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ON EVOLUTIONARY GENETIC ALGORITHM IN PATH PLANNING FOR A USV COLLISION AVOIDANCE

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Abstract. *In recent years, the development of unmanned surface vehicles (USVs) has been a field of increasing research interest. The technology of intelligent USVs path planning is one of the most important intelligent control research areas in this field. In this paper, under the USV collision avoidance environment with state constraints, a kind of path planning method for USV collision avoidance based on evolutionary genetic algorithm is designed. According to the actual requirements of USV autonomous navigation, the algorithm adopts the heuristic initialization method of population, the economy, smoothness and safety evaluation factors are introduced to the fitness function, and in the evolutionary operators, it adds delete operation, repair operation, smooth operation based on the traditional evolutionary operation, and then the population can be updated. The method establishes an optimization iterative process; when the iteration is completed, it can conclude a reasonable collision avoidance path. The results of simulation show that the path planning algorithm for collision avoidance is feasible and effective.*
Keywords: USV, Evolutionary genetic algorithm, Collision avoidance, Path planning

1. **Introduction.** In recent years unmanned vehicles have grown in popularity, with an ever increasing number of applications in industry, the military and research within air, ground and marine domains [1,2]. In particular, the challenges posed by unmanned surface vehicles in order to increase the level of autonomy include automatic obstacle avoidance and conformance with the rules of the road when navigating in the presence of other maritime traffic [3,4]. Therefore, planning a collision-free path and designing a navigation system for USVs are our goals for this study.

For the requirement of USV independent avoidance, combining maritime collision avoidance and collision avoidance algorithm of intelligent robot rules, the research on the field was discussed, and the USV avoidance system based on genetic algorithm can be designed. Based on USV's own particularity, some scholars based on the collision avoidance algorithm of ship and robot [5], have built USV collision avoidance path planning system. The path planning method in this field is mainly divided into two categories, namely the traditional and intelligent methods. Traditional collision avoidance path planning methods include free-space method [6], artificial potential field [7], based on random sampling planning method [7]. Intelligent collision avoidance path planning methods include fuzzy logic path planning [8], neural network path planning [9], and evolutionary algorithm [10,11]. In order to obtain a global path for static obstacles, this paper adopts genetic algorithm to design USV intelligent collision avoidance system. The system uses a heuristic method for generating initial population, and evolutionary operation from intelligent robot path planning algorithm. In the simulation multi obstacle environment, the path planning and intelligent collision avoidance problems have been completed about the USV.

2. **Collision Avoidance Path Planning Based on Genetic Algorithms.** Evolutionary genetic algorithm, based on canonical genetic algorithms, CGA [12,13], is applied to the USV path planning. That is to say the USV collision avoidance paths are simulation of biological species, and by the law of survival of the fittest, the feasible path can be obtained.

2.1. **Population initialization.** In the first iteration, an initial population with floating point [14] chromosomes encoding a sequence of route points is created. In population initialization process, according to the starting and end point of the USV, n initial paths can be randomly generated. Through the evaluation and update of the initial path of population, finally, the feasible path optimization solution can be output. The individuals of initial population are divided into two parts. In the first part, when the starting and end points are determined, if the environment does not have any obstacles, the connection between two points is the shortest and smoothest path. In the second part, when there are obstacles in the environment, in order to improve search efficiency, the heuristic group initialization method is used to generate the chromosomal gene. An example chromosome looks as the ith path P_i, and the path will be divided into three sections. In the jth ($j = 1, 2, 3$) section $P_{i(2j-1)}$ and $P_{i(2j)}$ are randomly selected. Within the scope of the two points, one point P_{ij}^m is randomly generated. By sequentially connecting point $P_{i(2j-1)}$, P_{ij}^m, $P_{i(2j)}$, the initial path P_i can be generated in system (1).

$$P_i = [s, p_{i1}, p_{i1}^m, p_{i2}, p_{i3}, p_{i2}^m, p_{i4}, p_{i5}, p_{i3}^m, p_{i6}, e] \quad (i = 1, 2, \cdots, n) \tag{1}$$

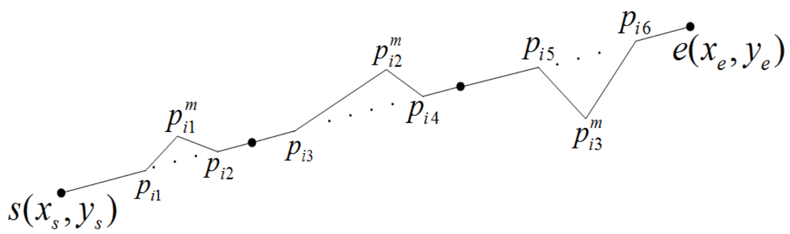

FIGURE 1. Sketch map of initial path based on heuristic algorithm

2.2. **Selection of fitness function.** The appropriate fitness function is the basis for solving practical problems by genetic algorithm. Considering three objective functions of USV, namely the minimum path cost, the average corner cost and the collision threat cost, a comprehensive minimum solution [15,16] can be gotten in system (2).

$$Value(P^*) = \min\left[f_1(P), f_2(P), f_3(P)\right] \tag{2}$$

where P^* is feasible path collection of USV, and the objective functions $f_1(P)$, $f_2(P)$, $f_3(P)$ represent the economy, smoothness, and safety about collision avoidance path. These calculation formulas of the objective function are as follows.

Formula 2.1. *System (3) is path length formula. System (4) is the minimum path cost.*

$$f_1(P) = \max_{i=1}^{n}\{Length(P_i)\} \tag{3}$$

$$Length(P_i) = \sum_{j=1}^{l_i-1}\left|p_{ij}p_{i(j+1)}\right| + m_i \times C_1 \tag{4}$$

Formula 2.2. *System (5) is path smoothness formula. System (6) is the average corner cost.*

$$f_2(P) = \max_{i=1}^{n}\{turning(P_i)\} \tag{5}$$

$$Turning(P_i) = \left(\sum_{j=2}^{l_i-1} a_{ij} + k_i \times \pi/2 \right) \Big/ (l_i - 2) + m_i \times C_2 \tag{6}$$

Formula 2.3. *System (7) is security formula.*

$$f_3(P) = \max_{i=1}^{n} \{danger(P_i)\} \tag{7}$$

$$danger(d_i) = 1/d_i \tag{8}$$

Through these objective functions evaluating the individual, then iteration cycle, global path planning better solutions can be generated.

2.3. **Evolutionary operator.** In the paper, a class heuristic evolutionary operator based on route optimization is adopted. Traditional evolutionary operators include selection operator, crossover operator and mutation operator. In order to improve the search efficiency of the algorithm and make the output path better to meet the requirements [17], other operators are joined that are delete, repair and smooth operators.

Operator 2.1. *Delete operator is the first operator. In the experiments, varied length chromosomes – routes, i.e., routes including different number of points, were used. To prevent fast uncontrolled growth of their size, the delete operation was applied [18]. There are two delete operators. The first is individual path as shown in Figure 2(a). That is, when there is a path through the obstacle O_k itself, you can use the delete operation to optimize. In the figure, the path point P_j in the two path segments P_i and P_j is not feasible, then deleting the point P_j, and connecting two points P_i, P_j. Infeasible path segments from the two become one, reducing the number of infeasible path segments. The second is the turn situation without obstacles nearby the path, as shown in Figure 2(b), then deleting the point P_j, and connecting two points P_i, P_j, so the length of path is shorter. In conclusion, the delete operation can not only control growth of their size, but also increase the effectiveness of the path [14].*

Operator 2.2. *Repair operator is the second operator. When there are a number of obstacles in the environment, appearance probability of infeasible path segment is greater. So, it needs repair operation to repair paths [14]. As shown in Figure 2(c), a part of*

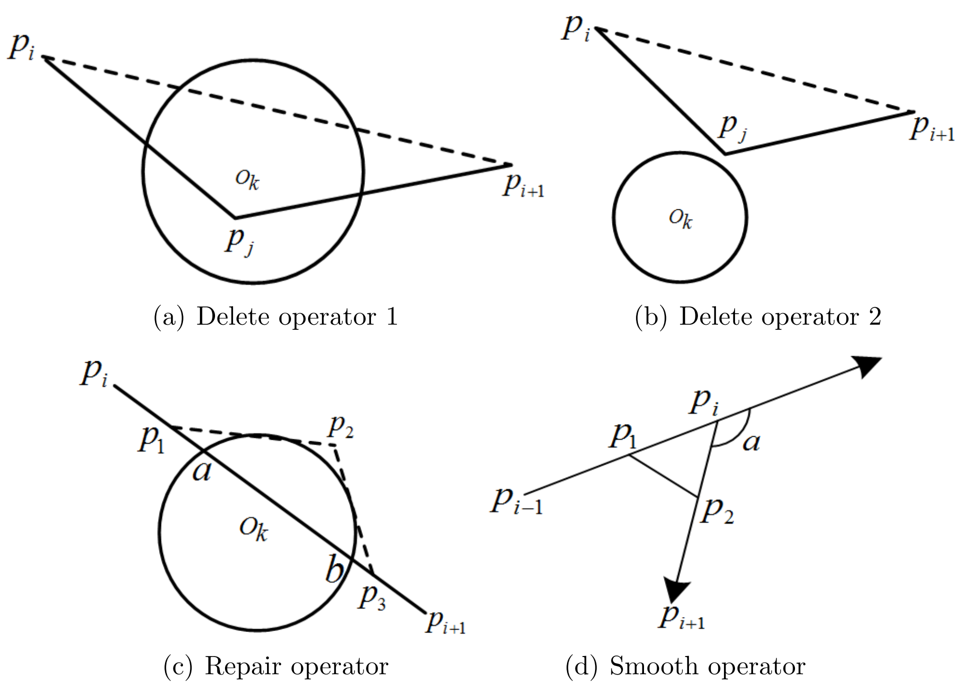

FIGURE 2. Sketch map of some genetic operators

the path P_iP_{i+1} and obstacle O_k cross to the two points a and b, respectively in the line P_ia near the point a and the line bP_{i+1} near the point b, and two points P_1 and P_3 are randomly generated. Through the two points, and drawing two obstacle O_k tangents, the intersection of two tangents is P_2. By sequential connecting these points P_i, P_1, P_2, P_3, P_{i+1}, the infeasible path can be repaired.

Operator 2.2. *Smooth operator is the third operator. Smooth operator is used to repair the path segment with large corner, to enhance the smoothness of the path [14]. As shown in Figure 2(d), the corner $\angle a$ is greater than 90 degrees, that is contrary to the principle of path smoothing, and is not conducive to operation of USV. Modification method is randomly selecting P_1 and P_2 in the two sides $P_{i-1}P_i$, P_iP_{i+1} of $\angle a$, and P_1P_2 is feasible path segments. By sequential connecting these points P_{i-1}, P_1, P_2, P_{i+1}, the feasible path can be gotten. The operation not only enhances the smoothness of the path, but also shortens the length of the path.*

In the paper, by using Bessel mathematical optimization method, the polyline of path can be curve optimized.

3. **Simulation Results and Analysis.** During the voyage, the USV accesses to environmental information by radar and AIS equipment. From the environmental information, the information of obstacles can be extracted [19]. And some assumptions are necessary for environmental model. The USV moves in a limited two-dimensional environment, without considering the height of the obstacle. And there are limited and known static obstacles in USV moving space. The obstacle boundary expands outward a radius of USV, so when path planning, the USV can be considered as a particle motion in any direction [20].

In the experiments, MATLAB was used to simulate. The starting position of the USV was located in the point $(10, 10)$, whereas destination position in point $(90, 90)$. And the USV keeps constant speed. Some parameters of the algorithm were set, i.e., the number of individuals (paths) in population is 20, the number of iterations is 300, probability of crossover is 0.7, probability of mutation is 0.1, the number of obstacles is 10, and initial course is 53 degrees. The simulation results are presented in Figure 3.

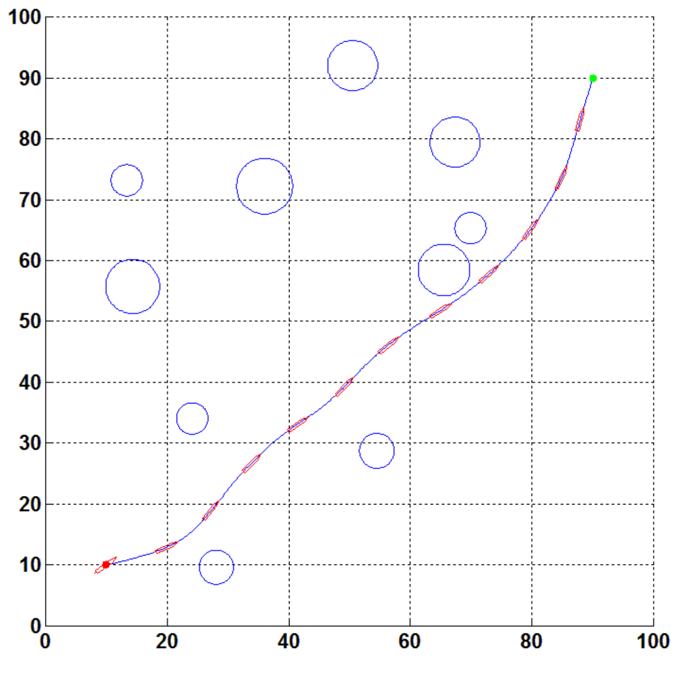

Figure 3. The simulation diagram about USV global path planning

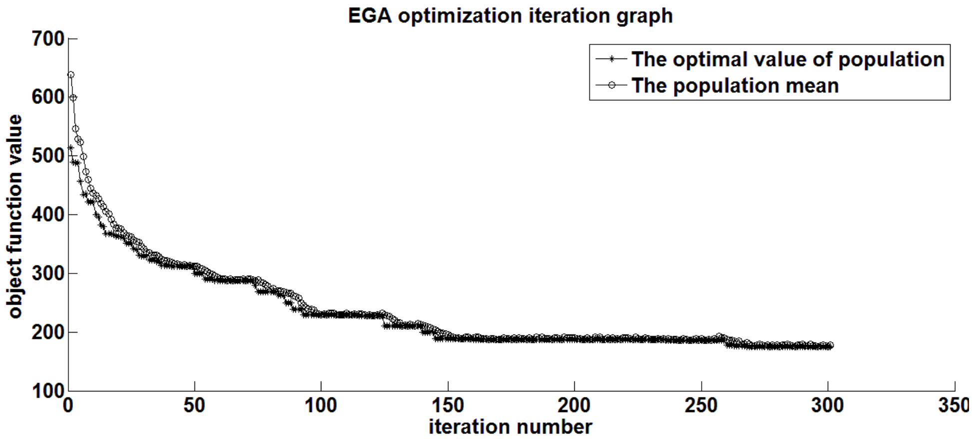

Figure 4. EGA optimization iteration graph

From the simulation results in Figure 3, the output path can accurately avoid obstacles in the environment and can roughly be a straight line without obstructions in the area. It meets the economic requirements of the path.

Figure 4 shows the trend of the fitness function values. With the increase in the number of iterations, the mean value of fitness function is getting close to the optimal value of population. So, by selecting the appropriate number of iterations, algorithm optimization time can be reduced, and the optimal solution can be obtained quickly.

4. **Conclusions.** USVs are able to complete a variety of tasks based on their equipped modules. There are two major areas in this field: control theory and path planning. Therefore, before these vehicles begin, guiding them through cluttered environments is the first challenge. In this paper, static obstacles in ocean environment are imitated by some circles in different radii. By using the evolutionary genetic algorithm, the path planning method for the USV collision avoidance is designed with MATALB software. The results of simulation show that the path planning method for the USV collision avoidance is effective. It can decide the collision risk real-time, the output path can avoid static obstacles effectively, and it can ensure the path smoothness and economy. In this study, the objectives focus on the path planning algorithm for collision avoidance, which will be applied to the USV in the future.

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REFERENCES

[1] J. E. Manley, Unmanned surface vehicles, 15 years of development, *OCEANS 2008*, Quebec City, Canada, pp.1-4, 2008.

[2] J. Colito, Autonomous mission planning and execution for unmanned surface vehicles in compliance with the marine rules of the road, *Autonomous Robots*, vol.14, pp.103-126, 2007.

[3] S. Campbel, W. Naeem and G. W. Irwin, A review on improving the autonomy of unmanned surface vehicles through intelligent collision avoidance manoeuvres, *Annu. Rev. Control*, vol.36, pp.267-283, 2012.

[4] T. Niu, L. Shen and B. Dai, A survey of unmanned combat system development, *National Defense Science and Technology*, vol.5, p.4, 2009.

[5] B. Wu, Y. Xiong and Y. Wen, Automatic collision avoidance algorithm for unmanned surface vessel based on velocity obstacles, *Journal of Dalian Maritime University*, vol.40, no.2, pp.13-16, 2014.

[6] P. T. Lozano, A simple motion-planning algorithm for general robot manipulators, *IEEE Trans. Robotics and Automation*, vol.3, no.3, pp.224-238, 1987.

[7] J. Barraqu and J. Latombe, Robot motion planning: A distributed representation approach, *International Journal of Robotics Research*, vol.10, no.6, pp.628-649, 1991.
[8] X. Zhuang and Q. Meng, A method of robot's path searching in dynamic environment based on fuzzy concept, *Robot*, vol.23, no.5, pp.397-399, 2001.
[9] C. Liu and K. Zhang, Application research of artificial neural network in robot trajectory planning, *Robot*, vol.23, no.5, pp.600-604, 2001.
[10] X. Yao, C. Chen, H. Xu and Y. Liu, A survey of evolutionary algorithms, *Chinese Journal of Computers*, vol.18, no.9, pp.1-2, 1995.
[11] Y. Zhang, *Research of USV Trajectory Planning*, Harbin Engineering University, Harbin, 2008.
[12] D. E. Goldberg, *Genetic Algorithms in Search, Optimization and Machine Learning*, Addison Wesley, Massachusetts, 1989.
[13] J. H. Holland, *Adaptation in Natural and Artificial Systems*, University of Michigan Press, 1975.
[14] X. Shen, Y. Guo and Q. Chen, Multi-robot path planning based on multiobjective co-evolutionary algorithm, *Journal of Nanjing University of Aeronautics and Astronautics*, vol.2, pp.245-249, 2008.
[15] V. Kanakakis, P. Spanoudakis and N. Tsourveloudis, Optimized design of an unmanned surface vehicle, *Elmar 09 International Symposium*, pp.181-184, 2009.
[16] W. Naeem and G. W. Irwin, Evasive decision making in uninhabited maritime vehicles, *Proc. of IFAC World Congress*, Milan, Italy, pp.12833-12838, 2011.
[17] M. A. Potter, *The Design and Analysis of a Computational Model of Cooperative Coevolution*, Ph.D. Thesis, George Mason University, 1997.
[18] T. Praczyk and P. Szymak, Using genetic algorithms to fix a route for an unmanned surface vehicle, *International Conference on Methods & Models in Automation & Robotics*, pp.487-492, 2012.
[19] C. Gu and D. Zhou, Application of an improved genetic algorithm in fast path planning for UCAV, *Fire Control and Command Control*, vol.2, pp.70-73, 2015.
[20] B. Xiao, Y. Yu, L. Yu and H. Chen, Mobile robot global path planning based on immune genetic algorithm, *Computer Engineering and Applications*, vol.43, no.30, pp.91-93, 2007.