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Intelligent Path Planning Approach to Flight

Merlin Mary James, Vinodh P Vijayan, Neena Joseph, Neethu Maria John
Department of CSE, Mangalam College of Engineering, Kerala, India

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ABSTRACT

The transfer of aircraft on the flight deck of carrier exerts a significant impact on the sortie and recovery capacity of aircraft fleet, and the safety of the transfer path is particularly important. In this paper, combining artificial experience and intelligent search, a path planning method for carrier aircraft on deck is proposed considering that the existing full-automatic methods can not deal with the problem in complex environment. Firstly, base models for transfer of aircraft which contain the flight deck boundary model, convex hull model for aircraft, Dubin and Reeds-shepp path model, and collision detection model for path are established. Secondly, the procedure of the deck path planning method for aircraft that combines the artificial expertise in setting intermediate path nodes and a local optimization mechanism based on the modified Artificial Bee Colony (MABC) algorithm is illustrated. Finally, the feasibility of the model and validity of the algorithm are verified by simulation under three typical transfer missions.

I. INTRODUCTION

Deck transfer is an important part of the fleet deck operation. Safety and efficiency of the transfer are important for improving the sortie and recovery capacity of the fleet. With the requirement of the mission, carrier aircrafts are usually transferred between parking spots on the flight deck. According to the fact that the aircraft relies on external power, the coordination and implementation of transfer between parking spots can be divided into towing and taxiing. How to plan a reasonable path based on the initial state (including the position and orientation of the aircraft), target state and environment on deck for an aircraft is an important part of deck scheduling [1].

The path planning strategies for aircraft deck and hangar environment are mainly divided into four kinds as follows:

(1) Pseudo-spectral method. This algorithm is an optimal control method based on kinematic differential equations of aircraft transfer. The solution output includes not only the path, but also the control variable of transfer, This algorithm has the advantage of high accuracy for planning, but its shortcomings of long calculation time cannot meet the requirements of real-time planning[2];

(2) Artificial potential field. By constructing a virtual artificial field of gravitation, this method makes the aircraft subject to the "gravitation" of the target point, and at the same time avoid the obstacle under the repulsion of the obstacle. It

has the advantage of fast planning. However, the merits of the planning path depend on whether the designed gravitational field is reasonable. Sometimes it cannot find a feasible path. Based on convex hull model of aircraft, Zhang et al[3] proposed a method for detection and distance calculation of different aircrafts, meanwhile, they proposed a strategy for avoiding obstacles based on the generalized symbol threshold function, and extended this method to the tractor towing situation in the Reference [4].

(3) Heuristic search algorithm. The method can reach the approximate optimal solution fast, but it cannot guarantee to obtain the global optimality. In this respect, Wu et al proposed an A* search algorithm [5] and a dynamic multistep optimization algorithm [6] combined with model predictive control for the taxiing path planning of aircraft.

(4) Swarm intelligence algorithm. Specifically, it includes particle swarm algorithm [7], genetic algorithm [8], chicken swarm optimization algorithm [9], etc. These algorithms has global optimization capability, strong computational robustness and high efficient calculation, but at the same time it cannot avoid the possibility of falling into a local optimum.

Those methods all depend on the automatic optimization of computers and cannot integrate the experience of dispatchers. In a complex environment, it usually takes plenty of time to search. It is easy to fall into local optimum and even it is difficult to achieve feasible paths. In this paper, to overcome the shortages of the above methods, we combine the experience of manual scheduling with the local optimization capability of modified artificial bee colony algorithm, and propose a path planning method for carrier aircraft on deck.

II. BASE MODELS FOR TRANSFER OF AIRCRAFT

2.1 Flight deck boundary model

Deck is the global environment for the implementation of aircraft transfer. The deck boundary is abstracted as irregular encircling domains of line segments connected by a series of convex points $[(x_1,y_1),(x_2,y_2),(x_3,y_3)\ldots\ldots(x_n,y_n)]$, and the linear equations are described by the two point equation of the straight line. :

$$\begin{cases} y=(x-x_2)(y_1-y_2)/(x_1-x_2)+y_2 \\ y=(x-x_4)(y_3-y_4)/(x_3-x_4)+y_4 \\ \vdots \\ y=(x-x_n)(y_{n-1}-y_n)/(x_{n-1}-x_n)+y_n \end{cases}$$

2.2 Convex hull model for aircraft

For the modeling of the aircraft entity, the primary consideration is to describe the space occupied by the aircraft. In order to reduce the calculation during the collision detection and reduce the probability of local minimum problems, we take advantage of the physical characteristics of the aircraft, and appropriately expand the occupied space to establish a convex shell model. The convex points of the carrier's contour are connected to build convex polygon, and the convex shell model is used to replace the aircraft with a specific shape. According to different requirements of mission condition, two kinds of state of the wings are considered: folded wings and unfolded wings, as shown in Figure 1.

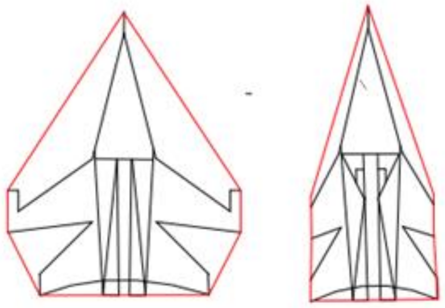
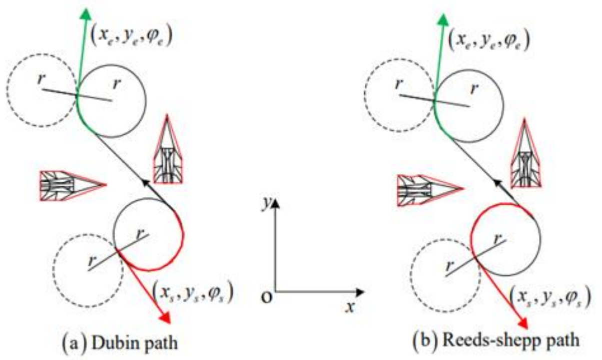


Figure 1. Aircraft Convex Hull Model

2.3 Dubin and Reeds-shepp path model

When transferring on the deck of the aircraft, the path has a kinematic constraint (minimum turning radius), it requires the carrier aircraft to reach a defined target state through a certain path under a defined initial state and limited movement conditions. So we choose Dubins path or Reeds-Shepp path [10] which can solve this problem with accurate planning. As is shown in figure 2, initial state (x_s, y_s ,ϕ_s) and target state (x_e, y_e,ϕ_e) of carrier aircraft are given, where the state (x y, ,ϕ)includes location (x y,) and direction angle ϕ . When the aircraft is in taxiing mode, due to the thrust of the engine, it can only move forward. In this case, the Dubins path is used; when the aircraft is in the towing mode, the tractor can choose to go forward or backward, using Reeds-Shepp path. In the figure, the radius of the path steering circle is r .When faced with a complex and multi-barrier environment, more intermediate path nodes $(x_i^m, y_i^m, \varphi_i^m)(i=1,2,\cdots,N)$ are needed to avoid obstacles.



(a) Dubin path (b) Reeds-shepp path

Figure 2. Dubins path and Reeds-Shepp path

2.4 Collision detection model for path

Based on the convex shell model and the Dubins and Reeds-Shepp path model, the aircraft transfer path can be expressed as a rectangular trajectory bounding box and an arc trajectory bounding box formed by the vertex of its convex shell. As is shown in Figure 3, the collision detection problem of the path can be expressed as a problem of interferes of the rectangle/arc trajectory bounding box with the remaining obstacles or boundaries. The rectangular trajectory bounding box interference detection model can refer to the literature [3], and the arc trajectory bounding box interference detection model can refer to the literature [8].

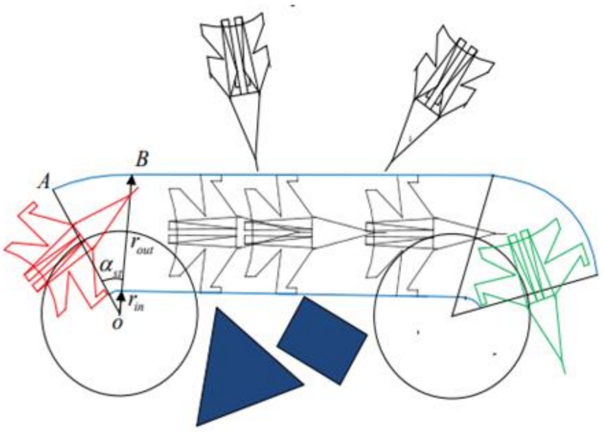


Figure. 3. Trajectory bounding box.

III. A PATH PLANNING METHOD FOR CARRIER AIRCRAFT ON DECK COMBINING ARTIFICIAL EXPERIENCE AND INTELLIGENT SEARCH

The core of the method consists of two parts. First, based on the experience of the dispatching commander, the state of the intermediate nodes are set according to the transfer task and the state of aircraft;Because the intermediate nodes set by human are not globally optimal, in the second part it is needed to optimize the intermediate nodes in local region. We propose a local path node optimization mechanism based on modified Artificial Bee Colony algorithm (MABC), so as to realize the combination of artificial experience and intelligent algorithm.

3.1 MABC-based local optimization for intermediate nodes

On the basis of the basic artificial bee colony algorithm, this algorithm combines the mutation strategy of differential evolution algorithm to improve the local search ability. In MABC, artificial bee colony include employee bees (EB), onlookers, and scouts. The size of population is 2NP(the number of EB=the number of onlookers= NP).The nectar source corresponds to the leader bee, and each nectar source represents a set of intermediate path node solutions.

$$\boldsymbol{X}_i\left(i=2,3,\cdots,NP\right)=[x_{1,i}^m,y_{1,i}^m,\varphi_{1,i}^m,x_{2,i}^m,y_{2,i}^m,\varphi_{2,i}^m,\cdots,x_{N,i}^m,y_{N,i}^m,\varphi_{N,i}^m]$$

Where, $\left(x_{j,i}^m,y_{j,i}^m,\varphi_{j,i}^m\right)\left(j=1,2,\cdots,N\right)$ represents the state of the j-th intermediate node. The nectar amount represents the quality of the solution. The procedure of the MABC algorithm is as follows.

1) The EB conduct a neighborhood search based on the current nectar source to generate a new nectar source, and greedily select a better nectar source;
2) The onlookers select a nectar source according to the information shared by the EB, perform a neighborhood search, and greedily select a better nectar source;
3) EB abandon nectar source, convert to scouts, and randomly search for new nectar source. In the search process, onlookers select a nectar source in a roulette based on information shared by EB.

$$P(\boldsymbol{X}_i)=fit(\boldsymbol{X}_i)\Big/\sum_{j=1}^{NP}fit(\boldsymbol{X}_j) \tag{1}$$

Where, $fit(\boldsymbol{X}_i)$ is the amount of nectar (fitness), which can be expressed as

$$fit(\boldsymbol{X}_i)=1/f\left(\boldsymbol{p}_i\right)=1/\left(w_{\mathrm{f}}L\left(\boldsymbol{p}_i\right)+w_{\mathrm{obs}}D_{\mathrm{obs}}\left(\boldsymbol{p}_i\right)+w_{\mathrm{fro}}D_{\mathrm{fro}}\left(\boldsymbol{p}_i\right)\right) \tag{2}$$

Where p_i represents the Dubins path or Reeds-Shepp path constructed with Xi , f (p_i) represents the objective function of path p_i ,w_f , w_{obs} , w_{fro} represent the weight of path length, collision avoidance safety and deck boundary safety respectively, L(p_i) represents the length of the path p_i , D_{obs} (p_i) and D_{fro} (p_i) represent the collision avoidance safety index and deck boundary safety index of path p_i respectively.

$$D_{\mathrm{obs}}\left(\boldsymbol{p}\right)=\begin{cases}\dfrac{1}{d_{\mathrm{obs}}\left(\boldsymbol{p}\right)}, & if\ d_{\mathrm{obs}}\left(\boldsymbol{p}\right)>0\\ M, & if\ d_{\mathrm{obs}}\left(\boldsymbol{p}\right)=0\end{cases} \tag{3}$$

$$D_{\mathrm{fro}}\left(\boldsymbol{p}\right)=\begin{cases}\dfrac{1}{d_{\mathrm{fro}}\left(\boldsymbol{p}\right)}, & if\ d_{\mathrm{fro}}\left(\boldsymbol{p}\right)>0\\ M, & if\ d_{\mathrm{fro}}\left(\boldsymbol{p}\right)=0\end{cases} \tag{4}$$

Where, d_{obs} (p) represents the safety distance of the path p relative to obstacles, d_{fro} (p) represents the safety distance of path p relative to obstacles the deck boundary. When d_{fro} (p) = 0 or d_{obs} (p) = 0 , the path is infeasible and M is a penalty item. The above parameters can be calculated by the path collision detection model.

EB and onlookers use DE/current-to-rand-best/1 strategy to search for new nectar sources

$$\boldsymbol{V}_i=\boldsymbol{X}_i+F\cdot\left(\boldsymbol{X}_{best}-\boldsymbol{X}_i\right)+F\cdot\left(\boldsymbol{X}_{r1}-\boldsymbol{X}_{r2}\right) \tag{5}$$

Where, F is a scale factor between 0 and 1. X_{best} is the current best nectar is a random integer, and r1,r2 ∈ 1, 2, NP r1 ≠ r2≠i. If the quality of the not increase after a limited number of cycles, EB gives up the nectar source, turns it into scouts, and randomly generates a new nectar source.

3.2 Path planning steps

The procedure of the deck path planning method for aircraft is shown in Figure 4, and the specific steps are described as follows:

Step1. Input the deck layout status and establish the deck digital environment model which includes the convex shell model and deck boundary model of the aircraft.

Step2. Input aircraft transfer mission. It includes the state of the wings of the aircraft to be transferred, the state of the initial parking spot(x_s, y_s,ϕ_s) , the state of the target parking spot(x_e, y_e, ϕ_e) , and the transfer mode.

Step3. According to the tasks and deck layout status of the carrier aircraft to be transferred, the dispatching commander manually sets N intermediate nodes $\left(x_i^m,y_i^m,\varphi_i^m\right)\left(i=1,2,\cdots,N\right)$ and sets the lower $\left(x_i^l,y_i^l,\varphi_i^l\right)\left(i=1,2,\cdots,N\right)$ and upper $\left(x_i^u,y_i^u,\varphi_i^u\right)\left(i=1,2,\cdots,N\right)$ bounds of the local optimization range of the intermediate nodes.

Step4. Aiming at the local fitness, the MABC algorithm is used to optimized the N intermediate path nodes within the local optimization range.

Step5. If the locally optimized output path is feasible, which means the constraints of collision and exceeding the deck boundary are satisfied, and the requirements of the dispatch commander are met, then the optimal intermediate path nodes and the full path are the outputs. Otherwise, the process returns to step 3 to update the intermediate nodes and iteratively optimizes.

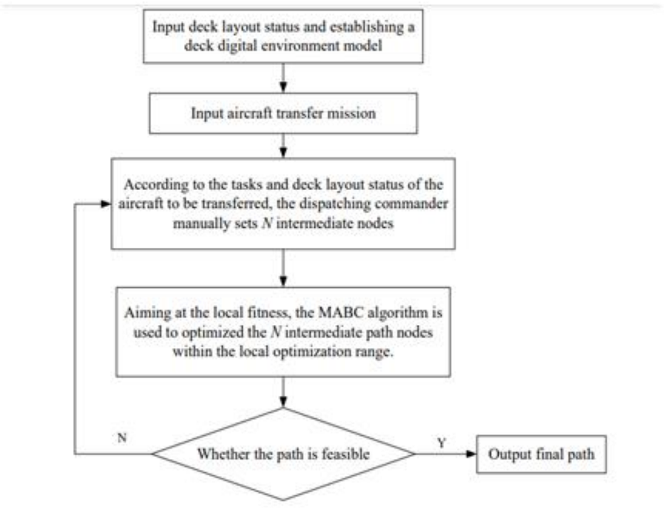


Figure 4. Procedure of the deck path planning method for aircraft

IV. EXPERIMENTAL STUDIES

When the aircraft is transferred on the deck, the aircraft will be transferred between the parking spot, the parking spot and the take-off spot according to the mission. Take the aircraft carrier of Marshal Kuznetsov as the simulation background, three types of transfer missions are introduced. The number of iterations of MABC algorithm is 50 times, and the initial size of the population is 30, F =0.7, limit=15, $w_f = 0.6$, $w_{obs} = 0.2$, $w_{fro} = 0.4$.

In mission A, taxiing mode is required, the aircraft is transferred from parking spot 7 to parking spot 1. The initial state is(173,212,-60.71°),the target state is(594,177,-6.27°). Setting two intermediate nodes manually, the state of two middle nodes are (79.79,145.66,-0.48°) and (504.78,116.43,-0.68°) after local optimization.

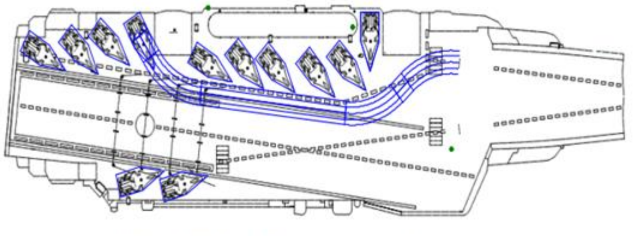


Figure 5. Transfer trajectory of mission A

In mission B, towing mode is required, the aircraft is transferred from parking spot 10 to parking spot 1. The initial state is (38.19,78.17,-29.90°),the target state is (478.22,487.17,-90.00°). Setting two intermediate nodes manually, and the state of two middle nodes are (147.66,125.32,-0.37°) and (518.82,111.92,-1.37°) after optimization.

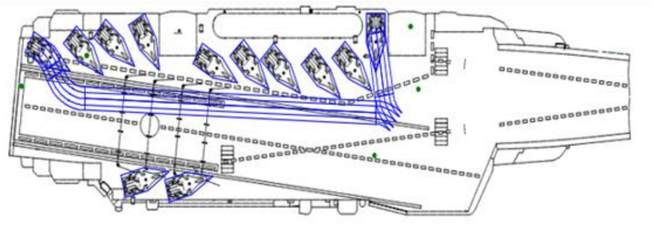


Figure 6. Transfer trajectory of mission B

In mission C, taxiing mode is required, the aircraft is transferred from parking spot 9 to parking spot 3. The initial state is (89.20,122.17,-44.12°),the target state is (327.81,428.91,5.60°). In this path, the demand of target pose can be achieved by one turn, so we only set one middle node. The state of the optimized intermediate node is(250.70,89.44,-0.18°).

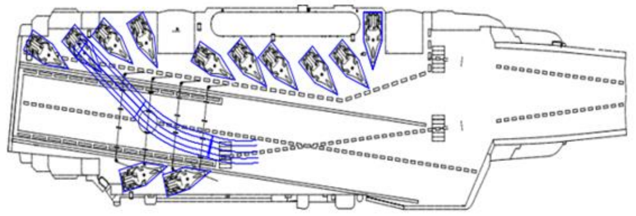


Figure 7. Transfer trajectory of mission C

V. SUMMARY

In this paper, in order to plan the path for transferring of aircraft efficiently and safely, a path planning method for carrier aircraft on deck combining artificial experience and intelligent search is presented. For the sake of simplification, the boundary of flight deck and the outline of aircraft are modeled as convex hulls, and the path is constructed as Dubins path or Reeds-Shepp path. In order to combine the advantages of artificial expertise and automatic optimization algorithm, the method allows the dispatch commanders to set intermediate path nodes according to current state, and then a MABC algorithm is applied to locally optimize the path nodes and the whole path. Simulation results verify the validity of the method.

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