Aerospace Science and Technology 14 (2010) 535–541

Contents lists available at ScienceDirect

Aerospace Science and Technology

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Chaotic artificial bee colony approach to Uninhabited Combat Air Vehicle (UCAV) path planning

Chunfang Xu, Haibin Duan *, Fang Liu

National Key Laboratory of Science and Technology on Holistic Flight Control, School of Automation Science and Electrical Engineering, Beijing University of Aeronautics and Astronautics, Beijing 100191, PR China

ARTICLE INFO

Article history:
Received 30 March 2010
Accepted 19 April 2010
Available online 21 April 2010

Keywords:
Uninhabited Combat Air Vehicle (UCAV)
Artificial Bee Colony (ABC)
Chaos theory
Path planning

ABSTRACT

Path planning of Uninhabited Combat Air Vehicle (UCAV) is a rather complicated global optimum problem which is about seeking a superior flight route considering the different kinds of constrains under complex combat field environment. Artificial Bee Colony (ABC) algorithm is a new optimization method motivated by the intelligent behavior of honey bees. In this paper, we propose an improved ABC optimization algorithm based on chaos theory for solving the UCAV path planning in various combat field environments, and the implementation procedure of our proposed chaotic ABC approach is also described in detail. Series of experimental comparison results are presented to show the feasibility, effectiveness and robustness of our proposed method.

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1. Introduction

Uninhabited Combat Aerial Vehicle (UCAV) is one of the inevitable trends of the modern aerial weapon equipments owing to its potential to perform dangerous, repetitive tasks in remote and hazardous environments [12]. Research on UCAV can directly affect battle effectiveness of the air force, therefore is crucial to safeness of a nation. Path planning is an imperative task required in the design of UCAV, which is to search out an optimal or near-optimal flight path between an initial location and the desired destination under specific constraint conditions. Series of algorithms have been proposed to solve this complicated optimization problem, including the A* algorithm, evolutionary computation [12], particle swarm optimization [2], genetic algorithm (GA) [9] and ant colony algorithm [11]. However, those methods can be easily trapped into the local best, hence would probably end up without finding a satisfying path. In our paper, we mainly focus on UCAV path planning in two dimensions.

Artificial Bee Colony (ABC) algorithm was originally presented by Dervis Karaboga in 2007 [5], under the inspiration of collective behavior on honey bees, and it has been proved to possess a better performance in function optimization problem, compared with genetic algorithm, differential evolution (DE) algorithm and particle swarm optimization (PSO) algorithm [5,6]. As we know, usual optimization algorithms conduct only one search operation in one iteration, for example the PSO algorithm carries out global search at the beginning and local search in the later stage. Compared with the usual algorithms, the major advantage of ABC algorithm lies in that it conducts both global search and local search in each iteration, and as a result the probability of finding the optimal parameters is significantly increased, which efficiently avoid local optimum to a large extent. Although the ABC algorithm has rarely been used in path planning field before, yet due to the above advantages we described, we adopted this algorithm to figure out the flight path. What is more, considering the outstanding performance of chaos theory in jumping out of stagnation, we introduced it to improve the robustness of basic ABC algorithm, and the comparative experimental results testified that our proposed method manifests better performance than the original ABC algorithm.

The remainder of this paper is organized as follows. Section 2 introduces the threat resource and objective function in UCAV path planning. Section 3 described the principle of basic ABC algorithm, while Section 4 specified implementation procedure of our proposed chaotic ABC algorithm. Then, in Section 5, series of comparison experiments are conducted. Our concluding remarks are contained in the final section.

2. Environmental modeling for UCAV path planning

2.1. Threat resource model in UCAV path planning

Modeling of the threat sources is the key task in UCAV optimal path planning. In our model, define the starting point as S and the target point as T, as is shown in Fig. 1. There are some threatening areas in the task region, such as radars, missiles, and artillery, which all are presented in the form of a circle, inside of which will be vulnerable to the threat with a certain probability proportional to the distance away from the threat center, while out of which

* Corresponding author. Tel.: +86 10 8231 7318.
E-mail address: hbduan@buaa.edu.cn (H.B. Duan).

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doi:10.1016/j.ast.2010.04.008

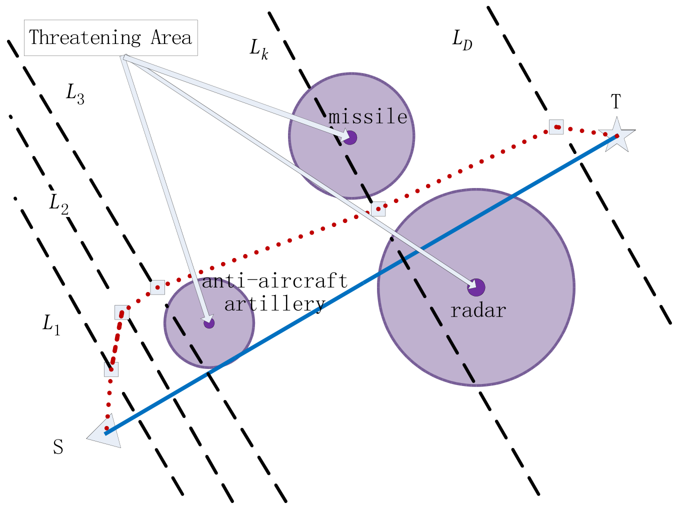

Fig. 1. Typical UCAV battle field model.

will not be attacked. The flight task is to generate an optimal path between S and T considering all these threatening areas.

First connect point S and point T, then divide segment ST into $(D+1)$ equal portions. At each segment point, draw the vertical line of ST, denoted as $L_1, L_2, \ldots, L_k, \ldots, L_D$. Take a discrete point at each vertical segment L_k, engendering a collection of discrete points $C = \{S, L_1(x(1), y(1)), L_2(x(2), y(2)), \ldots, L_k(x(k), y(k)), \ldots, L_D(x(D), y(D)), T\}$, and connect them in sequence to form a path. In this way, the path planning problem is turning into optimizing the coordinates series to achieve a superior fitness value of the objective function.

To accelerate the search speed of the algorithm, we can let line ST be the x axis and take the coordinate transformation on each discrete point $(x(k), y(k))$ according to formula (1), where θ is the angle that the original x axis contrarotates to parallel segment ST, while (x_s, y_s) represents the coordinates in the original coordinate system.

$$\begin{bmatrix} x'(k) \\ y'(k) \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x(k) - x_s \\ y(k) - y_s \end{bmatrix} \tag{1}$$

Thus, the x coordinate of each point can be obtained by a simple formula $x'(k) = \frac{|ST|}{D+1} \cdot k$, therefore the collection C of points can be simplified into $C' = \{0, L_1(y'(1)), L_2(y'(2)), \ldots, L_k(y'(k)), \ldots, L_D(y'(D)), 0\}$, which can greatly reduce the computational cost.

2.2. The performance evaluation function of route optimization

The performance indicators of the UCAV route mainly include the threat cost J_t and the fuel cost J_f, the calculating formulas of which are presented as follows:

$$J_t = \int_0^L w_t \, dl \tag{2}$$

$$J_f = \int_0^L w_f \, dl \tag{3}$$

where w_t and w_f are variables close related with the current path point and changing along with 'l', which respectively present the threat cost and fuel cost of each line segment on the route, while L is the total length of the generated path.

In order to simplify the calculations, a computationally more efficient and acceptably accurate approximation to the exact solution is adopted. In this work, the threat cost of each edge connecting two discrete points was calculated at five points along it, as is shown in Fig. 2.

If the ith edge is within the effect range, the threat cost is given by the expression [7,1]:

$$w_{t,L_i} = \frac{L_i}{5} \cdot \sum_{k=1}^{N_t} t_k \cdot \left(\frac{1}{d_{0.1,i,k}^4} + \frac{1}{d_{0.3,i,k}^4} + \frac{1}{d_{0.5,i,k}^4} + \frac{1}{d_{0.7,i,k}^4} + \frac{1}{d_{0.9,i,k}^4} \right) \tag{4}$$

where N_t is the number of threatening areas, L_i is the ith sub-path length, $d_{0.1,i,k}$ is the distance from the $1/10$ point on the ith edge to the kth threat, and t_k is the threat level of kth threat.

Consuming that the speed of UCAV is a constant, then the fuel cost of the path J_f can be considered equal to L, the total length of path.

The total cost for traveling along the trajectory comes from a weighted sum of the threat and fuel costs, as is defined in formula (5),

$$J = kJ_t + (1-k)J_f \tag{5}$$

where k is a variable between 0 and 1 (0.5 in our algorithm), which gives the designer certain flexibility to dispose relations between the threat exposition degree and the fuel consumption. When k is more approaching 1, a shorter path is needed to be planned, and less attention is paid to the radar's exposed threat. Otherwise, when k is more approaching 0, it requires avoiding the threat as far as possible on the cost of sacrifice the trajectory length. The optimized path is founded only when function J reaches its minimal value.

3. Principles of the basic ABC algorithm

Karlvon Frisch, a famous Nobel Prize winner, found that in nature, although each bee only performs one single task, yet through a variety of information communication ways between bees such as waggle dance and special odor, the entire colony can always easily find food resources that produce relative high amount nectar, hence realize its self-organizing behavior [4].

In order to introduce the self-organization model of forage selection that leads to the emergence of collective intelligence of honey bee swarms, first, we need to define three essential components: food sources, unemployed foragers and employed foragers.

(1) *Food sources* (A and B in Fig. 3)
For the sake of simplicity, the "profitability" of a food source can be represented with a single quantity. In UCAV path planning problem, the position of a food source represents a possible parameter solution to the optimization problem and the nectar amount of a food source corresponds to the similarity value of the associated solution.

(2) *Unemployed foragers*
If it is assumed that a bee has no knowledge about the food sources in the search field, bee initializes its search as an unemployed forager [3]. Unemployed foragers are continually at look out for a food source to exploit. There are two types of unemployed foragers: scouts and onlookers.
- *Scouts* (S in Fig. 3): If the bee starts searching spontaneously for new food sources without any knowledge, it will be a scout bee.
- *Onlookers* (R in Fig. 3): The onlookers wait in the nest and search the food source through sharing information of the employed foragers, and there is a greater probability of onlookers choosing more profitable sources.

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