scanning the environment, calibrating the position of mobile robot and obstacles. Finally get the environment map, which is shown in Fig. 2, left. Then modeled and simplified the environment by MATLAB, as is shown in Fig. 2, right.

**Figure 1** The panorama of laboratory

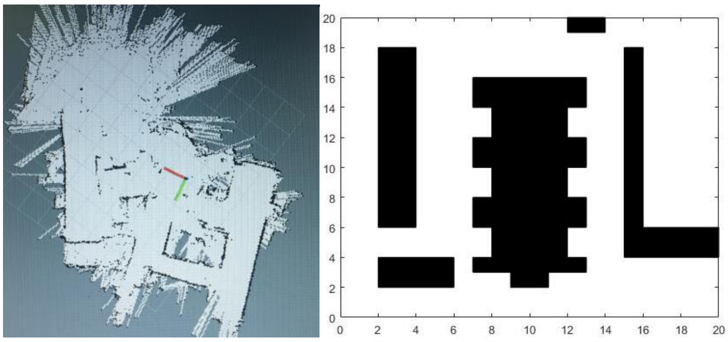


**Figure 2** Laboratory model map

# 3 Improved Genetic Algorithm

The flowchart of improved genetic algorithm is illustrated in Fig. 3.

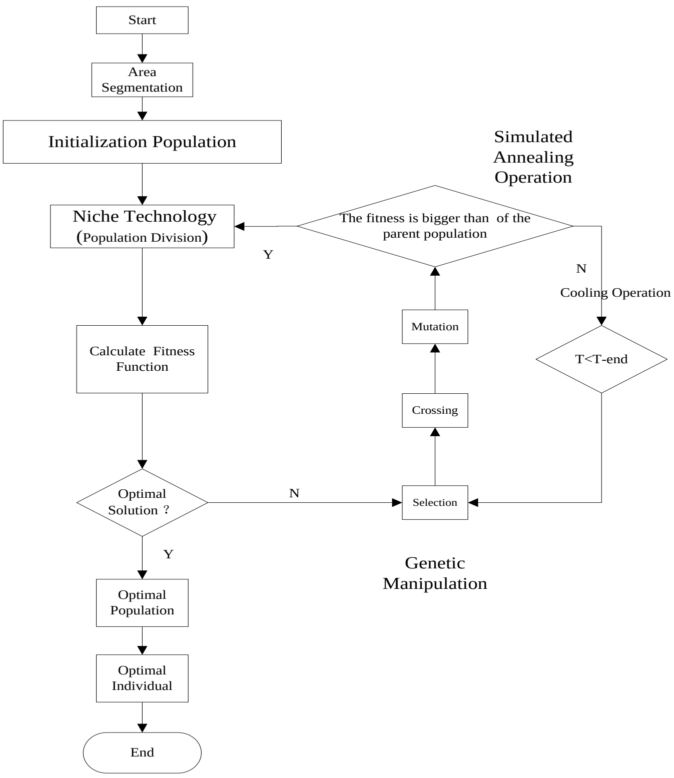


**Figure 3** Flowchart of improved genetic algorithm

### 3.1 Area Segmentation

In this paper divides the environmental map into 13 areas: *start, A1, A2, A3, B1, B2, C1, C2, D1, D2, E1, E2, End*, as is shown in Fig. 4, the areas are connected into a directed graph by directed line segments according to the graph theory, as shown in Fig. 5. According to the graph theory, the question of finding a path from *Start* point to *End* point can be transformed into a simple directed graph G, and the relation between regions can be represented by edge *e*, the feasible area of map partition can be represented by *start, A1, A2 ...D1, D2, End*.

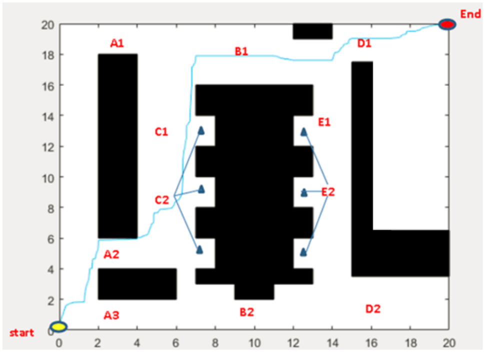


**Figure 4** The area Segmentation of environment

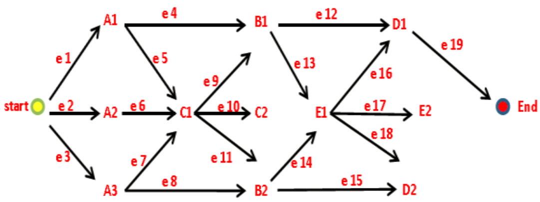


**Figure 5** Path directed graph G

The graph relation corresponding to the path problem of any two points in this graph is $G=(V(G),E(G),\varphi_G)$ [5], of which the element of *V(G)* represent the point of graph G, the element of *E(G)* represent the edge of graph G, $\varphi_G$ is the correlation function, it makes every element of *E(G)* corresponding to an unordered element pair in *V(G),* of which:

$V(G)=\{start, A1, A2, A3, B1, B2, C1, C2, D1, D2, E1, E2, End\}$,

$E(G)=\{e1,e2,e3,e4,e5,e6,e7,e8,e9,e10,e11,e12,e13,e14,e15,e16,e17,e18,e19\}$,

$\varphi_G(e1)=start*A1$ ; $\varphi_G(e2)=start*A2$ ; $\varphi_G(e3)=start*A3$

... $\varphi_G(e17)=E1*E2$; $\varphi_G(e18)=E1*D2$ ; $\varphi_G(e19)=D1*End$

Using $b_{ij}$ represent the correlation times of $v_i$ and $e_j$, the directed correlation matrix *B(G)* is:

$$B(G)=\begin{array}{r}start\\A1\\A2\\A3\\B1\\B2\\C1\\C2\\D1\\D2\\E1\\E2\\End\\ \\ \end{array}\left[\begin{array}{ccccccccccccccccccc}
1&1&1&&&&&&&&&&&&&&&&\\
-1&&&1&1&&&&&&&&&&&&&&\\
&-1&&&&1&&&&&&&&&&&&&\\
&&-1&&&&1&1&&&&&&&&&&&\\
&&&-1&&&&&-1&&&1&1&&&&&&\\
&&&&&&&-1&&&-1&&&1&1&&&&\\
&&&&-1&-1&-1&&1&1&1&&&&&&&&\\
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&&&&&&&&&&&&-1&-1&&1&1&1&\\
&&&&&&&&&&&&&&&&-1&&\\
&&&&&&&&&&&&&&&&&&1\\
e1&e2&e3&e4&e5&e6&e7&e8&e9&e10&e11&e12&e13&e14&e15&e16&e17&e18&e19
\end{array}\right] \quad (1)$$

The directed correlation matrix *B(G)* represent the association between regions: 1 means positive correlation; -1 means reverse correlation; 0 means no correlation. The point set of graph $G=(V,E)$ is $V$; $a_{ij}$ is the number of edges between point $v_i$ and $v_j$; *M(G)* is the adjacency matrix of graph G:

$$M(G)=\begin{array}{r} \\ start\\A1\\A2\\A3\\B1\\B2\\C1\\C2\\D1\\D2\\E1\\E2\\End\end{array}\left[\begin{array}{ccccccccccccc}
start&A1&A2&A3&B1&B2&C1&C2&D1&D2&E1&E2&End\\
&1&1&1&&&&&&&&&\\
1&&&&1&&1&&&&&&\\
1&1&&&&&1&&&&&&\\
1&&&&&1&1&&&&&&\\
&1&&&&&1&&1&&1&&\\
&&&1&&&1&&&1&1&&\\
&1&1&1&1&1&&1&&&&&\\
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&&&&1&&&&&&1&&1\\
&&&&&1&&&&&1&&\\
&&&&1&1&&&1&1&&1&\\
&&&&&&&&&&1&&\\
&&&&&&&&1&&&&
\end{array}\right]$$

Each edge is given a weight, the edge represents the path, and the weight of the edge represents the length of the path. Path planning of any two-point can be guided and found by *B(G)* and *M(G)*.

### 3.2 Encoding the Path

In this paper, the decimal system is used for individual paths, and the horizontal and vertical coordinates are simply coded independently. The structure is as follows:

$$X_i(X_{i1} \to X_{i2} \to .... \to X_{ik} \to ... \to X_{ij})$$
$$Y_i(Y_{i1} \to Y_{i2} \to .... \to Y_{ik} \to ... \to Y_{ij}) \tag{3}$$

Too much initial population will lead to large amount of calculation, and too little population will lead to the incorrect results. In this paper, 100 groups of path points will be distributed in the map environment at the beginning of the selection. In formula 3, $X_i$ represents all transverse coding of path *i*; $Y_i$ represents all vertical coordinate coding of path *i*. As is shown in Fig. 6, the line stands for the path *k*, and the initial point is (0,0) the target point is (20, 20).

$$X_k(0,1,2,3,6,9,10,11,12,13,14,15,16,17,18,20)$$
$$Y_k(0,1,3,4,7,8,9,9,11,13,16,17,18,19,19,20)$$

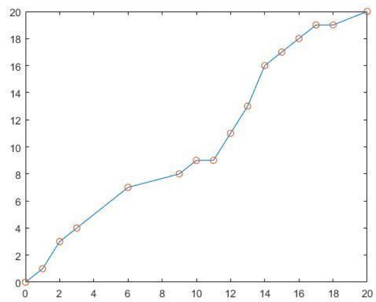


**Figure 6** Sample Path

## 3.3 Fitness Function

In this paper, two conditions are considered as the evaluation criteria of fitness function: (1) the path length; (2) the path feasibility.

### 3.3.1 The Factor of Path Length

$$K1 = (L - \sum\left[(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2\right]) \cdot m_1 \tag{4}$$

In formula, $L$ is a relatively large constant, $\sum\left[(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2\right]$ means the length of path, use $L$ minus it to get *K1*, the bigger the better. $m_1$ is the length operator that influences the path length.

### 3.3.2 The Factor of Path Feasibility

To judge the feasibility of the road, two measures are adopted in this paper:

1. When generating the initial population, determine if it falls into an obstacle area;
2. Detect if the adjacent path point connection interferes with the boundary of the obstacle.

To detect the interference between the path and the obstacle, using the vector method, shown as Fig. 7, is used to determine if the two segments *AB* and *CD* on the same plane are crossing. The coordinates of the points are $A(a_1,a_2)$, $B(b_1,b_2)$, $C(c_1,c_2)$, $D(d_1,d_2)$, then the question transformed to determine whether point *A* and point *B* straddles the two sides of segment *CD*.

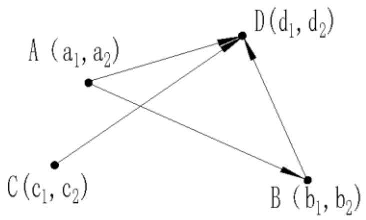


**Figure 7** Path interference detection model

According to the basic law of vector, the following equations are obtained:

$$\begin{aligned}
&\overrightarrow{AD} = (d_1\text{-}a_1, d_2\text{-}a_2)\\
&\overrightarrow{CD} = (d_1\text{-}c_1, d_2\text{-}c_2)\\
&\overrightarrow{BD} = (d_1\text{-}b_1, d_2\text{-}b_2)\\
&\vec{j} = \overrightarrow{AD} * \overrightarrow{CD}\\
&\vec{i} = \overrightarrow{BD} * \overrightarrow{CD}\\
&u = \vec{j} \bullet \vec{i}
\end{aligned} \tag{5}$$

Obviously, the positive and negative of *u* can judge whether the line segment *AB* crosses the line segment *CD*. When it is a positive number, it means segment *AB* has no intersection with *CD*, no interference. When it is negative, means segment *AB* intersected with segment *CD*. Then get the factor of path feasibility *K2*, $K2 = m_2 \cdot n$ of which $m_2$ means the operator of obstacle interference, *n* means the number of interference between the path and the boundary of the obstacle.

The fitness function is:

$$F = K1 + K2 = (L - \sum\left[(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2\right]) \cdot m_1 + m_2 \cdot n \tag{6}$$

### 3.4 Niche Technique for Population Division

Niche technology can better preserve the diversity of progeny population [6], and divide the population according to the individual dissimilarity of the population. In this paper, different path selection is used as the basis of population division, such as Fig. 5 above, there can be a variety of path choices based on the starting point "start" and the target point "end", such as "*start-A2-C1-B1-D1-End*" or "*start-A3-B2-E1-D1-End*" and so on.

### 3.5 Genetic Operation

#### 3.5.1 Selection

In this paper, firstly sort the fitness, compare the individual probability between the new population and the original population, then select the better individuals according to the championship method, removes the individuals whose fitness is 0 or low. Ensure that the survival increases so that good individual can evolve to the next generation and form a new population.

#### 3.5.2 Crossover

For the new population formed after selection, all individuals are divided into two parts: pre-chromosome and post-chromosome by single-point crossover method according to the cross rate. A new individual is formed by splicing the pre-chromosome of one individual with the post-chromosome of another.

$$\begin{cases} P_1' = r_c \cdot P_1 + (1 - r_c) P_2 \\ P_2' = (1 - r_c) P_1 + r_c P_2 \end{cases} \tag{7}$$

$P_1$'and $P_2$' are the newly generated individuals. $r_c$ randomly generates a number between 0 and 1 according to the roulette gambling method [7].

#### 3.5.3 Mutation

In order to prevent genetic algorithm fall into precocious and local optimization, mutation is needed. Select an individual, randomly select a node for its chromosome, and replace it with another node randomly. If the mutation rate is more than

0.5%, the genetic algorithm will degenerate to random search [8]. In order to ensure that the better path in the later stage is preserved, the value of variation in this paper used an adaptive function. In this paper, the mutation rate is chosen by:

$$r_m = \begin{cases} k\left(1-\dfrac{\arcsin(\frac{f_m}{f_{\max}})}{\pi/2}\right) & ,\arcsin\left(\dfrac{f_m}{f_{\max}}\right) \geq \pi/6 \\ k\left(\dfrac{\arcsin(\frac{f_m}{f_{\max}})}{\pi/2}\right) & ,\arcsin\left(\dfrac{f_m}{f_{\max}}\right) < \pi/6 \end{cases} \tag{8}$$

Where $k$ is the mutation factor and $f_m$ is the average of fitness, $f_{max}$ is the maximum of fitness.

### 3.6 Simulated Annealing Operation

The new generation population is generated by genetic operation, then the newly generated individuals are adjusted to produce a new solution *NS*, calculates the objective function *OB*, and determines whether it accepts the new solution or not by the design criterion to realize the optimization of local optimal solution and global optimal solution in solution space, and to improve the convergence rate [9]. The actions are as follows:

1. Set the current solution *OS* and the current temperature *Ti.*
2. *NS* is the adjusted solution, and the objective function is *OB*, $\Delta f$ represents the variable of the objective function. $\Delta f=abs(NB-OB)$. The design criterion is $E=\begin{Bmatrix} \exp(\frac{\Delta f}{Ti}) \\ 1 \end{Bmatrix}$, when $E$=1, accept the new solution, or use $\exp(\frac{\Delta f}{T_i})$ as probability to abandon the new solution.
3. Cooling operation with attenuation rate $r$, $T_{i+1} = T_i \cdot r$.
4. Determine whether the termination condition is met. If it is meet, jump to the next step, otherwise go to step 2.
5. Output result.

### 3.7 End condition

In this paper, set the fitness function to be the termination condition, and select the shortest path which has the best fitness as result.

## 4 Simulations and Analysis

In order to verify the feasibility of the algorithm, the laboratory map is selected and simulated by software MATLAB. The initial population is 100; the number of genetic evolution is 100, produce 100 new populations at one time; the service robot is regarded as a particle, the starting point coordinates are (1,1), and the target point coordinates are (20,20), as shown in Fig. 8. The lines in the graph represent the path trajectory by improved genetic algorithm.
The final figure shows that the robot can circumvent obstacles under the control of the algorithm in this paper. Multiple experiments have taken out multiple tracks, and all the tracks are safe obviously, meeting the requirements of trajectory planning and also showing the uncertainty of navigation, as shown in Fig. 8, left. The right of Fig. 8 shows the path diagram obtained from the same starting point and the target point under the traditional general algorithm. Fig. 9 shows the average fitness growth curve of GA and IGA. Table 1 shows the parameters of GA and IGA.

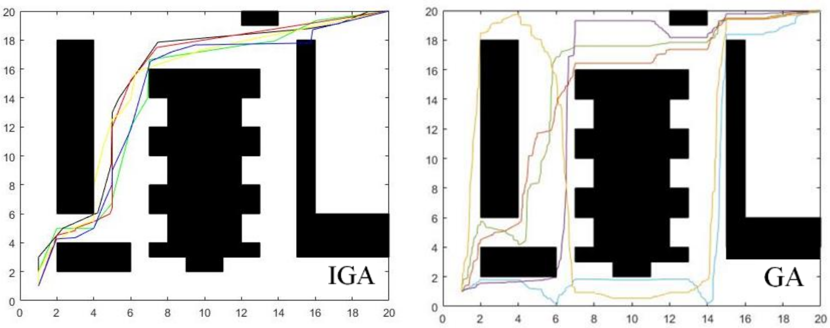


**Figure 8** Repetitive trajectories planning with different algorithms

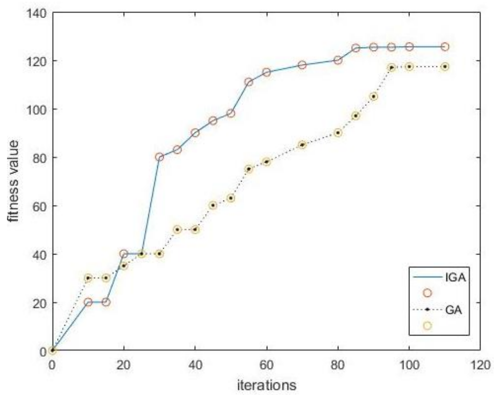


**Figure 9** Average Fitness growth curve

**Table 1.** Parameters of IGA and GA

| | | | | | | |
|---|---|---|---|---|---|---|
| IGA | Path | 1 | 2 | 3 | 4 | 5 |
| | length | 33.8220 | 32.8112 | 31.6743 | 32.6322 | 32.9052 |
| | fitness | 124.6349 | 125.3910 | 126.2443 | 125.5259 | 125.3211 |
| | convergence iteration number | 56 | 90 | 85 | 76 | 82 |
| GA Algorithm | Path | 1 | 2 | 3 | 4 | 5 |
| | length | 44.4539 | 39.5081 | 37.9869 | 71.5301 | 34.145 |
| | fitness | 116.6596 | 121.8670 | 121.5098 | 96.3525 | 124.3913 |
| | convergence iteration number | 62 | 98 | 96 | 90 | 96 |

As is shown in Table 1, the IGA improves the fitness value of the path, reduces the number of iterations, and optimizes the length of the path. The comparison results and the path graph show that the improved algorithm is feasible and effective, and has higher convergence efficiency and better optimization results than before.

## 5 Conclusions

In this paper, the global optimization ability and the convergence rate of the algorithm are improved. This paper uses the graph theory to guide the path planning, and the niche technology to guarantee the diversity of population. After genetic operation, simulated annealing algorithm is used to improve the quality of the global optimal solution. The fitness function is improved, and removed the invalid path points, which improves the efficiency of evolution. The mutation rate is chosen by adaptive function in order to ensure the excellence of individuals in the later stage and to prevent the degradation of genetic algorithm due to the low mutation operator. Combined with simulated annealing algorithm, the new generation population is judged and selected to ensure the evolve direction of the offspring population. The simulation results show that the improved genetic algorithm is feasible and effective in the path planning of home service robot.

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