Genetic Algorithms for Coverage Path Planning using Mobile Robots

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Abstract. Using the grid method to establish the environmental model, the map is divided into several sub-regions according to the environmental characteristics, and the connection between the sub-regions is established. Next, the Genetic Algorithm encodes all sub-regions, and the base point information between and within each region is established to obtain the optimal coverage sequence. Partial coverage is achieved in each sub-region by means of reciprocating motion, which turns the complete coverage problem into a traveling salesman problem (TSP). Finally, the Genetic Algorithm is used to conduct an experimental simulation to obtain the correlation between the fitness and the number of iterations, and obtain the optimal traversal sequence, which proves that the method is effective and feasible.

Keywords: sub-region, mesh method, genetic algorithms.

1. Introduction

Today, with science and technology's rapid development, families and society have higher expectations for liberating people from heavy work. For example, cleaning robots have been highly valued and respected by people. Therefore, full coverage path planning technology has always been an important research direction. Today, coverage path planning techniques are widely used in many aspects, such as mine detection in the military, environmental sanitation in the home, and map creation in different fields such as the detection of drones. In practical applications, we require the robot to cover all areas without environmental obstacles. In order to have better work efficiency, many full coverage path planning methods are derived.

Currently, the coverage path planning [1] methods of robots can be divided into three categories: traditional coverage methods, coverage methods based on area decomposition, and coverage methods based on grid maps [2]. The traditional covering methods include the template method and the inner spiral method [3]. The template method sets the motion template in advance according to the characteristics of the environment, and the robot moves according to this template after the environment is matched. This method can complete the traversal, but the environment cannot be changed, and the application range is minimal. The inner spiral method is an edge-wise method. When encountering a covered area or boundary, the inner spiral method will continue to work by one unit. This method requires extremely high environmental accuracy and is difficult to achieve complete coverage. The coverage method based on area decomposition is to divide the area according to the shape of the obstacle, and there are no obstacles in the sub-area, and then set the sub-area traversal method and sub-area traversal order, etc., including the Boustrophedon Cellular Decomposition [4]. The grid-based map coverage methods include the spanning tree method, biological excitation neural network method, etc. The spanning tree method combines every four grids into a unit and realizes traversal by connecting all units. This method requires a lot of storage space, and the path turns into the biological excitation neural network algorithm [5]. The neuron uses the shunt equation to communicate with the adjacent neurons. The next grid the robot will travel to is selected by the neuron activity value. In this paper, the combination of the Genetic Algorithm and Boustrophedon Cellular Decomposition will be chosen to study and discuss coverage path planning.

The concept of the Genetic Algorithm (GA) [6][7] was proposed by John Holland in the United States in the 1970s. Genetic Algorithms simulate the evolutionary process of organisms in the natural environment. The algorithm realizes the birth of new individuals by means of mathematics, computer

simulation operation, chromosome crossover operator, and mutation operator. The fitness function simulates the rules of survival of the fittest in the natural environment. When solving more complex permutation and combination optimization problems, better optimization results can usually be obtained faster than some conventional optimization algorithms. The core process of the Genetic Algorithm can be divided into the following five steps: (1) chromosome coding; (2) random generation of initial population; (3) fitness calculation function; (4) genetic operation (crossover, mutation); (5) selection. It is suitable for finding the optimal solution in full coverage path planning.

Boustrophedon Cellular Decomposition (BCD) is an offline whole coverage algorithm for regional decomposition. Before traversing, Boustrophedon cell decomposition is used to segment the map. The non-overlapping cells formed by the segmentation form a connected graph traversed through Depth First Search (DFS) [8]. The connectivity graph generates the traversal path between units. When the robot moves to the boundary of the current unit, it is judged that the current unit has been traversed, and then it can go to the next unit on the path. If the current cell has already been walked, the robot will move to the next cell along the edge of the obstacle. The coverage in the unit is completed by the Boustrophedon Cellular Decomposition. That is, the four possible directions of the map are traversed in a specific order North, South, East, and West, to form a reciprocating motion. The BCD algorithm reduces the time complexity of the calculation during the planning and has a higher coverage rate. However, in an environment with many obstacles and more scattered elements, the number of decomposed cells may be large and scattered, the traversal between cells will be more complicated. Boustrophedon Cellular Decomposition motion may have missing areas in the process of covering each unit and cannot complete the whole coverage task. The demonstrated algorithms can be extended to multi-robot systems to allow multiple robots to cover an area cooperatively [9][10][11].

2. Problem Formulation

The following three key problems need to be solved in the study of coverage path planning technology (1) the robot needs to traverse all areas in the environment except obstacles; (2) the robot can effectively avoid obstacles when traversing; (3) the robot can when traversing, try to avoid path repetition and shorten the moving distance. In the grid map, the total coverage path planning becomes the search for the following moving position of the robot. The robot can autonomously plan a feasible and efficient moving path with no collision and a low repetition rate when the next position is accurately found.

The coverage path planning method combines the Genetic Algorithm and Boustrophedon Cellular Decomposition used in this paper. Firstly, the Boustrophedon Cellular Decomposition is used to divide the simulated environment into several sub-areas according to the characteristics of the created grid map, and the coverage is realized by round-trip motion in each sub-area. Next, the Genetic Algorithm is used to encode all sub-regions to obtain the optimal coverage sequence.

3. Methods

3.1. Raster Map Creation

This paper uses the grid method to establish the environment model. The created grid map as in Figure 1. To create the map, we first let the length of the environment model be L, the width be W, and the grid is a square with side length A. Then we let the size of the mobile robot be $B \times B(A < B < 1.5A)$. Finally, we set the value C to represent the state of each grid, with 0 representing obstacle existence, 1 representing obstacle inexistence, and *n* representing the number of iterations over a grid.

The sum of the distances covering all areas in this way can be expressed as

$$Dis(R) = A \times \sum_{i=1}^{L/A} \sum_{j=1}^{W/A} C[i][j] \quad (1)$$

Where i represents the i row, and j represents the j column.

1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1
1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1
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1	1	1	1	1	1	1	1	1	0	1	1	0	0	0	0	1
1	1	1	1	0	0	0	1	1	0	1	1	0	0	0	0	1
1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1

Figure 1. 17×17 grid map.

3.2. Boustrophedon Cellular Decomposition

Use BCD to decompose the grid map into a series of sub-regions and obstacles according to the terrain characteristics. The basic idea of this method is: Suppose there is a line perpendicular to the x-axis to scan the map from left to right according to the connectivity and generate scan lines covering the area, as shown in Figure 2. Start scanning from the left side of Figure 2 to generate sub-area 1. When the scan line passes through the obstacle, it generates connectivity and sub-areas 2 and 3. Scan to the far-right side of the map, and the final generated environment map as in Figure 2. As shown, the grid map model consists of 8 obstacles and 19 sub-regions.

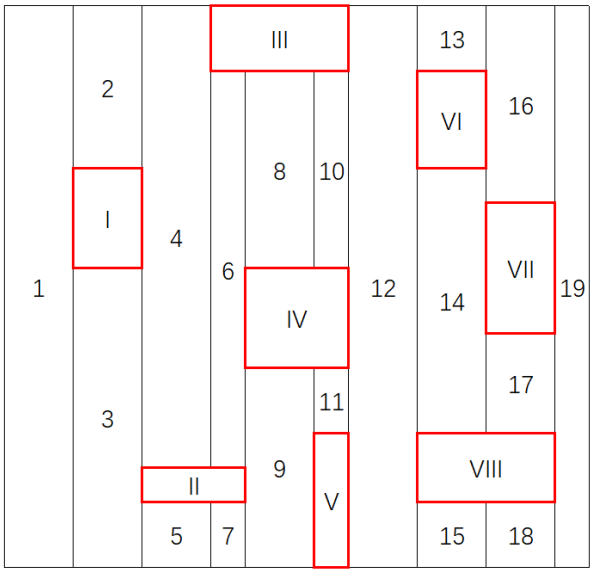


Figure 2. Environment map obtained by BCD method.

The information of obstacles or passing areas is expressed as sub-area coordinate information, and sub-area vertex attributes are contained in each divided area. Since the traversing area must have two sides parallel and adjacent to both sides, if the mobile robot traverses to a standard edge, the mobile

robot has traversed the common area. Since this article will cover all areas and use the Boustrophedon Cellular Decomposition to traverse all sub-areas, as shown in Figure 3, the distances are equal, so it is only necessary to compare the total distance required for the mobile robot to move between the various sub-areas. The Genetic Algorithm can determine the best sequence of the mobile robot covering each sub-area. So far, the whole coverage problem in this paper has been transformed into a TSP [12][13] problem based on the Genetic Algorithm.

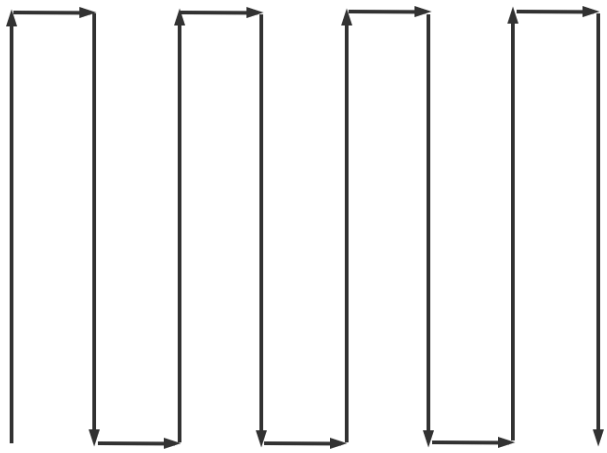


Figure 3. The mobile robot does the reciprocating motion of Boustrophedon Cellular Decomposition in the sub-region.

3.3. Genetic Algorithm

3.3.1. Chromosome Coding

Coding is an essential step in solving the Genetic Algorithm. Since the specific conditions inside the sub-regions are not considered, we only perform coding operations on each sub-region. This paper uses decimal numbers to encode the sub-regions from left to the right, as shown in Figure 2.

3.3.2. Generate Initial Population

Genetic Algorithms generally use random methods to generate initial populations. For example, 1→2→5→7→11→3→6→12→17→4→13→19→15→8→10→14→9→16→18 represents a set of full coverage path sequences starting from sub-region 1. In this paper, the initial population number is set to N.

3.3.3. Fitness Function

Since each operation of the Genetic Algorithm performs genetic operations and iterations on the population according to the fitness value information, the selection of the fitness function will directly affect the convergence speed of the Genetic Algorithm. The chromosome fitness function in this paper is mainly composed of the constraint condition of the total distance. The larger the distance value, the smaller the fitness value, so the form of the fitness function is shown as

$$f(x) = \frac{c}{\sum d(i,j)} \tag{2}$$

Where $d(i,j)$ represents the distance between sub-region i and sub-region j. c is the adjustment constant, so that the fitness is in a suitable range between 0 and 1.

3.3.4. Select Action

The selection operation is an essential step in the Genetic Algorithm. In this process, the individual determines the probability of being selected for the next generation according to the size of the fitness value. The selection operator can gradually increase the number of outstanding individuals in the group, making the algorithm develop a better solution. The selection method used in this paper is roulette. This classic selection operator is easy to implement. At the same time, it gives individuals

with low fitness a chance to be selected to the next generation, which well maintains the diversity of the population. However, individuals with high fitness may also be eliminated. In order to avoid operators with high fitness being eliminated, this paper selects z individuals with the highest fitness to enter the next generation before playing roulette, and the size of z changes with the number of population N.

In the roulette algorithm, according to the fitness $f_i(x)$, the probability P_i of the y path being selected is calculated by the equation (3).

$$P_i = \frac{f_i(x)}{\sum_{i=1}^{N-k} f_i(x)} \tag{3}$$

After that, the roulette operation is performed according to P_i until the replicated individuals reach the population maximum N.

3.3.5. Genetic Manipulation

Genetic operations include crossover and mutation, the two most essential operators in Genetic Algorithms, and fundamentally promote evolution. The crossover probability and mutation probability need to be set in advance at runtime, affecting the Genetic Algorithm's performance.

In the process of crossover recombination, the k groups of chromosomes with the most significant fitness value are selected according to the crossover probability P_c, as in equation (4).

$$k = N * p_c \tag{4}$$

Among them, N is the population size, and then the k sets of chromosomes are randomly paired.

For each pair, select a random natural number in [0, 15], and perform a crossover operation on this number and the last three genes. For example,

$P1$:1 2 5 7|11 3 6 12|17 4 13 19 15 8 10 14 9 16 18

$P2$:3 19 4 11|10 2 16 15|9 1 7 12 8 14 5 13 17 18 6

The random number 5 is drawn, and the gene sequences from positions 5 to 8 in the parent chromosomes $P1$ and $P2$ are selected, and corresponding rules are established through their corresponding relationships, namely 11-10, 3-2, 6-16, 12-15; Swap the fifth to eighth loci in the $P1$ and $P2$ chromosomes; finally, replace the corresponding loci in the rest of the respective chromosomes according to the corresponding rules to obtain the progeny chromosome as:

$G1$:1 3 5 7|10 2 16 15|17 4 13 19 12 8 11 14 9 6 18

$G2$:2 19 4 10|11 3 6 12|9 1 7 15 8 14 5 13 17 18 16

Mutation operation is mainly for cross-operated chromosomes, using a specific method to convert genes at a particular position into other genes, thereby forming new individuals. In this paper, we use exchange mutation to operate, that is, randomly select two loci on a chromosome for exchange.

4. Optimization of GA Parameters and Simulation Results

This paper chooses MATLAB for simulation experiments. First, two base points are selected in each sub-area, one is the starting base point of the traversal in the sub-area, and the other is the end base point of the traversal in the sub-area. It is stipulated that the mobile robot moves from the end base point of the traversed sub-area to the start base point of the next sub-area and the optimal sub-area traversal sequence with the shortest moving distance between the sub-areas is found by the Genetic Algorithm.

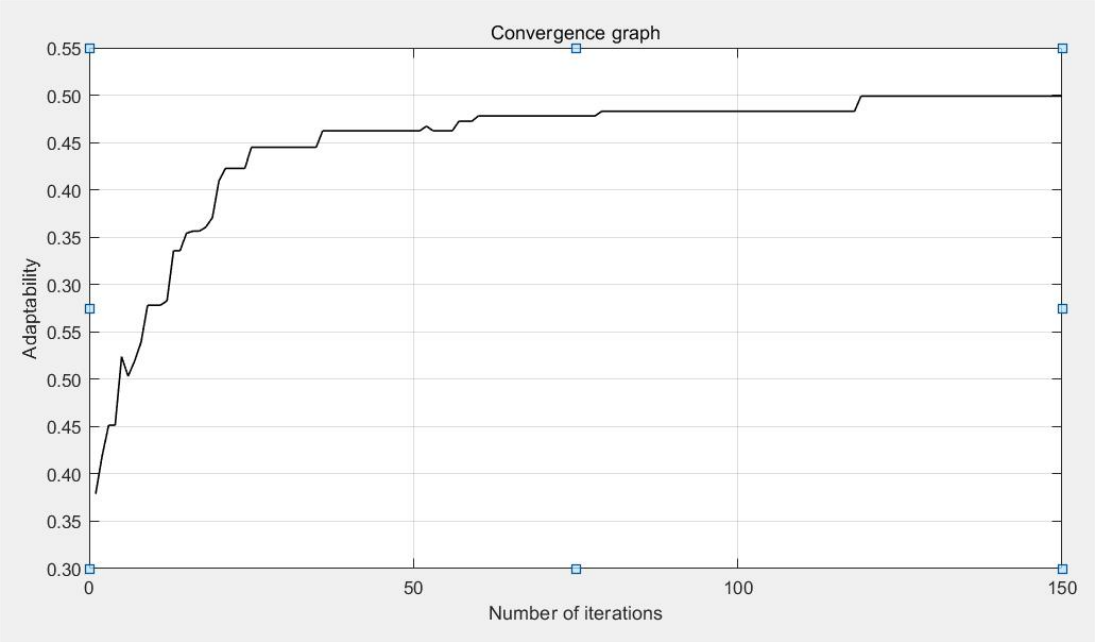


Figure 4. The graph of the number of iterations and fitness.

In this paper, the number of the initial population is set to 50, the crossover probability is set to 0.8, the mutation probability is set to 0.1, and the number of iterations is set to 200 in the simulation. Finally, the simulation results shown in Figure 4 are obtained.

It can be seen from the relationship between the number of iterations and the size of the fitness that the increase in the number of iterations makes the fitness continue to increase, and the shortest distance tends to remain unchanged at about 120 generations, and the optimal traversal sequence is 3→1→2→4→6→8→10→12→13→16→19→18→ 15→17→14→11→9→7→5.

5. Conclusions

This paper introduces a method combining the Genetic Algorithm and the BCD method, which is used in full coverage path planning technology and obtains the optimal sequence of full coverage path planning. The optimal choice of the above parameters is determined through research and analysis, and then the program is run to obtain the optimal solution for whole coverage path planning based on the Genetic Algorithm. In this paper, we use the BCD method to divide sub-regions and cleverly convert the full coverage problem into an STP problem to solve. The experimental simulation proves that the Genetic Algorithm has an excellent convergence speed and efficiency performance and confirms the feasibility and superiority of the Genetic Algorithm in the field of full coverage path planning technology.

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