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Researches on the Coordinated Rescue of Multi-helicopters Based on Feasibility Matrix and Track Planning

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***Abstract*—the multi-objective distribution of multi-helicopter based on the feasibility matrix was proposed in this paper, which enhanced the effectiveness of aviation emergency rescue. The horizontal track planning of helicopters was put forward based on the morphology graphic process technology and heuristic A* search algorithm, which can obtain the feasible shortest flight path with the condition of safety separation. Therefore, the plans were formed and the aviation emergency rescue auxiliary system was developed, which can improve the efficiency and safety through preflight preparation.**

Keywords- Feasibility; Morphology; Track Programming

I. INTRODUCTION

In the event that some major disasters happen, aviation emergency rescue based on utility of helicopters, owing to the advantages of rapidity, high efficiency and relative less limits to geography and space, is able to reach the most devastating areas and carry out tasks such as investigation, casualty and material transportation, which has crucial significance to reduce losses of life and property. However, there is no law or regulations on Aviation Rescue Operation and no emergency rescue plan at present, the efficiency of rescue is low while the security cannot be guaranteed. Taking the 5.12 Earthquake happened in Wen Chuan of China as an example; Chinese Civil Aviation Administrative Bureau assembled 31 civil aviation helicopters to carry out the rescue mission. Due to a shortage of information about the disaster-affected area and scarce of aviation intelligence on one hand, and the pilots' unfamiliarity to terrain and meteorological information and unawareness to the damage on the other hand, the efficiency and security of primary stage were significantly affected. So the preflight preparation is of critical importance to the implementation of emergency aviation rescue missions when natural disasters happen, while rescue route planning is the core issue to the preflight preparation. Therefore, as a prerequisite to ensure the security of aviation, to make out the shortest feasible flight route rapidly will greatly reduce the losses of the disaster-affected areas. How to allocate helicopters to disaster-affected areas reasonably, and how to program a round route and then formulate a plan for emergency aviation rescue, are the key points to improve the efficiency and security of emergency aviation rescue.

The essence of coordination of multi-helicopters is an issue of allocation and dispatching of resources, whose purpose is to accomplish the mission at the minimum cost. Common algorithms include the genetic algorithm, the ant colony algorithm, and the simulated annealing algorithm. Route planning refers to seek an optimal moving track from the initial point to the target point while meeting specific performance index under the restriction of specific condition. The research work on route planning focus on the military fields in China, including military pilotless aircraft, cruise missile, movable robot, etc.. The nature of route planning lies in the search of route, and commonly used algorithms include the approach based on the skeleton diagram and approach based on unit decomposition. The former one is commonly used in planar track programming which has low requirements on real time effectiveness; while the precision of later one is closely related to the precision of unit grid, thus the calculation volume of high precision will be huge and more time will be consumed. Some foreign scholars argued that dynamic programming and 0-1 programming (BIP) algorithm can be used to address the problems of three dimensional tracks, which can avoid getting in partial optimism.

The features of route planning method and allocation algorithm for multi-objects were researched in this paper. Based on the character that multi-helicopters are needed to complete different rescue missions jointly in case of disasters, we analyzed different types of rescue missions, the performances of helicopters, and the meteorological and geographical features of disaster areas deeply, and put forward the algorithm of coordinated rescue of multi-helicopter based on the feasibility matrix of rescue missions, which is supposed to allocate helicopters to disaster stricken areas rationally and enhance the overall effectiveness of emergency aviation rescue. The algorithm of horizontal route planning for helicopter was put forward based on morphology image processing and heuristic search algorithm, we tried to find a solution through the diversion of three-dimensional route search algorithm into several horizontal route search issues on certain altitude and then seek for the feasible minimum flight path under the prerequisite to meet the safe interval, so as to form a rescue plan in case of emergency when major disasters happen and ensure the security of emergency rescue.

II. DISTRIBUTION OF MULTI-HELICOPTERS BASED ON FEASIBILITY MATRIX

A. Feasibility analysis

The feasibility is the feasible degree of a helicopter to carry out a rescue mission. The higher the value is, the more suitable for the helicopter to carry out the mission. We proposed that evaluating the feasibility of the rescue mission to get the feasibility matrix between multi-helicopters and multi-targets, based on which helicopters can be allocated and dispatched reasonably.

The evaluation of feasibility for aviation rescue missions always involves the following factors: the distance between the target point and the command center, the ceiling of helicopters, the clearance environment and terrain environment of the disaster areas, the type of mission and its emergency degree, etc. The quantitative factors in the evaluation of feasibility can be evaluated by the quantitative methods based on threshold value, while the qualitative factors can be assessed by ambiguous comprehensive assessment method, then weight the evaluated value of feasibility of each factor, and obtained the weight of each factor by Delphi Method as table 1. Finally, linear sum up the total value to get the feasibility value c_{ij} for a helicopter to carry out a specific rescue mission, and then get the matrix $C=(c_{ij})_{n\times m}$ through two cycles.

$$c_{ij}=\sum_{k=1,2,3,4,5}\omega_k f_k \qquad (1)$$

Where the c_{ij} stands for the feasibility for aircraft i to carry out the mission at the disaster area j, and c_{ij} can be calculated by formula (1), while ω_k stands for the weight of the factor, and f_k stands for the feasibility of factor k.

TABLE I. THE WEIGHT OF FACTORS THAT AFFECT FEASIBILITY

Factors	Distance	Altitude	Clearance environment	Terrain environment	Mission type
Weight ω_k	0.25	0.25	0.2	0.2	0.1

B. Distribution

The essence of the coordination of multi-helicopters is a problem of allocation and dispatching of resources, whose purpose is to accomplish the mission at the minimum cost. The designation issue of the inequality between the number of helicopters and target points is supposed be diverted to balanced designation by adopting virtual variables, and address it by using the Hungarian algorithm.

In the issue of balanced designation, each element in any row (line) of the matrix C subtract the minimum element in that row (line), then we can get a new matrix called C^*; and the optimal solution of matrix C^* is the same as that of feasibility matrix C of the original matrix. The Hungarian algorithm, through equivalent substitution, finds a new matrix that is equivalent to the original feasibility matrix, making the 0 element exists in different rows and lines of the new matrix; then set the elements of the solution matrix at corresponding positions as 1, and other elements as 0, then the optimal solution to the balanced designation can be obtained.

In case the number of helicopter is different from target points (n<m or n>m), that is the feasibility matrix is not a square matrix, then the matrix C can be compensated to a square matrix (for example, if $n<m$, add $m-n$ rows 0 elements in C, then we get the matrix $Q=\left|\frac{C}{0}\right|$, and then apply the Hungarian algorithm to Q until we get the optimal solution.

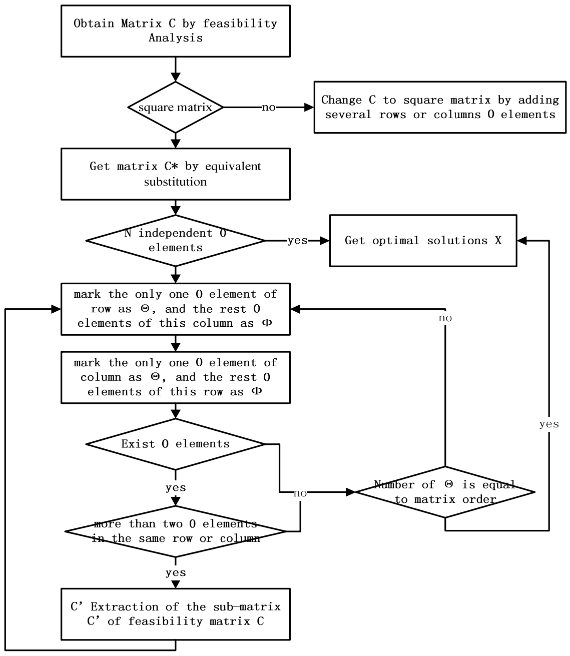

Figure 1. The flow chart of Hungarian algorithm.

C. Example Analysis

If the feasibility matrix between three helicopters and three disaster areas is C, and the equivalent matrix is C^*.

$$C=\begin{pmatrix}6&8&6\\7&7&9\\10&9&12\end{pmatrix}\rightarrow\begin{pmatrix}0&2&0\\0&0&2\\1&0&3\end{pmatrix}\rightarrow\begin{pmatrix}0&2&0\\0&0&1\\1&0&2\end{pmatrix}=C^* \qquad (2)$$

And the optimal solution can be got by using the Hungarian algorithm as follows:

$$\begin{pmatrix}\Phi&2&\otimes\\\otimes&\Phi&1\\1&\otimes&2\end{pmatrix} \qquad (3)$$

Then the corresponding relations between aircrafts and target points are as follows:

$$\begin{array}{lccc} \text{Helicopter } i & \{3 & 2 & 1\} \\ \text{Disaster area } j & \{2 & 1 & 3\} \end{array} \qquad (4)$$

If the feasibility matrix between three helicopters and three disaster areas is C, and the compensated square is Q.

$$C = \begin{pmatrix} 1 & 5 & 6 & 3 \\ 3 & 2 & 3 & 8 \end{pmatrix} \qquad (5)$$

$$Q = \begin{pmatrix} 1 & 5 & 6 & 3 \\ 3 & 2 & 3 & 8 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \rightarrow \begin{pmatrix} 0 & 4 & 5 & 2 \\ 1 & 0 & 1 & 6 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \rightarrow \begin{pmatrix} \otimes & 4 & 5 & 2 \\ 1 & \otimes & 1 & 6 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \qquad (6)$$

While the solution doesn't satisfy the optimal answers, so the Hungarian algorithm was applied to the sub-matrix and then got the following process as in (7).

$$\begin{pmatrix} 5 & 2 \\ 1 & 6 \end{pmatrix} \rightarrow \begin{pmatrix} 3 & 0 \\ 0 & 5 \end{pmatrix} \rightarrow \begin{pmatrix} 3 & \otimes \\ \otimes & 5 \end{pmatrix} \qquad (7)$$

Finally, the optimal solution of distribution can be got as：

$$\begin{array}{lcccc} \text{Helicopter } i & \{1 & 2 & 1 & 2\} \\ \text{Disaster area } j & \{1 & 2 & 4 & 3\} \end{array} \qquad (8)$$

III. TRACK PLANNING

The definition of track planning is to find the optimal motion trail of the object from the initial point to the target point under specific constraints. Track planning is an important preparation for aviation emergency rescue flight, which can greatly improve the efficiency and safety of the rescue. The binary image processing method was used to process contour digital maps in this paper, which can obtain the obstacle diagram. Then, the mathematical morphological image processing technology was used to expand the obstacle diagram, through which can exclude the unsafe areas of the white space. Moreover, the corrosion method was adopted to extract the skeleton features to get the track planning space indicated by the binary image. Finally, the heuristic track search algorithm A * algorithm was used to find out the shortest path in the two dimension flat.

A. *Obstacle Diagram*

The binary image processing method was used to transpose the contour digital map to get the obstacles diagram. The black part of figure 2 surrounded by the contour lines indicates the obstacles, while the white part indicates the security zone. Therefore, the prohibited zone, restricted zone and artificial obstacle just like pylon and high voltage wire, the equivalent contour line on the map can be added as obstacles F area in figure 2. And the meteorological condition which affects the flight can be reflected on the diagram by the same method.

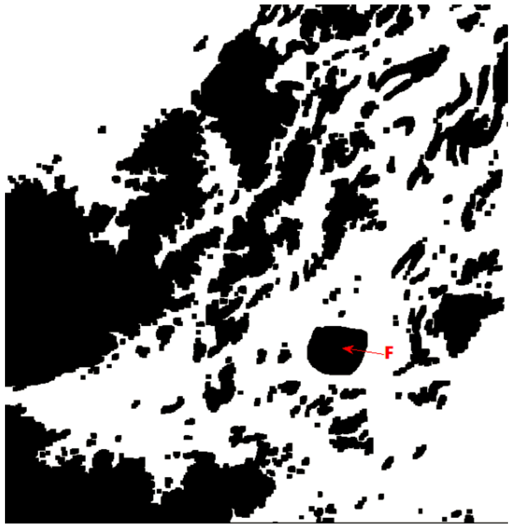

Figure 2. Obstacle diagram which was obtained from contour map.

B. *Track Solution Space*

The rescue helicopter must keep the lateral separation with obstacles and other helicopters when flying in the mountainous areas. Therefore, the method of morphological image processing called expansion was choose to compress the security zone in the obstacle diagram, so as to eliminate the area which can't satisfy the safety separation. Then, the method called skeleton feature extraction was used to get the feasible track set in the two dimensional flat as the broken line in figure 3.

In order to clearly show the relationship between feasible track and obstacle, the matrix additive method is used to get the obstacle diagram and the overlay display of the feasible flight track, and two matrixes were added in MATLAB in order to show the relationship between the feasible tracks and the terrain obstacles.

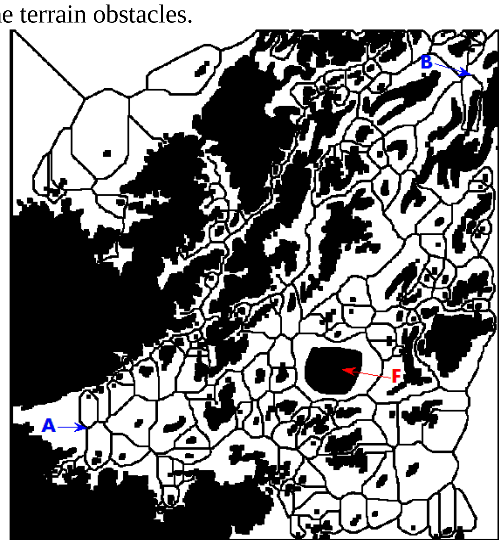

Figure 3. Feasible track and terrain obstacle.

C. Horizontal Optimal Path

The essence of track planning is a matter of path search. And the method called Dijkstra is usually adopted to figure out the shortest path in the two-dimensional plat, which can get the optimum of the shortest path. However, its efficiency is relatively low, with the time complexity of n^2. The heuristic search algorithm-A* algorithm was proposed to seek the shortest path in this paper. The formula of A* algorithm is shown as f(n) = g(n) + h(n), within which f(n) is the evaluation function about the node n from the initial to the objective point. Besides, g(n) is the actual value from the initial to the n node in the state space, and h(n) is known as the estimated value of the optimal path from node n to the objective point. As the path depicted in the chart between the starting point A and the end point B, this shortest one is able to be utilized as the anticipated flight path of rescue helicopters. In order to reveal the relationship between the charts the available flight path and obstacles clearly, the matrix of the available flight paths and obstacles were added as the figure 4 illustrated below.

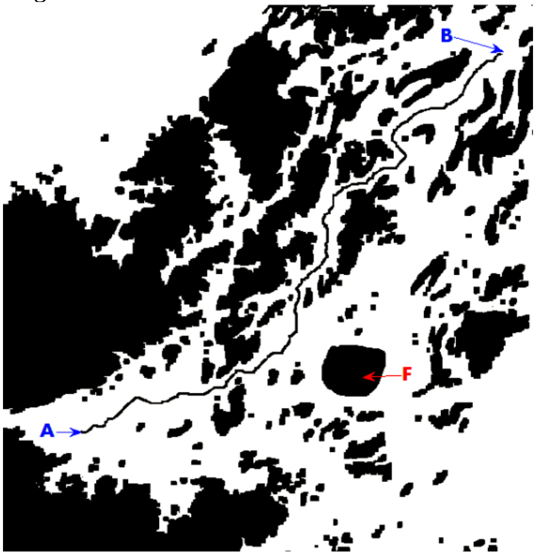

Figure 4. The Shortest Horizontal Path.

D. Three-dimensional Flight Path

In consideration of factors like vertical, longitudinal, and lateral separation and round trips among multiple rescue helicopters, we try to ensure that the round-trip flight path is free of overlap, and cannot use the same altitude to carry out the round-trip rescue in the area where the width of the flight path cannot guarantee the lateral separation. Consequently, the idea that converts the issue of three-dimensional flight path planning to several horizontal flight track planning in the usable levels, and gets the shortest flight path in each level respectively was proposed in this paper. Meanwhile, it combines with the multi-helicopter and multi-objective allocation algorithm, and makes plans for aviation emergency rescue. The chart below gives a view of feasible three-dimensional flight path between starting point A to end point B in aviation emergency rescue flight. And the longitudinal and latitudinal coordinates of A and B are shown in the chart.

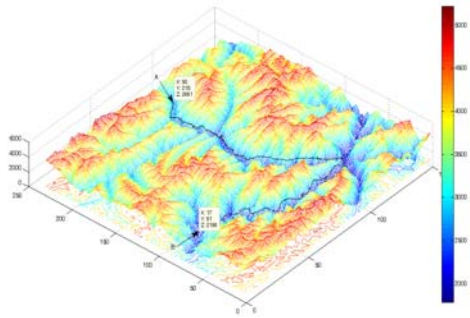

Figure 5. Three dimentioal flight path for helicopter from A to B.

IV. CONCLUSIONS

The factors that can affect the efficiency of aviation emergency rescue were analyzed deeply in this paper, through which the multi-objective distribution of multi-helicopter based on the feasibility matrix was proposed, and then the helicopters can be allocated to disaster areas reasonably. The horizontal route planning approach of helicopters was put forward based on the morphology graphic process technology and heuristic A* search algorithm, which can obtain the feasible shortest flight path with the condition of safety separation. Therefore, the rescue plans were formed and the aviation emergency rescue auxiliary system was developed, which can improve the efficiency and safety through preflight preparation.

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