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Application of Dynamic Ant Colony Algorithm in Route Planning for UAV *

Tian Zhao
Company of Postgraduate Management
Academy of Equipment
Beijing, China
e-mail: ianworkmail@sina.com

Xianjun Pan
Company of Postgraduate Management
Academy of Equipment
Beijing, China

Qifang He
Company of Postgraduate Management
Air Force Engineering University
Xi'an, China

***Abstract*—According to the characters such as complex constraint condition, multi uncertainty factors, real time demand for UAV route planning and the characters such as strong robustness, sub-optimal solution, easy implement for Dynamic Ant Colony Algorithm, This paper is applying the Dynamic Ant Colony Algorithm in route planning for UAV. Firstly, the characters of Dynamic Ant Colony Algorithm is analyzed. Secondly, the modeling and processing for Dynamic Ant Colony Algorithm are described in detail. Thirdly, Dynamic Ant Colony Algorithm is applied in UAV reconnaissance scenario. And the DACA is realized in Matlab.**

Keywords—dynamic ant colony algorithm; UAV; route planning; pheromone matrix; tabu list

I. Introduction

Unmanned Aerial Vehicle (UAV) is a new type of combat platform with the ability of autonomous flight and perform task independently [1]. It can not only perform non attack missions, such as military investigation, surveillance, search and so on, but also perform attack missions, such as ground attack and bombing. With the rapid development of UAV technology, more and more UAV will be used in future battlefield.

Route planning is an important function of UAV mission planning [2]. It can plan and coordinate the routes of UAV, and guide UAV accurate operation in specified time and area, to avoid space conflict for UAV. The algorithms can be divided into the traditional classical algorithm and the modern intelligent algorithm, which can be used in UAV route planning. The traditional classical algorithms has Dynamic Programming, Integer Programming, Enumeration Method and so on. The modern intelligence algorithm has Genetic Algorithm, Swarm Algorithm, the Ant Colony and so on. Compared with other algorithms, Ant Colony algorithm has strong robustness [3] and sub-optimal search ability. Therefore, the algorithm of AC got good applicability in UAV route planning.

II. Model and Process

Ant colony algorithm [4], as it named, originated from the process of ant searching food. It realized the path searching through information exchange and individuals cooperation.

Because of unique pheromone, ants could be able to search the best path from net to foods. The pheromone could influence other ant's path choice. Assuming that in the initial stage, the ants select different paths with same probability. In unit time, the shorter path got more ants, the more pheromones have been released in the path. More pheromones guide more ants to choose the path. Therefore this path has become the best path from starting point to destination point.

A. Model

The movement process choosing is based on pheromone concentration of each path in Ant Colony algorithm. According to state transition probability to determine the movement direction of next step [5]. As formula (1)

$$\boldsymbol{p_{ij}^{k}}=\begin{cases}\dfrac{[\tau_{ij}(t)]^{\alpha}\cdot[\vartheta_{ij}(t)]^{\beta}}{\sum_{j\in\Phi}[\tau_{ij}(t)]^{\alpha}\cdot[\vartheta_{ij}(t)]^{\beta}} & \boldsymbol{if\ j\in\Phi}\\ \boldsymbol{0} & \boldsymbol{Otherwise}\end{cases} \tag{1}$$

Where i is the current location of UAV; j is the location that UAV can reach; Φ is the set of all feasible route points from i position; $\tau_{ij}(t)$ is the pheromone concentration from node i to node j; $\vartheta_{ij}(t)$ is the heuristic function from node i to node j; α is the pheromone factor; β is the heuristic function factor.

The heuristic function should satisfy the expectation of the shortest path. Therefore, the heuristic function can be expressed as formula (2).

$$\vartheta_{ij}(t)=d_{ij}^{-1} \tag{2}$$

Where d_{ij} is the straight line distance from node i to node j.

Determine the movement direction of next step, it complete a cycle and update pheromone for ant colony. Pheromone function update rule as formula (3).

$$\begin{cases}\tau_{ij}(t+1)=(1-\rho)\tau_{ij}(t)+\Delta\tau_{ij}(t)\\ \Delta\tau_{ij}(t)=\sum_{k=1}^{m}\Delta\tau_{ij}k(t)\end{cases} \tag{3}$$

Where m is the total number of ants; ρ is the pheromone evaporation factor; $\Delta\tau_{ij}(t)$ is the pheromone increment in this circulation; $\Delta\tau_{ij}k(t)$ is the pheromone increment of ant k through path ij in this circulation.

B. Process

The route optimize problem transform into two-dimensional planning problem by abstracting the area from starting points to target points for UAV. Based on performance indicators of UAV and state transition rules to determine the route of ants. After once route determine, the algorithm adjust pheromone intensity on each nodes. Then the better route will be founded after multiple iteration. Route planning process of UAV by DAC as in Figure 1.

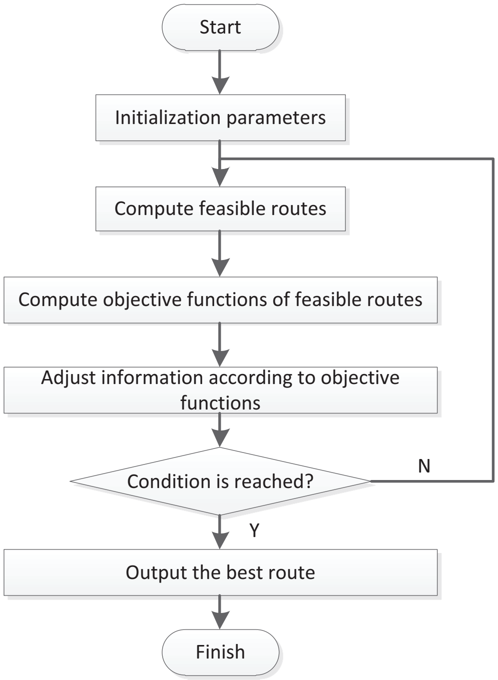

Fig 1. Route planning process of UAV by DAC

Set the number of ants is m, and waiting by start point. Set the probability of new node selection as state transition rules. According to state transition rules, each ant chooses from one node to the next node, eventually reach the target point. Then one feasible solution of the problem will be found by route from start point to target point.

III. EXAMPLE DESCRIPTION

In order to ensure the completion of reconnaissance mission and minimizing the risk of mission execution, the best flight route and mission scheduling strategy of reconnaissance UAV need be planned.

The UAV deployed in 4 military bases. The coordinates are [(256,121), (368,319), (392,275), (392,220)]. The cruise speed is 200km/h. The longest cruise time is 10h. The cruising altitude is 1500m. In order to achieve accuracy target recognition, the distance from target is not more than 7.5km when taking reconnaissance pictures. UAV have to return to original base after mission execution.

According to mission requirement, UAV troops need to execute reconnaissance mission for 10 targets group which contains numbers of ground targets and radar stations. The effective detection range of radar is 70km. The coordinate of target group and radar stations is showing in Table 1.

Table1. Coordinate of Targets and Radar stations

Target Group	Target	Coordinate	Radar
T1	T101	264，715	√
	T102	258，719	
	T103	274，728	
	T104	264，728	
	T105	254，728	
	T106	257，733	
	T107	260，731	
	T108	262，733	
	T109	268，733	
	T110	270，739	
T2	T201	225，605	√
	T202	223，598	
	T203	210，605	
	T204	220，610	
	T205	223，615	
	T206	209，615	
	T207	230，620	
	T208	220，622	
	T209	205，618	
T3	T301	168，538	√
	T302	168，542	
	T303	164，544	
	T304	168，545	
	T305	174，544	
T4	T401	210，455	√
	T402	180，455	
	T403	175，452	
	T404	170，453	
	T405	185，460	
	T406	178，460	
	T407	190，470	
	T408	183，473	
	T409	175，472	
	T410	180，476	
T5	T501	120，400	√
	T502	119，388	
	T503	112，394	
	T504	125，410	
	T505	114，405	
	T506	116，410	
	T507	113，416	
T6	T601	96，304	√
	T602	88，305	
	T603	100，312	

	T604	93，311	
	T605	86，310	
	T606	94，315	
T7	T701	10，451	√
	T702	11，449	
	T703	13，450	
	T704	16，450	
	T705	12，453	
	T706	15，455	
T8	T801	162，660	√
	T802	161，659	
	T803	159，659	
	T804	160，657	
	T805	164，658	
T9	T901	110，561	√
	T902	110，563	
	T903	110，565	
	T904	109，567	
	T905	112，568	
T10	T1001	105，473	√
	T1002	106，471	
	T1003	103，473	
	T1004	107，475	
	T1005	104，477	

IV. Example Solution

The example can be classified as multiple traveling salesman problem. That is, the UAV from one or more bases, traversing all targets area to return to original starting bases. In order to reduce risk of mission execution, planning target is minimum the time for UAV trapping in radar detection range.

A. Route Adjustment

In order to achieve an accuracy target recognition, the distance from target is no more than 7.5km when taking pictures to ground target. The reconnaissance range of UAV can be expressed as formula (4).

$$\boldsymbol{D_j} < \boldsymbol{D_{max}} \tag{4}$$

Where, D_{max} was the maximum of reconnaissance distance, it took 7.5km. The reconnaissance mission could not be completed until reached the maximum of reconnaissance distance when UAV flying forward from node *i* to node *j*. Then UAV turn to next target node.

The route adjustment model can be expressed as formula (5).

$$\begin{cases} v_{ij} = l_{ij} \\ e_{ij} = c_{ij} \end{cases} \tag{5}$$

Where v_{ij} is flight direction from node *i* to node *j*; l_{ij} is line direction from node *i* to node *j*; e_{ij} is terminal of flight route from node *i* to node *j*; c_{ij} is the new route node which is a crossover point between flight direction and maximum reconnaissance distance.

B. Tabu List Update

When UAV fly to a position of target reconnaissance, the other targets nearby may in scope of reconnaissance, it can be executed at the same time to multi targets reconnaissance. This targets should be out of consideration and added to tabu list. Tabu list update rule can be expressed as formula (6).

$$\begin{cases} Tabu(t) = Tabu(t) + Z_s(t) \\ Z_s(t) = \{s \mid D_s < D_{max}\} \end{cases} \tag{6}$$

Where $\boldsymbol{Tabu(t)}$ is the tabu list in time *t*; $\boldsymbol{D_s}$ is the straight line distance from UAV to node *s* in list $\boldsymbol{\Phi}$; $\boldsymbol{Z_s(t)}$ is the set of target nodes which in the scope of imaging.

C. Solution Process

The number of targets is *n*; the shortest route is *Shortest_Route*; the best route is *Best_Route*; the actual route node set is *Route*; the total number of running times is *Max_GEN*; the running time is *T*. The route planning process of dynamic ant colony algorithm is as followed.

1) STEP 1: Initialization

Setting t=0, $\boldsymbol{Shortest\_Route} = +\infty, \boldsymbol{Best\_Route} = \emptyset, \boldsymbol{Route} = \emptyset, \Delta\boldsymbol{\tau_{ij}} = \boldsymbol{0}, \mathbf{Tabu} = \emptyset$. Add all target nodes in list $\boldsymbol{\Phi}$.

Random the initial position for all ants. Add initial node in Tabu list and Delete initial node in list Φ.

2) STEP 2: Node Selection

a) STEP 2.1: Selecting the next target node for each ant. The node who in list $\boldsymbol{\Phi}$ could be searched according to formula (1).

b) STEP 2.2: Calculation the actual route node according to formula (5). When getting the searching outcome, add the node to Tabu list and delete the node in list $\boldsymbol{\Phi}$.

c) STEP 2.3: Based on the actual route, searching the target nodes according to formula (6). Then update Tabu list.

d) STEP 2.4: Repeat *STEP2.2* and *STEP 2.3* until all target nodes to traverse once.

e) STEP 2.5: Add initial target node to Tabu list. $\boldsymbol{\Phi} = \emptyset$.

3) STEP 3: Update Pheromone Matrix

According to formula (3), calculate $\boldsymbol{\tau_{ij}(t)}$ for each ant and *Best_Route*. Compare route cost with *Shortest_Route*. if route cost less than *Shortest_Route*, the value assigned to *Shortest_Route*, and the Tabu list corresponding *Route* give to *Best_Route*.

*4) STEP **4:** Checking Termination Condition*

If the maximum running times *Max_GEN* is reached, calculation terminates and goes to *STEP 5*. Otherwise, initialization, repeat *STEP 2*, *STEP 3*, *STEP 4*.

*5) STEP **5:** Output Optimal Value*

D. Planning Results

There are at least 4 route planning options, because of 4 UAV bases. That is, starting from 1 base to traverse all target nodes, starting from 2 bases to traverse all target nodes, starting from the 3 base to traverse all target nodes, starting from the 4 base to traverse all target nodes.

In Matlab platform, using Dynamic Ant Colony algorithm to calculate the optimal route planning of 1 UAV base. The total flight time is 7.882h, the time of staying in radar detection range is 6.058h. As in Figure 2.

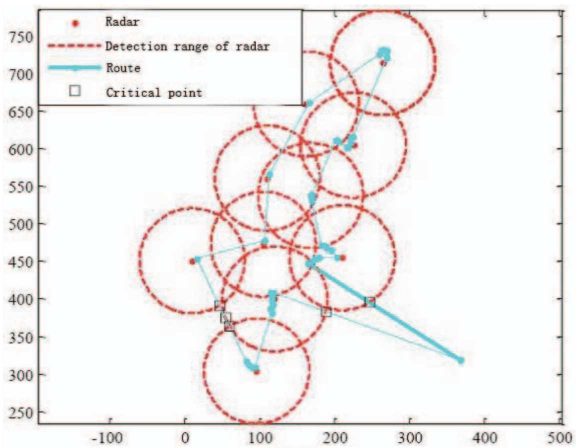

Fig 2. The optimal route planning of 1 UAV base

In Matlab platform, using Dynamic Ant Colony algorithm to calculate the optimal route planning of 2 UAV base. The total flight time is 11.805h, the time of staying in radar detection range is 6.107h. As in Figure 3.

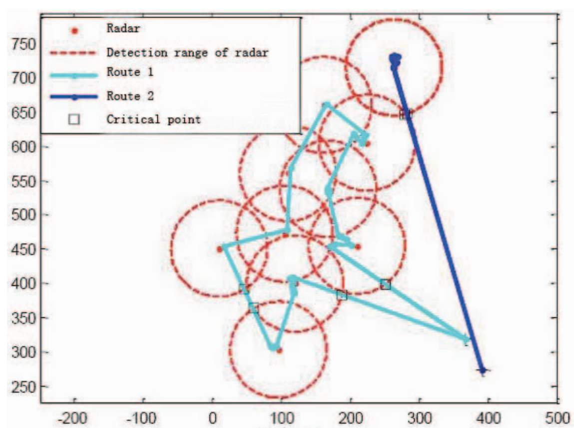

Fig 3. The optimal route planning of 2 UAV base

In Matlab platform, using Dynamic Ant Colony algorithm to calculate the optimal route planning of 3 UAV base. The total flight time is 13.725h, the time of staying in radar detection range is 6.296h. As in Figure 4.

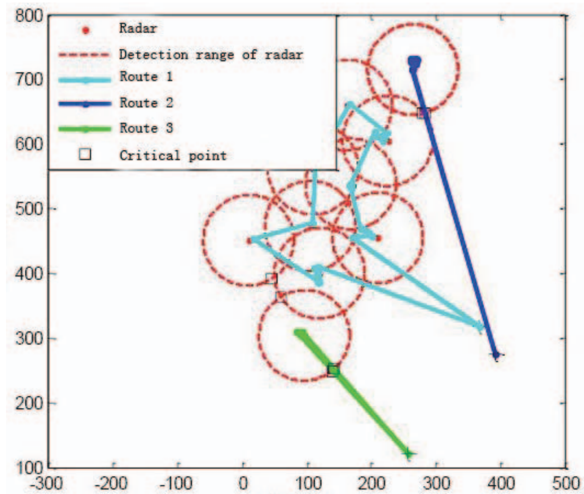

Fig 4. The optimal route planning of 3 UAV base

In Matlab platform, using Dynamic Ant Colony algorithm to calculate the optimal route planning of 4 UAV base. The total flight time is 16.249h, the time of staying in radar detection range is 6.120h. As in Figure 5.

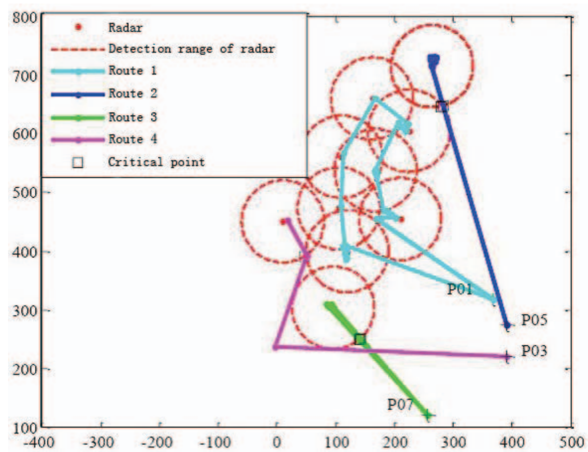

Fig 5. The optimal route planning of 4 UAV base

E. Algorithm comparison

The traditional algorithms such as Dynamic Programming, and Dijkstra might in combinatorial explosion trouble. The intelligence algorithms such as Simulated Annealing, Genetic Algorithm and Dynamic Ant Colony could solve the problems. Therefore, this paper compare Dynamic Ant Colony with Simulated Annealing. For example of one UAV base route planning. The route planning results was showing in Figure 6. We can found that the route planning could be calculated in both algorithms, and the difference between two planning results was very small. But the convergence rate was different. The Dynamic Ant Colony Algorithm has the faster convergence rate. As in Figure 7. When cycle index was 18, the route planning by DAC have been got. When cycle index was 36, the route planning by SA have been got. And the route planning distance by DAC was shorter than route planning distance by SA. The results of algorithm comparison showed that algorithm of DAC got good applicability in UAV route planning.

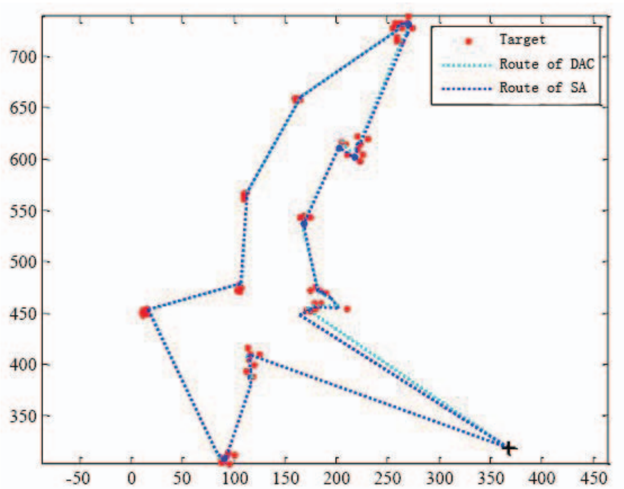

Fig 6. Route planning of 1 UAV base for two algorithms

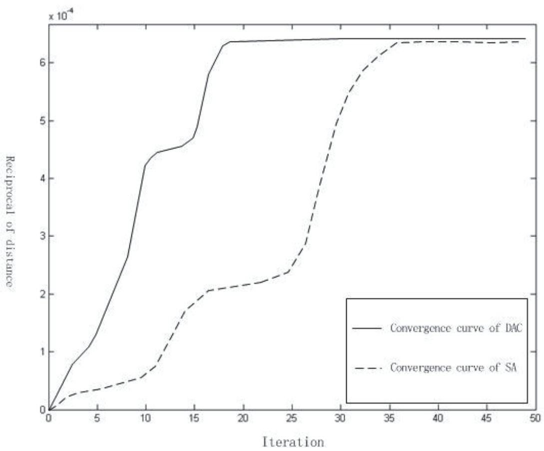

Fig 7. Convergence rate comparison between DAC and SA

V. CONCLUSIONS

Dynamic Ant Colony Algorithm with the characters of strong robustness, sub-optimal solution, easy implement and so on has a good application prospect in UAV route planning. Based on model and process analyze for Dynamic Ant Colony Algorithm, according to a military example, we applied the Dynamic Ant Colony Algorithm in route planning for UAV. By means of simulation test, we brought the optimal plan, increased planning efficiency and verified the feasibility and effectiveness of the algorithm.

REFERENCES

[1] H.B. Mao, S. Tian, and A.N. Chao, UAV Mission Planning, National Defense Industry Press, Beijing, China, 2015.

[2] A. Tsourdos, B. White, M. Shanmugavel, Cooperative Path Planning of Unmanned Aerial Vehicles, National Defense Industry Press, Beijing, China, 2013.

[3] K. Miettinen, Nonlinear Multiobjective Optimization. International series in operations research & management science. Kluwer Academic Publishers, 1999.

[4] J. Yang, Y. Zhuang, "An improved ant colony optimization algorithm for solving a complex combinatorial optimization problem," Applied Soft Computing. vol.10, pp.653-654, 2010.

[5] M. Dorigo, M. Vittorio, and C. Aaberto, "The ant system: optimization by a colony of cooperating agents," IEEE Transactions on Systems, Man, and Cybernetics, vol.26, pp.1-2, 1996.

[6] S. Lee, T. Jung, and T. Chung, "Improved ant agents system by the dynamic parameter decision fuzzy systems," The 10th International Conference on Fuzzy Systems, vol. 2, pp. 666-669, 2001.

[7] M.D. McKay, R.J. Beckman, and W.J. Conover, "A comparison of three methods for selecting values of input variables in the analysis of ouput from a computer code," Technometrics, vol.42, pp. 55-56, 2000.