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Chaotic predator–prey biogeography-based optimization approach for UCAV path planning

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ABSTRACT

This paper proposes a novel Chaotic Predator–Prey Biogeography-Based Optimization (CPPBBO) approach for solving the path planning problems of Uninhabited Combat Air Vehicle (UCAV). To generate optimal or near-optimal flight path, path planning is a key part of UCAV assignment planning system. The planned path can ensure UCAV avoid hostile threats and safely reach an intended target with minimum fuel cost. An improved biogeography-based optimization algorithm is presented for solving the optimization problem in the path planning process. Biogeography-Based Optimization (BBO) is a new bio-inspired optimization algorithm. This algorithm searches for global optimum mainly through two steps: migration and mutation. To enhance the global convergence of the BBO algorithm, the chaos theory and the concept of predator–prey are adopted to get new search mechanism. The comparative simulation results are given to show that our proposed CPPBBO algorithm is more efficient than basic BBO, CBBO and PPBBO in solving the UCAV path planning problems.

1. Introduction

Military operations are turning to more complex and advance automation technologies for minimum risk and maximum efficiency, a critical piece to this strategy is Uninhabited Combat Air Vehicles (UCAVs), owing to their potential to perform dangerous, repetitive tasks in remote and hazardous environment [7]. Path planning for UCAVs is intended to creating a flight plan to guide the UCAV from its initial position to the pre-arranged destination under specific constraints, it is one of the essential parts of the UCAV research. Series of algorithms have been proposed to solve this complicated optimization problem, for example, Eva Besada-Portas presented a path planner for multiple Uninhabited Combat Air Vehicles (UCAVs) based on evolutionary algorithms (EAs) for realistic scenarios [3]. In Ref. [5], Duan et al. presented an Intelligent Water Drops (IWD) optimization algorithm for solving the single UCAV path planning problems in various combating environments. In Ref. [14], a new vibrational genetic algorithm was developed enhanced with a Voronoi diagram. In Ref. [8], a new variant of PSO, named θ-QPSO algorithm was proposed and has shown its high performance in solving path planning problem for UAV in different known and static threat environments.

Biogeography-Based Optimization (BBO), which is a new evolutionary optimization algorithm based on the science of biogeography for global optimization, was originally presented by Simon [16] in 2008. BBO has some features in common with other population-based optimization algorithm, such as the ability to share information between candidate solutions. However, the BBO also has certain features that differ from other population-based optimization methods. One of the characteristics of BBO is that it maintains solutions from one iteration to the next and improved the solutions by migration [17]. As a popular and competitive optimization approach, BBO has been applied to certain problems. What's more, several variations of BBO have been proposed to improve the optimization performance of the basic BBO and to solve a number of constrained optimization problems. Wenyin Gong et al. extended the original BBO and proposed a Real-Coded BBO (RCBBO) approach for the global optimization problems in the continuous domain, and the mutation operator is integrated into RCBBO. In this way, the diversity of the population can be improved, and the exploration ability of RCBBO can be enhanced [9]. Seyed Habib A. Rahmati et al. developed the migration operators of BBO for searching a solution area of Flexible Job Shop Scheduling (FJSP) problem and introduced BBO algorithm to scheduling area [15]. Ling Wang et al. proposed a hybridized BBO with DE, and a simplex search operator was used to design a hybrid algorithm called SSBBODE, which combines the migration and mutation mechanism to enhance the exploration and the exploitation ability [18]. Xiangtao Li et al. introduced multi-parent crossover to the standard BBO and developed a Multi-Operator Biogeography-Based Optimization (MOBBO) method, which cannot only satisfy a balance of exploration and exploitation but also improve the diversity of population [12].

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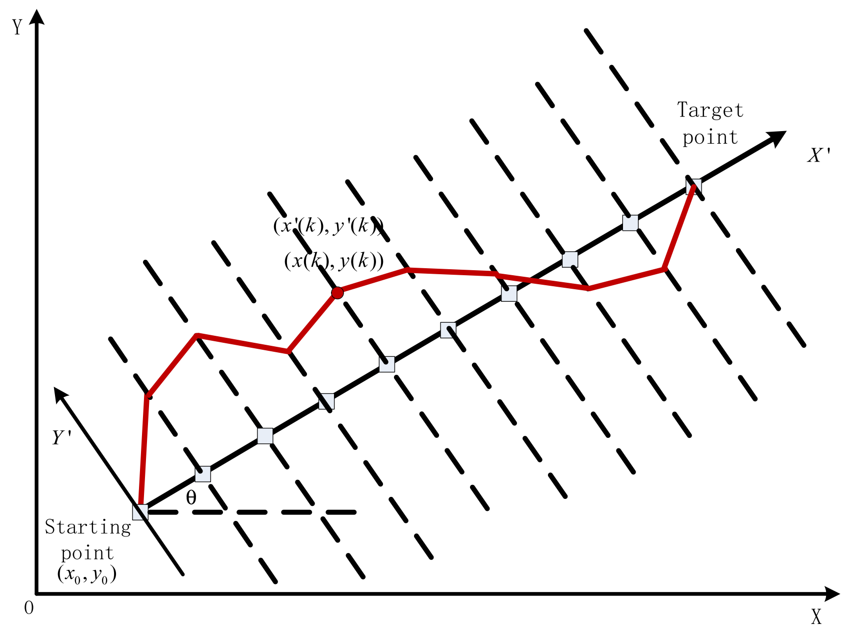

Fig. 1. Transformation of coordinates system.

In this paper, we propose a chaotic predator–prey biogeography-based optimization (CPPBBO) method, integrating the chaos theory and the concept of predator–prey into the classical BBO, to solve the UCAV path planning problem. First, we propose a new migration operation based on the chaos theory to generate new offspring to find the global optimal solution. Second, we include the concept of predator–prey in BBO algorithm in order to improve its capability of finding satisfactory solutions and increasing the diversity of the population. Simulation results and comparisons demonstrate the effectiveness of the proposed algorithm.

The rest of this paper is organized as follows. Section 2 introduces the threat resource and objective function in UCAV path planning. Section 3 describes the principle of basic BBO algorithm, while Section 4 specifies implementation procedure of our proposed chaotic predator–prey BBO algorithm. Finally, in Section 5, series of comparative experiments with basic BBO, CBBO and PPBBO are conducted. Our concluding remarks are contained in the final section.

2. Problem formulation

2.1. Path elements model in UCAV path planning

Modeling of the threat sources is the key task in UCAV optimal path planning. In an abstract term, path planning involves creating a plan to guide a point-like object from its initial position to a destination waypoint [1]. In our model, the path planning process is initialized by determining the start 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 missiles, radars, and artillery, which are all 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 will not be attacked. The flight task is to generate an optimal path between S and T considering all these threatening areas and the fuel cost.

Firstly, we connect point S and point T, then divide segment ST into $(D+1)$ equal portions. Draw a vertical line of ST at each segment point, this set of lines can be denoted as $L_1, L_2, \ldots, L_k, \ldots, L_D$. Take a discrete point at each line, engendering a discrete points collection $C = \{S, (x(1), y(1)), (x(2), y(2)), \ldots, (x(k), y(k)), \ldots, (x(D), y(D)), T\}$, and connect them in sequence to form a flight path. In this way, the path planning problem is turning into optimizing the coordinate 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 counterclockwise rotate to parallel segment ST, while (x_s, y_s) represents the coordinates in the original coordinate system.

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

As shown in Fig. 1, x coordinate of each point can be obtained by a simple formula $x'(k) = \frac{|ST|}{D+1} \cdot k$, therefore the points collection C can be simplified to $C' = \{(0,0), (x'(1), y'(1)), (x'(2), y'(2)), \ldots, (x'(k), y'(k)), \ldots, (x'(D), y'(D)), (|ST|, 0)\}$, we also normalized $x'(k) = \frac{k}{D+1}$ when computing, and then multiplied it with $|ST|$ after optimization, which can greatly reduce the computational cost (see Fig. 2).

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, which can be evaluated as follow [11,2]:

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

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

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

In order to simplify the calculations, more efficient approximation to the exact solution is adopted. In this work, threat cost of each edge connecting two discrete points was calculated at five points along it, as is shown in Fig. 3.