Automatic Pilot Ship Route Planning Based on A RRT Guided Genetic Algorithm

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Abstract. The reasonable and optimized navigation for an automatic pilot ship is one of the key technologies in ship bridge system. In this paper, a genetic algorithm based path planning method is introduced for this kind of problem. In order to build efficient chromosome to improve the searching efficiency, before the planning procedure of the GA, a traditional but efficient fast searching method - RRT is utilized to give a clue to build the chromosomes. In this paper, at first, a searching area is constructed based on the result of RRT and secondly, a GA based planning algorithm is proposed for the ship to find a path from the start to a target. The fitness function and genetic operator are selected by roulette to ensure the robustness of genetic algorithm. The diversity of population is enhanced by two point crossover operators. Finally, the simulation results show the effectiveness of the proposed algorithm.

1. Introduction
For an automatic pilot ship, the ability to find an optimal or near-optimal path with no collision to the obstacles in a specific environment is one of the most important issue. Many kinds of searching algorithms and sampling based algorithms have been used for path planning, for example, A*, D*, Dijkstra algorithm, RRT algorithm. These algorithms are effective and easy to grasp, but unfortunately, they hardly got the optimal solution, so intelligent approaches have become the mainstream methods for researchers. And heuristic algorithms [3][4] are widely adopted in intelligent planning approaches. Meanwhile, in order to improve the efficiency of the planning algorithm, the intelligent approaches are often used to combine with the traditional methods [5].

Among different kinds of evolutionary algorithms, GA is a traditional and powerful algorithm frequently used in finding optimal solutions based on its deterministic and probabilistic scheme with operators like reproduction, crossover and mutation[6]. In automatic pilot path planning, GA is also a popular approach, for example, Taharwa et al. [7] proposed a GA based path planning method in static environment and Hong Qu et al. [8] proposed a co-evolutionary improved genetic algorithm for global path planning with multiple ships. However, for genetic algorithm, one of the most difficult problems in path planning is the construction of the chromosome. The most used technique is to build grid map or take obstacles' corners as genes. But all these two methods have problems such as the accuracy of the grid will influence the accuracy of the generated path and usage of the obstacles' corners may cause the ship too close to the obstacles and this approach cannot guarantee to obtain the global optimal solution. Considering this situation,
Different from the tradition GA applications, in our algorithm, we first utilize RRT algorithm to obtain an initial path, and based on this result, a searching area is constructed at first. Then the free links are built in the searching area, and at last the genes of the chromosomes are picked in the free links to generate the ideal path.

This paper is organized as follows. A GA based path planning method is proposed in section 2, and the simulation results are given in section 3. At last, we presents the conclusion and discuss future work in section 4.

2. Path planning method for the automatic pilot ship

2.1. Construction of the searching area

The purpose of global path planning is to generate a non-collision path from a starting point to a target under a specific environment meeting with the criteria like shortest path length, energy saving or specific application requirements. In this research work, the ship is supposed moving on a horizontal plane with X and Y coordinates and the boundary of the obstacles are treated as enlarged with a safety distance, thus the ship can be treated as a point in the world map. The procedure of the proposed path planning algorithm is provided in Algorithm 1.

The first step of the planning algorithm is to generate an initial path using RRT algorithm, this path is used as a hint to construct the searching area. Rapidly-exploring Random Tree (RRT) is an effective and quickly search method with efficient data structure and random sampling scheme [9]. That's the reason why we choose RRT as the first step.

Algorithm 1: Procedure of Path Planning Algorithm

1: INPUT: environment map and coordinates of $S$ and $T$;
2: OUTPUT: a path from $S$ to $T$;
3: BEGIN
4: Execute RRT algorithm to generate an initial path;
5: Construct a searching area based on the initial path;
6: Construct free links within the searching area;
7: Execute GA to generate an optimal path;
8: END

As depicted in Fig.1, Fig.1(a) shows the planning outcome of RRT algorithm, obviously, this is not an ideal path, but it can be looked upon as a good clue for the searching trend, so along with this path the working space boundary and the vertices of the obstacles are linked together to construct a searching area, as showed in Fig.1(b).

![Figure 1](image1)

Figure 1 Planning result of RRT and the construction of searching area.

2.2. GA based planning algorithm

When the searching area is constructed, the free links are generated in this zone. A free link is a line whose two edges are either corner of two obstacles or one is a corner and the other one is a point on a working space boundary and could not intersect with the obstacles or each other, as the green lines showed in Fig.2(b). The constructing procedure of free links are introduced in [10].

![Figure 2](image2)
After the searching area and free links are built, the candidate path point will be picked on the free links, these path point can be designed as genes of chromosomes. The encoding scheme is showed as in Fig.3, each chromosome contains M+2 genes begin with the start point and end with the target, in which M is the number of the free links.

![Chromosome encoding scheme](image)

For each random nodes $N^l_{ij}$, the superscript $I$ denotes the serial number of the selected link, the subscript $il$ is a random number from 0 to 1, the coordinate of the random nodes are calculated as:

$$
\begin{align*}
x_0 &= x_i + (x_j - x_i) \times il \\
y_0 &= y_i + (y_j - y_i) \times (x_0 - x_i)
\end{align*}
$$

where $(x_0, y_0)$ denotes the coordinate of the selected point and $(x_i, y_i), (x_j, y_j)$ are the endpoint coordinates of the selected free link. In order to make decimal code string, the serial number of the path points is calculated as follows:

$$N^l_d = [(il \times 10) + l \times 10] + 1$$

for the start and target nodes, they are defined as:

$$S = 0$$

$$T = \max N^l_d + 1$$

After the chromosomes are built, the planning algorithm is applied to obtain a path, the outline of the proposed algorithm is listed in Algorithm 2.

**Algorithm 2: GA Based Planning Algorithm**

1: BEGIN  
2: Initialize a population;  
3: while stopping criteria are not meet do  
4:   Calculate the fitness of each individual;  
5:   Select individuals to form the mating pool based on roulette wheel selection and elitism strategy;  
6:   Perform crossover operation;  
7:   Perform mutation operation;  
8: end while  
9: END  

While the population is generated, the fitness value of each candidate is calculated according to the following fitness function:

$$f = \frac{1}{m} + \sum_{i=1}^{m} e^{-0.8 \times d_i}$$

where $m$ is the total number of the line segments from S to T, $d_i$ is the length of the $i$th segment, $n$ is the total number of the waypoint selected in the free links and is the distance from the $j$th point to the nearest obstacle. Based on the fitness values of each individual, the evolutionary operators of selection, crossover and mutation are applied to improve the individual generation by generation.

The roulette wheel selection is utilized here to select the superior individuals with the fitness value, and the two-point crossover is applied. The first step is to randomly choose two individual chromosomes
and two random points are selected. Then the genes between these two random points are exchanged which generates two new individuals. After the operation of crossover, mutation is the last step, in this step all chromosomes are subjected with a mutation rate. Then the chromosomes may have a small change in one of the genes, this operation is applicable for all genes except S and T. The evolution process is repeated until the stop criteria are met.

3. Simulation results
The performance of the proposed planning and tracking algorithm are tested in the software of MATLAB. In this section, several planning simulation results were provided to demonstrate the effectiveness of the proposed algorithm and then the tracking ability is illustrated.

3.1. Planning results in different environments
A simulation result of the planning algorithm is illustrated in Fig3, Fig.3(a) is the searching results through RRT algorithm, and Fig.3(b) is the constructed searching area (surround in red dash lines) and free links(green dash lines) based on the searching results of Fig.3(a), the planning results are showed in Fig.3(c), it is can be seen that the planning result is improved and easy to be tracked than in Fig.3(a). Fig.3(d) is the evolution procedures of the simulation result, it is showed that the solution is converged quickly in this algorithm. The control parameters of the GA algorithm are listed in Table 1.

Figure.3 Planning result of the proposed algorithm based on two global maps.

| Parameters           | value |
|----------------------|-------|
| Population size      | 100   |
| Max generations      | 100   |
| Crossover probability| 0.9   |
| Mutation probability | 0.4   |

4. Conclusions
In this paper, we have proposed a route planning method for automatic pilot ship based on the genetic algorithm. RRT algorithm was utilized to generate valid chromosome for the genetic algorithm. In order to improve the planning efficiency, a searching area and free links are built at first and then the ideal path is generated in this area. Then the GA planning procedure are introduced. The simulation results have demonstrated that based on the proposed planning method, the automatic pilot ship could generate
an efficient route from the start point to a given target under a global map and further experiments would be completed in practical scenario.

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