Modeling Analysis of Carrier-based Aircraft’s Scheduling on Flight Deck

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Abstract. The scheduling efficiency of carrier-based aircrafts on flight deck is an important factor on improving the sortie rates of aircrafts. Based on the key process of the sortie of deck-based aircrafts, the main research directions in the field of the scheduling of carrier-based aircrafts are summarized, which are the path planning and collision detection of carrier-based aircrafts, the integrated scheduling method of carrier-based aircraft fleets, and the coordinated scheduling strategies of carrier-based aircrafts. Then, the researches of carrier-based aircrafts dispatch system are introduced. The progress and shortcomings of the existing research results were pointed out, also, the feasible development directions in the future are proposed, which provides a reference for the research on the scheduling of aircrafts on flight deck.

Keywords: Carrier-based aircrafts; deck scheduling; path planning; collision detection; collaborative strategy.

1. Introduction

As the carrier of aircrafts, the scale and operation level of carrier-based aircraft reflect the combat capability of the aircraft carrier. In view of the narrow space of deck of the aircraft carrier and the complicated factors such as carrier-based aircrafts, equipment, personnel, and materials, which occupy a large amount of deck area, tasks of take-off and recovery further reduce the area available for carrier-based aircraft dispatch. Simultaneously, efficiently scheduling the carrier-based aircrafts in a limited space and optimizing the fleet's dispatch time are the key factors to ensure the combat effectiveness of aircraft carriers [1]. Therefore, a reasonable arrangement of the dispatch and transfer plan of the carrier-based aircraft on the deck is of great significance for improving the dispatching capability of the carrier-based aircraft [2] and improving the working efficiency of the aircraft carrier deck.

The activities of the carrier-based aircraft on the flight deck include taking-off of the carrier-based aircraft, landing and recovering, allocating parking space, operation, and access to the hangar. The deck deployment process in this article specifically refers to [3]: After the flight plan is issued, guaranteed aircraft in the carrier-based aircraft fleets on the flight deck taxis or tows to the designated catapult from the initial position then takes off and leaves the ship according to a certain timing plan. In view of the proposed carrier-based aircraft deployment process on deck, we divide the main content of the current research into the following three aspects: one is the research on the path planning and collision detection of the carrier-based aircraft, and the second is the overall deployment method of the carrier-based aircraft fleet, the third is to consider the method and strategy of multi-carrier-based aircraft coordinated transportation. Consequently, the introduction and arrangement of the existing research results provides reference for the future research of aircraft carrier deck scheduling.
2. Path Planning and Collision Detection Methods for Scheduling of Carrier-based Aircraft

2.1. Path Planning Method for Scheduling of Carrier-based Aircraft

There are many studies on the path planning and collision detection of carrier-based aircraft in the current research of deck dispatching. The commonly used deck path planning methods for carrier-based aircraft are mainly divided into two categories which are global path planning and local path planning [4]. Global path planning requires priori information of the specified environment where the obstacles are known in the process of the path planning. Therefore, global path planning is often called static path planning generally tending to plan the best path, including heuristic search algorithm (A* algorithm, Dijkstra algorithm), intelligent algorithm (particle swarm optimization algorithm (PSO), ant colony algorithm (ACO) [4], genetic algorithm (PA), tabu search algorithm (TS), Neural network algorithm [5]) and reinforcement learning algorithm. Local path planning algorithms are usually used in dynamic environment that contains moving obstacles, which is the so-called dynamic path planning, most of which use artificial potential field method (APF). The local path planning algorithm has high reliability and does not depend on the prior information of the environment and the shape of obstacles, where it is easy to fall into the local optimal solution.

Figure 1. Classification of path planning method on deck.

There are generally two ways to use global path planning to solve path planning model on deck. One is to initially set up intermediate nodes or environmental road maps with known starting points, then optimize the parameters of the intermediate node or path segments through intelligent optimization algorithm, finally solve feasible paths by establishing dynamic constraints of obstacles and environmental constraints. The second is to find the optimal path nodes through the heuristic search method, then solve the feasible path according to dynamics and environmental constraints.

For the first method, different optimization algorithms and prior knowledge have been applied in studies. For example, Yang Bingheng et al. [6] designed a transportation network model when multiple dispatching tasks needed to be carried out at the same time in the narrow environment on the deck. Through the misalignment in time of different steps, the dispatching operation path was selected to obtain the overall dispatching time of multiple tasks is optimal.

The method of path planning by optimizing intermediate path nodes has been widely used in the research of path planning on deck. Xiong Hua et al. [7] used GA algorithm to find the best feasible path by means of optimizing intermediate node. Su Xichao et al. [8] combined expert experience with intelligent optimization algorithms to perform intelligent optimization by way of manually setting three intermediate initial nodes, taking models of traction and taxiing into consideration, Han Wei et al. [9] also established a mathematical model of the multi-path dynamic planning problem for the carrier-based aircrafts, the number of intermediate nodes being determined by comprehensively considering the starting point and ending point of the path and the length of the path segment, owing to the little time consumed in PSO algorithm, the overall planning was considered to be capable of dynamic planning.

Zhang Zhi et al. [10] proposed a genetic collision avoidance planning algorithm with kinematic constraints, that is, designed targeted hybrid encoding of three-dimensional position and posture based on the traditional genetic path planning algorithm, at the same time, penalty items and repair strategies and three-segment path decoding were introduced in genetic operations to assist the optimizing algorithm, as the purpose of uniquely restore the continuous motion path based on the intermediate path point sequence for the path planning problem of irregular targets in complex environments. Focused on
the selection of the number of path nodes, the choose of optimization algorithms, and the completeness of the generated path, most researches could expertly generate feasible paths under the condition of known environmental obstacles and starting points, making a contribution in the field of path planning on deck.

Modeling the environmental road map to achieve the optimal combination path is also a common research method. Li Xiaojie et al. [11] geometrically model the dispatching environment and dispatching entities of carrier-based aircraft used a Voronoi diagram-based path network, then the route network diagram was obtained through the Voronoi diagram and weights were assigned. On the basis of the candidate dispatching path intelligent optimization algorithm was adopted to detect and calculate whether the steering region overlaps with the obstacle. Zhang Tianhe et al. [12] improved Voronoi diagrams with different weights contrary to different threat levels of obstacles, then ant colony algorithm was employed to solve question. Zhang Jing et al. [13] used geometric shapes to design a search area for path planning with the maneuverability constraints, obstacle avoidance and mission requirements of the carrier-based aircraft fully into consideration. Then the optimal path was obtained based on the Dijkstra algorithm. Si Weichao et al. [14] studied the outbound scheduling optimization problem of carrier-based aircraft multi-machine, and improved the original crossover and mutation strategies to ingratiate the model of multi-machine outbound scheduling problem of carrier-based aircraft, then the general view algorithm of the path detection and planning was assimilate, that is, the path planning problem was converted into the convex hull problem of solving obstacles. Then the initial path formed by the convex hull was optimized to obtain all collision-free paths in turn. In order to obtain the optimal taxiing trajectory, Wu Yu et al. [15] established a mathematical model including the ground motion model of the carrier aircraft, collision detection strategies and constraint conditions, as well as proposing a general method to convert the trajectory optimization problem into a control variable optimization problem, which is solved by the chicken group algorithm. In general, the research on planning path through the environmental road map mainly concentrated on finding the method of constructing the environmental geometric model containing obstacles and searching for feasible solutions according to the optimization strategy from the perspective of the above research. On the basis of obtaining the feasible path, the smoothness of the path could be further optimized.

For the second method, the most frequent heuristic search algorithm is A* algorithm and Dijkstra algorithm, while they are different on the basis of heuristic search, among them the Dijkstra algorithm can be regarded as breadth first search, while A* can be regarded as Depth first search. Zhang Jing et al. [16] established the path planning of the traction system composed of aircraft and the tractor in the deck environment, then the optimal path search method was designed based on the geometric theory and the Dijkstra algorithm, on this basis of which the trajectory tracking control algorithm of implicated motion. With behavioural dynamics method introduced to realize the collision avoidance path planning of the traction system. Good results have been obtained through simulation. Si Weichao et al. [17] also expand the boundary line of obstacle polygons according to the buffer distance then the path directed graph was found in the case of obstacles according to the convex hull algorithm, consequently the shortest path was solved according to the Dijkstra algorithm. Wu Yu et al. [18] designed an improved A* algorithm, introducing the idea of model predictive control into the A* algorithm to dynamically select the weight function according to the distance from the current node to the target node. At the same time, a dynamic multi-step optimization algorithm was proposed, namely according to the relationship between the carrier-based aircraft and obstacles. Then the direction of movement of the carrier-based aircraft can be changed in advance, optimizing the path from the starting point to the catapult and predicting the trajectory of carrier-based aircraft to avoid collision, so aircrafts could reach the target point in a short distance and planning efficiency could be improved. Li Yongtao et al. [19] used the rolling optimization method to optimize the established path tracking performance indicators when generating the taxi path. While the heuristic search algorithm has been widely used in the field of ship surface path planning and has achieved good results, the A* algorithm can be appropriately modified as needed to improve the calculation efficiency of path planning.

Recently, the adoption of multi-agent reinforcement learning methods in path planning has also attracted much attention. Zhang Pengyi et al. [20] used multi-agents for the path planning of ship-based aircraft fleets, abstracted the regular hexagonal spatial discrete grid model as a spatial agent, and represented
the environment through the location, state, and neighbours of the agent, and adopted the basis model with the improved A* algorithm for path planning. At present, the multi-agent path planning method has not been widely used in the field of ship surface dispatch, and it is a feasible research direction in the future.

When the environmental information is completely unknown or partially known, local path planning is performed, which is a dynamic path planning. Because of the focuses on improving real-time obstacle avoidance capabilities and the lack of global environmental information, the planning results may not be optimal, or even the correct path or the complete path may not be found, so it is less used in path planning on deck. In the field of path planning, artificial potential field method is often used for local path planning. The artificial potential field method does not plan the space in the form of graphics, but regards the movement of objects as the result of the action of "force" and "gravity", abstracting the path planning problem into a composite problem in mechanics, that is, under the action of repulsive force, the behaviour of avoiding obstacles and tending to the target point happened for the moving object is in gravity. On the artificial potential field problem, Barraquand [21] et al. used discretization space and meta-graph method to solve the skeleton diagram based on the Cartesian coordinate space from the distance of the dangerous area, thus avoiding the local extreme value problem. In addition, Connly and Akiskita [22] applied the circumfluence phenomenon in fluid mechanics to the artificial potential field method, successfully solving local extremum problem. Yang Kai et al. [23] integrated the Euclidean distance between the mobile robot and the target point into the objective function, then the mathematical relationship was established according to the position of the mobile robot, the maximum influence distance of obstacles, and the Euclidean distance between the mobile robot and the target point. Since virtual target points have been found, the local minimum problem when the resultant force received in the process of moving of mobile robots will get solved. As the global algorithm has optimality in the process of planning path, the path smoothness is low and there are many inflection points. In contrast, the local algorithm has high path smoothness, while the planning path may not be optimal. Therefore, combining global and local algorithm for path planning on deck could make the movement path of the carrier aircraft better, for example, the global algorithm could be used in path nodes planning, while the local algorithm could be adopted in path generation.

Generally speaking, the global path planning algorithm has been widely in the path planning on deck. When the environmental information and obstacle movement are known, the environmental road map or heuristic algorithm can be used to obtain path planning results successful. However, due to the poor real-time performance, it is difficult to obtain satisfactory results in the unknown environment with pop-up obstacles; some studies use multi-agent reinforcement learning methods in path planning, considering the mutual influence of aircrafts. This method improves the independence of the planned path and has a wide range of application prospects. However, a large amount of information exchange is required in multi-agent collaborative path planning, which could easily lead to excessive calculations, resulting in low search efficiency and problems of local optimization; although local path planning algorithm has good applicability in dealing with dynamic environments, the possible missing of the optimal solution leads to the poor application on deck; on the basis of path planning, part of researches [24] converted the path planning problem into the solution of the optimal control problem, making the planned path more suitable for the actual movement path of the carrier-based aircraft. Dynamic environments could be successfully dealt with this method but the solution speed is low. In general, Since the relatively high degree of maturity of research in the field of ship surface path planning, more accurate modeling and a combination of local and global algorithms can be considered in future research.

2.2. Collision Detection Method for Dispatch of Carrier-based Aircrafts

The collision detection method of carrier aircraft dispatching is usually combined with the path planning method, which usually starts with the perspective of two-dimensional detection at present. Two types could be generally divided in the two-dimensional collision detection algorithms: one is to calculate whether the carrier-based aircraft collides with the outer line of the obstacle through geometric methods; the other is to simplify the carrier-based aircraft to a mass point and to expand the boundary of the obstacle simultaneously, then the process of calculating whether the carrier is within the obstacle area could be carried out.
In the aspect of two-dimensional collision detection, part of the researches focuses on the determination conditions of collision detection through geometric methods. Zhang Zhi et al. [25] introduced polygonal line segment sets to represent carrier aircrafts under the extended and retracted wings, as well as deriving the calculation method of shortest distance between the line segments for collision detection. Wang Yunxiang [26] designed a side-line detection method when the collision happened, that is, to determine the collision result by calculating the distance between the centre line of the path and obstacles. Another part hands on expanding the boundary of obstacles in collision detection. Wu Yu et al. [27] simplified the shape of a single carrier-based aircraft into a circle, with the carrier-based aircraft group and obstacles simplified into rectangles and polygons respectively. It could be judged whether a collision occurred by the method of expanding area, which was extending the radius of the A characteristic circles representing the shape of carrier aircrafts to the characteristic rectangle representing obstacles. Liu Yajie et al. [28] also expanded the boundary line of the obstacle polygon according to the buffer distance, then continuously optimized the path segment according to the line between the start point and the end point and the convex hull model of the obstacle, which would be fitted the as arc segment according to the data interpolation method. Finally, safety detection the collision detection algorithm based on grid overlay analysis method would be conduct. Zheng Yue et al. [29] extended the traditional collision detection method in connection with the complex-shaped carrier-based aircrafts based on the trajectory bounding box. The entire area swept by the motion of the object would be regarded as a bounding box, thus the collision detection could be completed when each path segment and its corresponding bounding box have been traversed.

In general, the research on the two-dimensional collision detection on deck mainly relies on the research of path planning. Since the simplified shape of the collision detection model is continuously accurate as the research progresses, collisions could be identified quickly according to the simplified model and the efficiency of path planning could get improved.

In terms of three-dimensional collision detection, Zhang Puchuan et al. [30] established three-dimensional collision detection method using the OBB hierarchical bounding box tree and octree method. Combined with the two-dimensional collision detection method, the accuracy of the entire detection process was improved. Compared with the two-dimensional detection, the research on the three-dimensional collision detection on deck is off the beaten track, provided with good research prospect. Since carrier-based aircrafts are usually transported on deck, two-dimensional collision detection is frequently used, which could basically meet accuracy requirements of transportation on deck in engineering, and it also has a high degree of accuracy. However, due to the complexity of the objects on deck, it cannot solve the situation where obstacles are under the wing. The following table shows the difference between 3D and 2D methods of collision detection.

| Calculation speed | Calculation accuracy | Model complexity |
|-------------------|----------------------|-----------------|
| 2D                | high                 | medium          |
| 3D                | medium               | high            |

In order to improve the accuracy of collision detection on deck, combining two-dimensional collision detection and three-dimensional collision detection could be considered in future research, which improve the accuracy and efficiency of research.

3. Research on the Fleet Allocation Method of Carrier-based Aircraft

In the research on the dispatching method of the carrier-based aircraft fleet, research generally focuses on formulating the overall optimization plan of a series of process such as taxiing or towing to the designated catapult according to a certain timing plan, preparation, taking off of the guaranteed carrier-based aircraft fleet and cooling of the catapult after the flight plan is issued, covering two levels of the allocation of scheduling target points [31] and the optimization of the overall scheduling path. Li Xiaojie et al. [32] borrowed the logistics location method to solve the problem of path planning in carrier-based aircraft dispatch operations. By setting dispatch nodes on the flight deck, the problem of
path planning in two-dimensional plane was transformed into the shortest path finding in graph theory. Then the state transition diagram was adopted to control the sequence of multi-aircrafts dispatching to optimize the dispatching time of the fleet from the start point to the target point. Li Qian et al. [33] studied the take-off route planning and take-off scheduling of carrier-based aircraft, and used the principle of simulated annealing to construct a parallel time scheduling scheme for the carrier-based fleet from the initial station to the fixed parking position. Simultaneously, a priority-based dynamic scheduling strategy and the dynamic scheduling strategy based on speed adjustment have been designed to solve the collision and conflict problem of the dispatch queue. In order to improve the fleet dispatch rate, Wu Yu et al. [27] designed the task layer, sequence layer, and path layer of the fleet to optimize the dispatch time of the fleet. The A* algorithm was carried out to plan the offline path for multiple aircrafts and the actual motion model of the carrier aircraft model was used to track the planned path in the path layer, while the time cost function was established to determine the take-off timing scheme during the scheduling process of the carrier-based aircrafts in the timing layer. It could be found that many studies start with the scheduling process of carrier-based aircraft fleet, combining method strategy adjustment and timing allocation to optimize the fleet deployment time.

Part of the studies comprehensively considered the process of target point allocation and path planning, the result of which path planning was regarded as cost item to arrange the allocation of catapult. Si Weichao et al. [34] also optimized the dispatch timing of carrier-based aircraft at different parking positions using the HPSO algorithm based on multiple group cooperation mechanisms, so that the movement distance of aircraft fleet on deck was as short as possible while the overall fleet dispatch time is as short as possible. By comparing with the PSO particle swarm optimization algorithm, the superiority of the HPSO algorithm was demonstrated and the best scheduling scheme is obtained. In addition, considering research programs in other fields, using reinforcement learning [35] and neural network algorithms [36] to optimize the solution made the carrier aircraft system more intelligent, autonomous, capable to learn obstacle avoidance and approach goals and adapt to different environmental scenarios with the target point used as the reward function, which is a feasible research direction.

On this basis, some studies considered integrated solution of the dispatch priority of carrier-based aircrafts and the allocation process from the parking space to the catapult, ensuring the completeness of the process of dispatching on deck. Zhang Puchuan et al. [30] comprehensively considered the dispatch priority of the carrier-based aircraft, the allocation of the carrier-based aircraft dispatched to the catapult, the preparation of the catapult, the take-off of the catapult, etc., and fully optimized the overall process of dispatching and transportation on deck combining the genetic algorithm and simulated annealing algorithm, obtaining a good scheduling plan.

The above research established the carrier-based aircraft fleet deployment model with the different constraints of the optimization problem. With the deepening of the understanding of the problem of fleet deployment, the accuracy of the model has gradually improved. The integrity of research and the transform from the partial optimization to the overall optimization of the overall process of carrier-based fleet dispatching should be taken into consideration in the field of carrier-based aircraft scheduling on deck.

4. Cooperative Taxi Strategy of Carrier-based Aircrafts
The main content of multi-carrier aircraft cooperative taxiing is to plan the taxi path of the carrier aircraft on deck and consider the interaction between other aircrafts moving at the same time, so that multiple carrier-based aircrafts can complete the taxing task from the starting point to the target place quickly and efficiently. Since most research on multi-aircraft taxiing strategy is carried out accompanying with path planning, the taxiing strategy can be divided into two categories: the waiting strategy after the collision happened according to the priority sequence of the carrier fleet and the adjustments of dispatching timing to resolve conflicts.

He Shaohua et al. [38] designed to check whether the candidate nodes collide with other carrier aircrafts while expanding the path nodes at each step so as to achieve the safety of multi-plane taxiing on deck. Gao Jie et al. [39] used the “three-stage” and “two-stage” methods to generate the path of the carrier-based aircraft, then used the evaluation model to assess the pros and cons of the path based on the length
and stability. After the potential collision areas based on the collision detection algorithm during the movement of the carrier aircraft, the mixed integer nonlinear programming would be conduct to make aircrafts with higher priority first pass the collision area, achieving feasible optimization under the constraints. Wang Guoqing et al. [40] first planned the dispatch path from the carrier-based aircraft to every take-off position and used genetic algorithm to generate the static optimal scheduling sequence of carrier-based aircrafts; then introduced priority scheduling strategies to select the most forward carrier-based aircraft from the carrier-based aircraft queue allocated to the same catapult, thus the path would be re-planned when a collision had been detected. The research about cooperative taxiing strategies based on path planning mostly adopt methods such as adjusting the dispatch sequence or waiting halfway according to the collision detection situation, that is, following the path planning-collision detection-avoidance solution circuit. It is hardly difficult to see there is a lack of the coordination planning of carrier fleet above researches proposed.

In order to reflect the collaboration of path planning of multi-carrier aircrafts, multi-agent system [41] was widely employed to carry out collaborative path planning in the field of path planning. Wang Yiran et al. [42] adopt a multi-agent path planning method based on reinforcement learning, where the Q learning method of joint state and action set was introduced to avoid adopting adjustment strategies. On this basis, Liu Hui et al. [43] recommended the concept of maximum return frequency to avoid the dimensional explosion that behaviours action sets brought out. At present, the multi-agent reinforcement learning method is still in its infancy in the coordinated path planning of the carrier-based carrier fleet, and the communication between multi-carrier aircrafts has not been studied in depth. Using methods such as waiting strategy or adjusting dispatch sequence for multi-agent cooperative path planning has high speed, but the strategy update rate is lower when obstacles environment is dynamic and the real-time performance is poor; the collaborative information exchange between multi-agent systems could improve the robustness of the path planning for aircrafts, but the amount of calculation is huge for a large number of fleets. Simultaneously, it is easy to fall into the local optimum and the convergence and rapidity are poor.

5. Dispatch System Design on Deck
The aforementioned path planning and collision detection of carrier-based aircraft, the overall deployment method of the aircraft fleet, and the method of coordinated deployment of aircrafts, etc. mostly focused on one aspect in the process of deployment. Part of researchers carried out the integrated application design of the integrated information system including the transportation system and other stages on deck, in order to practice the automation of the transportation system.
MIT’s Ryan et al. [44-45] developed an auxiliary flight deck management software called Deck Operation Course of Action Planner (DCAP), as well as studying inverse reinforcement learning methods and the strategy optimization based on queuing network, which was applied in multi-stage scheduling problem of carrier-based aircraft. Finally, the optimization algorithm based on the linear integer programming model was compared with the traditional expert heuristic rules on the scheduling performance, both of which had been tried and tested on the Nimitz-class aircraft carrier. Zhang Zhi et al. [46] introduced the operator experience into the autonomous planning algorithm, developed an improved Aircraft Carrier Deck Operation Planner (ACDOP) system, where the reference path points of models, the timing allocation of tasks, resource allocation, and periodic commands were all predetermined by the operator. Collision detection, path planning, task logic constraints and automatic personnel scheduling were completed through algorithms, thus the timing and path constraints have been greatly improved.

6. Conclusion
The scheduling research of carrier-based aircraft on flight deck is an important part of improving the capabilities of dispatch and recovery of the carrier-based aircraft fleet. Focusing on the transportation process and research methods, three aspects of research status and future prospects have been given below:
1) In the research on path planning and collision detection of aircrafts on flight deck, the research on path planning under conditions of known environmental information and movement of obstacles haven
been relatively mature, the problem under complex dynamic constraints and combining the rapidity of two-dimensional collision detection with the accuracy of three-dimensional collision detection is a feasible research direction.

2) In the research of the overall dispatching method of carrier-based aircraft fleet, seeking optimization performance on fields of allocating aircrafts to catapults and optimizing path length (or scheduling time) are hot topics, which has been fully studied and satisfactory results can be obtained. however, how to achieving the global optimization solution of the whole process of aircraft fleet dispatching is a problem that needs to be solved urgently.

3) In terms of the strategy research of carrier-based aircraft coordinated dispatch, the coordination, intelligence and dynamics of taxiing of multi-carrier aircraft on flight deck needs to be considered in the future, so as to improve the robustness and efficiency of dispatch of carrier-based aircrafts on deck and achieve the fully intelligent operation of dispatching.

References

[1] Liu X C, Lu J and Huang X Z 2011 Analysis on the Index System of Sortie Generation Capacity of Embarked Aircrafts (Chinese Journal of Ship Research vol 6) chapter 4 p 1

[2] Zhou X G, Zhao R H, Wang S Y, He J 2014 Research on Influence of Flight Deck Operation Exerts upon Sortie Generation of Carrier-Based Aircraft (Journal of System Simulation vol 26) chapter 10 p 2447

[3] Bai J Y 2018 Research and Simulation on Dynamic Path Planning for Deck Operators Based on Behavioral Decomposition Algorithm (Harbin: Harbin Engineering University)

[4] Liu J 2018 Research on Obstacle Avoidance and Path Planning for Mobile Robots Based on Optimized Hybrid Ant Colony Algorithm (Chongqing: Chongqing University of Posts and Telecommunications)

[5] Shiri H, Park J, Bennis M 2020 Wireless Communications Letters vol 9 (Piscataway: IEEE) chapter 6 PP 1-1

[6] Yang B H, Han F, Wang H D 2012 Research on aircraft handling workflow path (Ship Science and Technology vol 34) chapter 8 p 141

[7] Xiong H, Qi Y D, Si W C, Cui J 2014 Carrier Moving Path Planning Based on GA (Value Engineering vol 7) p 35

[8] Su X C, Li Z Y, Song J Y, Wang L G 2018 IOP Conf. Series on Materials Science and Engineering p 381

[9] Han W, Si W C, Ding D C 2013 Multi-routes dynamic planning on deck of carrier plane based on clustering PSO (Journal of Beijing University of Aeronautics and Astronautics vol 39) chapter 5 p 610

[10] Zhang Z, Li S L, Xiao G H, Zhu Q D 2014 (Journal of Harbin Engineering University vol 35) chapter 1 p 9

[11] Li X J, Xie J 2016 Path Planning of Carrier-borne Aircrafts on Flight Deck Motion Schedule Based on Assign Weights Voronoi Diagram (Ship Electronic Engineering vol 36) chapter 8 p 42

[12] Zhang T H, Peng S X, Luo Y M, Wang C C 2017 Analysis of obstacle avoidance route of carrier based on ant colony algorithm: submitted to Ordnance Industry Automation (Ordance Industry Automation vol 36) chapter 10 p 71

[13] Zhang J, Yu J, Qu X J, Wu Y 2017 3rd IEEE International Conference on Control Science and Systems Engineering p115

[14] Si W C, Qi Y D, Han W 2015 Hangar-exporting Optimization Schedule of Multi- carrier Plane Based on NGA (Fire Control and Command Control vol 40) chapter 11 p 13

[15] Wu Y, Hu N, Qu X J 2018 A general trajectory optimization method for aircraft taxiing on flight deck of carrier (Journal of Aerospace Engineering vol 233) chapter 4 pp 1340-1353

[16] Zhang J, Wu Y, Qu X J 2018 Path planning method for traction system on carrier aircraft (Journal of Beijing University of Aeronautics and Astronautics vol 44) chapter 10 p 2125

[17] Si W C, Qi Y D, Han W 2015 Carrier plane transportation in hanger based on convex hull algorithm combined with Dijkstra (Systems Engineering and Electronics vol 37) chapter 3 p 583
[18] Wu Y, Qu X J 2013 Path planning for taxi of carrier aircraft launching (Science China Technological Sciences vol 56) chapter 6 pp 1561-1570
[19] Li Y T, Wu Y, Su X C 2018 Path Planning for Aircraft Fleet Launching on the Flight Deck of Carriers, Mathematics (Mathematics vol 6) p 175
[20] Zhang P Y, Huang B Q 2019 Carrier Aircraft Group Scheduling Path Planning Based on Space Agent (Journal of Ordnance Equipment Engineering vol 41) chapter 3 p 106
[21] Ngo V, Viet N Y, Lee S G 2008 International Conference on Advances in Computer Human Interaction pp 704-713
[22] Lu W, Camino F M, Bou K A 2005 Digital Avionics Systems Conference p 2155
[23] Zhang Y J, Li H L 2017 Research on mobile robot path planning method based on improved artificial potential field (Modern Electronics Technique vol 3) p 135
[24] Liu J, Han W, Liu C, Peng H J 2018 A new method for the optimal control problem of path planning for unmanned ground systems (Modern Electronics Technique vol 6) pp 1-1
[25] Zhang Z, Lin S L, Xia G H, Zhu Q D 2014 Collision avoidance path planning for an aircraft in scheduling process on deck (Journal of Harbin Engineering University vol 35) chapter 1 p 9
[26] Wang Y X, Wang H D, Yang M S, Fan J L 2020 Shipborne aircraft deck transit route optimization based on collision detection (Command Control and Simulation vol 42) chapter 1 p 58
[27] Wu Y, Qu X J 2013 Path planning for taxi of carrier aircraft launching (Science China Technological Sciences vol 56) chapter 6 pp 1561-1570
[28] Liu Y J, Li Z M, Shan C X 2015 Path planning for transferring shipborne aircraft restricted to hangar space (Fire Control and Command Control vol 40) chapter 9 p 152
[29] Zheng Y, Zhang Z, Xia G 2015 The 27th Chinese Control and Decision Conference (Piscataway: IEEE) p 3408
[30] Zhang P C 2019 Research and Simulation of Multi-Carrier Aircraft Dispatching on Aircraft Carrier Deck (Beijing: Beihang University)
[31] Zhang Z Y, Gong S Y, Xu D, Meng Y L 2019 Research on multi-robot task assignment and path planning algorithm (Journal of Harbin Engineering University vol 40) chapter 10 p 1753
[32] Xiao J L, Jun X, Bing F U 2017 An Application of the Logistics Center Location to the Carrier-borne Aircrafts Transportation on Flight Deck (Command Control and Simulation vol 39) chapter 2 p 129
[33] Li Q 2009 Reasearch on path planning, scheduling and simulation of airplane (Harbin: Harbin Engineering University)
[34] Si W C, Han W, Song Y, Shi W W 2013 Takeoff scheduling of carrier plane based on multi-colonies cooperation and CLS intelligence algorithm (Application Research of Computers vol 30) chapter 2 p 454
[35] Moon S, Oh E, Shim D H 2013 An Integral Framework of Task Assignment and Path Planning for Multiple Unmanned Aerial Vehicles in Dynamic Environments Journal of Intelligent and Robotic Systems vol 70 (Netherlands: Spring) pp 1-4
[36] Qie H, Shi D, Shen T 2019 Joint Optimization of Multi-UAV Target Assignment and Path Planning Based on Multi-Agent Reinforcement Learning (IEEE Access vol 7) pp 146264-146272.
[37] Liu J, Han W, Li J 2020 Integration Design of Sortie Scheduling for Carrier Aircrafts Based on Hybrid Flexible Flowshop (IEEE System Journal vol 14) chapter 1 pp 1503-1511
[38] Shaohua H E, Shiwei Y, Jingwei X U 2019 Path Designing for Aircrafts’ Taxiing on Flight Deck while Launching (Journal of Naval Aeronautical and Astronautical University vol 34) chapter 1 p 126
[39] Gao J, Zhao H D, Hu C J 2018 Research on Moving Path Planning and Motion Coordination Method for Carrier-borne Aircraft on Deck (Command and Control) p 494
[40] Wang G Q 2012 Optimization method of aircraft scheduling path on deck (Harbin: Harbin Engineering University)
[41] Ming L 2012 Decentralized multi-agent based cooperative path planning for multi-UAVs (Computer Science vol 39) chapter 1 pp 219-222
[42] Wang Y R, Jing X C, Tian T, Sun Y Q, Cong S J 2019 Multi-agent path planning based on reinforcement learning (Computer Application and software vol 36) chapter 8 p 165
[43] Liu H, Xiao K, Wang J B 2020 Multi-agent path planning method based on multi-agent reinforcement learning (Automation and Instrumentation vol 35) chapter 2 pp 84-89
[44] Ryan J C 2011 Designing an interactive local and global decision support system for aircraft carrier deck scheduling American Institute of Aeronautics and Astronautics (St. Louis. Missouri: AIAA) p 1516
[45] Ryan J C 2011 Assessing the performance of human-automation collaborative planning systems (Massachusetts Institute of Technology)
[46] Zhang Z, Lin S L, Dong R 2013 Designing a human-computer cooperation decision planning system for aircraft carrier deck scheduling American Institute of Aeronautics and Astronautics (St. Louis. Missouri: AIAA) p 1111