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Optimal Path Planning for Helicopter Based on Visual Flight Rules Aeronautical Chart

-- Take a Complex Terrain in Chongqing as an Example

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Abstract

At present, helicopter has become a common emergency rescue method in many countries in the world, and visual aeronautical charts are the necessary aeronautical information and the main means of navigation for helicopter low-altitude visual flight. In the area of complex terrain, there are many limitations in helicopter emergency rescue, so it is urgent to optimize the visual aeronautical charting specification and consolidate and enhance the leading force and safety guarantee capability of helicopters in aviation emergency rescue. Therefore, taking a complex terrain area in Chongqing as an example, this paper uses ArcGlS software to digitize the visual aeronautical map and plan the optimal fight path of helicopter emergency rescue, laying a foundation for the subsequent development of emergency rescue drill system under complex terrain, which is of great significance to improve the efficiency of helicopter emergency rescue.

Keywords

Visual Flight Rules Aeronautical Chart; Helicopter; ArcGIS; Complex Terrain.

1. Introduction

With the gradual development of general aviation and the expansion and opening of low-altitude airspace, the domestic general aviation market has shown unlimited potential and broad prospects. How to break the low-level visual aeronautical chart a breakthrough and seize the opportunity to develop the aviation rescue career has become a practical proposition with great practical and strategic significance[1].

Judging from the technical characteristics of the helicopter, it has the advantages of vertical take-off and landing, hovering in the air, flying back and forth, left and right, and is not restricted by airports and runways. Compared with other types of aircraft, it is more suitable for undertaking complex rescue tasks. At the same time, disasters are mostly occur in complex terrain areas, and the most effective emergency rescue can only be carried out by using the advantages of low-altitude fight performance and good maneuverability of helicopters, through aerial command, hovering rescue, precise material airdrops, which has become a common emergency rescue method in many countries in the world. In such a typical "mountain city" and "foggy city" complex terrain area in Chongqing, helicopters often need to execute rescue tasks under complex terrain and low-visibility weather conditions in a low-altitude flight environment. In order to solve many problems in flight and reduce potential safety hazards , it is necessary to use auxiliary means such as GIS system to reasonably plan the optimal path of rescue flight.

2. Helicopter Visual Flight Rules Aeronautical Chart under Complex Terrain based on GIS

The study area is located in the west of Chongqing (29°N~30°N, 106°E~107°E) with an overall area of about1×10^4km^2. It is a typical mountainous and hilly landform with large fluctuations, which can be used as a complex terrain area for research. This paper adopted the production map mode of GIS software [1], which based on the location information and attribute information of spatial entities, the data are modified, edited and symbolized according to the actual application requirements, so as to visually display regional spatial data. According to the visual aeronautical chart production specification, the visual aeronautical chart elements are generally divided into geographic elements and aviation elements [2]. The geographic elements mainly include terrain, rivers, road networks and urban buildings, etc., and the aviation elements mainly include airports and routes. and airspace, etc., the three-dimensional landform is displayed by shading in the cartographic expression, the terrain fluctuation is represented by the color scale, and the important information (such as route points, airports, and routes, etc.) is marked by point symbols and linear symbols.

ln this paper, ArcGIS software is used as a platform to obtain the basic geographic information of Digital Elevation Model (DEM) with 30m resolution in the research area. The classification method of ArcGlS self-defined spacing is adopted to classify the DEM. The spacing is set at 60 and the DEM is divided into 22 categories, and the layered coloring of the elevation is carried out through ArcGIS's own color band, where the background color is green-yellow-brown to indicate the elevation from low to high, and then 3D analysis is performed in ArcGIS Grid surface in the tool, set relevant parameters to generate hillshade. The transparency of DEM layered color map is set to 50% and the stretch is set to 20%, which are superimposed on the mountain shadow layer to make the shaded image display a better three-dimensional effect. As shown in Fig. 1, simulate the lighting conditions of light coming from the northwest direction to form a shading map with a three-dimensional effect.

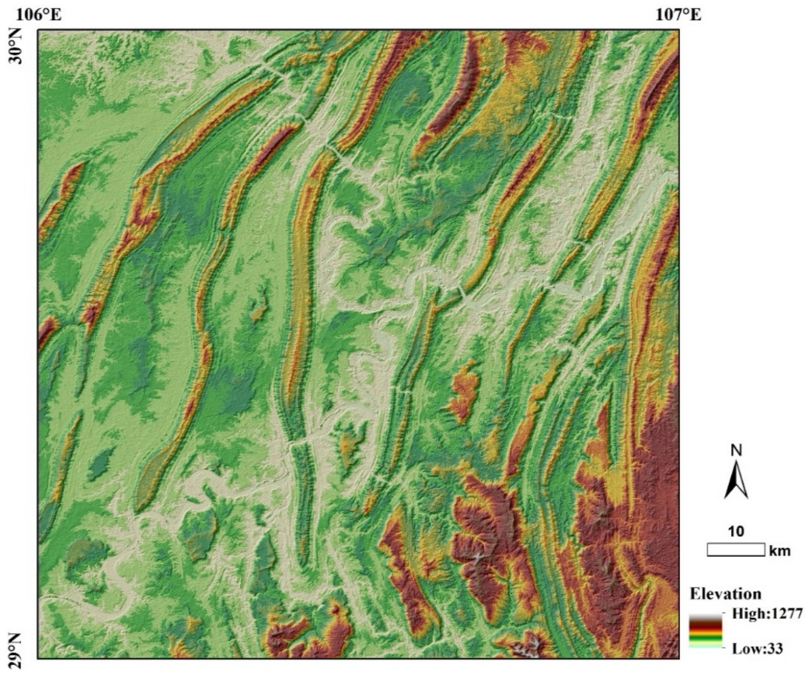

Fig 1. Hill shading map

Then the main road network (roads and railways) and rivers above grade 3 in the main urban area are vectorized to plot the maximum height of artificial buildings in residential areas (the highest artificial obstacle), and the route points information are added according to the requirements of specific flight tasks. In this paper, Jiangbei Airport is taken as the starting point, Jiangjin heliport is taken as the landing point, towns distributed between them and the highest artificial obstacle are selected as flight points. It is assumed that point-to-point flight is carried out at these fight points (regardless of the flight ability of the flightpath in realty), and the flight network is constructed by using ArcGIS to plot flight paths. At the same time, considering that the visual aeronautical map needs to provide accurate geographic orientation information and aerial positioning reference for pilots, in order to ensure the uniformity and accuracy of data and minimize the emergency rescue difficulties caused by complex geographical location and terrain, a unified coordinate system should be used and map name, legend, compass, scale and other related cartographic elements should be added at the end, as shown in Fig. 2, to form a digital visual aeronautical map of the study area.

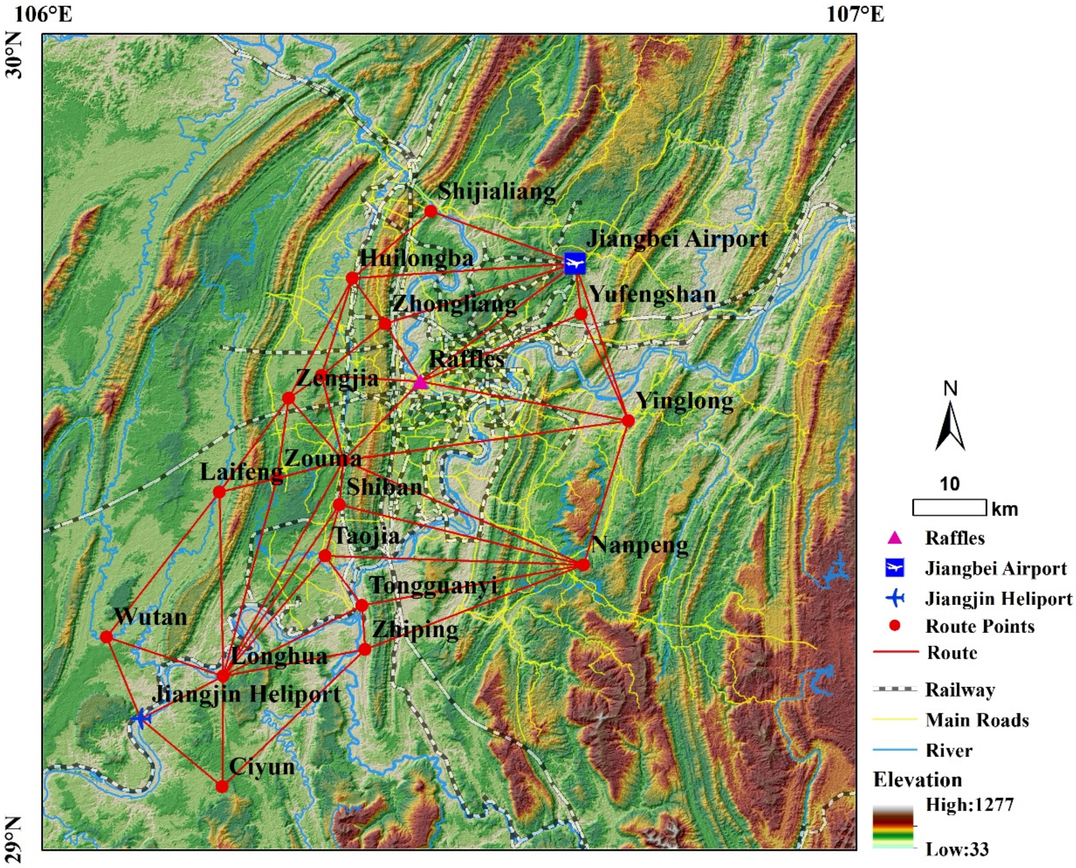

Fig 2. Digital visual flight rules chart of the study area

3. Optimal Path Planning for Helicopter based on Visual Flight Rules Aeronautical Chart

3.1. Theoretical Basis of Optimal Path Planning

By optimizing the flight path of aviation rescue, it can not only improve the support capability of aviation emergency rescue, but also provide some technical support for the development of aviation rescue system, which involves the problem of flight track planning. Track planning is to find the optimal track from the initial point to the target point under specific constraints, which can be the shortest flight time, the shortest distance, or the lowest altitude from the ground, etc. Its essence is a path search problem. It is more convenient to query the parameters to be considered in the course planning, such as the highest point, the lowest point, route distance and so on, and to find the optimal path by using computer when using digital map for emergency rescue in complicated terrain. As a matter of fact, many methods are used to solve the track planning problems, and most of them adopt the idea of hierarchical programming, which is divided into global flight planning and local track optimization. Thus, it can not only ensure that the specific requirements are met on the whole, but also reduce the amount of calculation in local planning. The single track planning research of aviation emergency rescue is relatively mature, such as single track planning and optimization correction [3], flight plan track estimation method [4], etc. According to their own advantages and disadvantages and different application scope, the main algorithms of single track planning can be roughly divided into two categories. One is intelligent algorithm based on analogy, including artificial potential field method, genetic algorithm, neural network method, simulated annealing method, ant colony algorithm, particle swam optimization algorithm etc. The second is based on graphics algorithm, including A* algorithm, Dijkstra algorithm, dynamic programming method, etc [5-9]. l In view of the stability and wide application of Dijkstra algorithm, this paper uses Djikstra algorithm to solve and analyze helicopter flight path network.

3.2. The Implementation of Optimal Path

Based on each route segment generated above, a helicopter route network is constructed. First, the distance of each flight segment is obtained through the distance measurement function of ArcGIS, and then the elevation value of the flight segment is extracted by using the route profile generated by the Interpolate Line tool in 3D Analyst. At the same time, considering that the terminal area flight limits the minimum sector height MSA (Minimum Sector Altitude), in order to ensure the safety of helicopter visual flight in mountainous areas, the obstacle clearance margin is set to 100m, and the minimum safe flight altitude is rounded up to 50m. The final data set includes flight distance, maximum elevation value, and elevation difference. Attribute information such as value and minimum safe height value. Table 1 is the attribute information of each flight segment of two routes.

Table 1. The segment attribute values of least and most time consuming

Route	Segment	Distance	Maximum Elevation	Elevation Difference	Minimum Safety Height
1	Jiangbei to Raffles	24.473km	486.672m	314.460m	600m
	Raffles to Baishiyi	14.022km	627.044m	477.116m	800m
	Baishiyi to Longhua	32.544km	450.675m	277.944m	600m
	Longhua to Jiangjin	11.584km	311.659m	128.621m	450m
2	Jiangbei to Yinglong	22.230km	592.324m	433.452m	700m
	Yinglong to Nanpeng	20.217km	417.944m	241.074m	550m
	Nanpeng to Zhiping	28.616km	554.969m	416.940m	700m
	Zhiping to Ciyun	25.159km	387.927m	218.633m	500m
	Ciyun to Jiangjin	13.603km	358.148m	170.321m	500m

Since the helicopter is easily disturbed by factors such as terrain fluctuations and bad weather during the rescue flight in the complex terrain area, considering the actual rescue situation in the area, this paper sets the flight time as impedance to plan the optimal route. It is assumed that the used helicopter model is Enstrom480B. According to its performance, the helicopter

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can climb at a horizontal speed of 96km/h during the take-off stage, and its climb rate is 8.1m/s; after climbing to the minimum safe flight altitude and reaching the intermediate stage, the helicopter can climb at a level of 213km/h The speed is in level flight. If it needs to continue to climb in the middle flight stage, the climb rate and horizontal speed are the same as those in the take-off and climb stage; in the descending stage, the helicopter can descend at a horizontal speed of 128km/h, and its descent rate is 11m/s. The helicopter flight process can usually be divided into the take-off and climb stage, the intermediate flight stage and the final landing stage [10]. The helicopter flight time is calculated for different stages. The specific analysis process is as follows.

(1) When the helicopter is in the take-off and climb stage, the horizontal distance of the flight segment must meet the requirements of the helicopter to reach the minimum safe flight altitude at the specified climb rate and climb speed. The calculation formula is as follows:

$$T = \frac{H_{MAX} - H_{START}}{V_1} + \frac{S - V_{CLIMB} \times (H_{MAX} - H)/V_1}{V_{LEVEL}} \quad (1)$$

Among them, T is the time spent in the climb phase, V_1 is the rate of climb in the take-off phase, V_{CLIMB} is the climb speed of the helicopter, V_{LEVEL} is the level flight speed of the helicopter, H_{MAX} is the minimum safe flight altitude for the segment, H_{START} is the elevation of the take-off point (Jiangbei Airport), S is the distance in the climb phase.

(2) When the helicopter is in the middle flight stage, if the flight altitude remains unchanged, it is considered that the helicopter maintains a constant speed and level flight in this segment. The calculation formula is as follows:

$$T = \frac{S}{V_{LEVEL}} \quad (2)$$

Among them, S represents the distance to maintain level flight in the intermediate stage. In the intermediate stage, two factors need to be considered: one is whether the current flight altitude can meet the minimum safe flight altitude requirement of the next flight segment, if not, it should climb in advance; the other is whether the flight distance from the level flight stage to the landing stage meets the helicopter's descending requirements, if not, it should descend in advance. The calculation formulas corresponding to the above two cases are as follows:

$$T = \frac{H_{MAX} - H}{V_2} + \frac{S - V_{CLIMB} \times (H_{MAX} - H)/V_2}{V_{LEVEL}} \quad (3)$$

$$T = \frac{H_{MAX} - H}{V_2} - \frac{V_{CLIMB} \times \frac{(H_{MAX} - H)}{V_2} - S}{V_{LEVEL}} \quad (4)$$

Among them, V_2 represents the climb rate in the intermediate flight phase, and H represents the flight height in the level flight phase.

(3) When the helicopter is in the final landing stage, the remaining flight distance has been ensured to meet the descending requirements. The calculation formula is as follows:

$$T = \frac{H_{MAX} - H_{END}}{V_3} + \frac{S - V_{DECLINE} \times (H_{MAX} - H)/V_3}{V_{LEVEL}} \quad (5)$$

Where V_3 represents the final stage decline rate, and $V_{DECLINE}$ represents the decline horizontal velocity.

According to the above method, the flight time is calculated for all flight segments, and the time impedances of 13 routes are compared and analyzed. The elevation profile of the route with the smallest impedance is shown in Fig. 3(a). The highest point between Jiangbei Airport and Raffles (the highest artificial obstacle) and Baishiyi Town is the climbing stage, and the flight altitude reaches 700m, which takes about 9.498 It took about 10.864 minutes to maintain level flight until Longhua Town. Finally, the descent stage from Longhua Town to Jiangjin Heliport takes about 3.456 minutes. The total helicopter flight time is about 23.818 minutes. As shown in Fig. 3(b), the climb stage from Jiangbei Airport to the highest point between it and Yinglong Town takes about 3.731 minutes to fly at an altitude of 700m, and it takes about 16.637 minutes to maintain level flight to Zhiping Town. It takes about 10.985 minutes to reach the Jiangjin Heliport, and the total flight time of the helicopter is about 31.353 minutes.

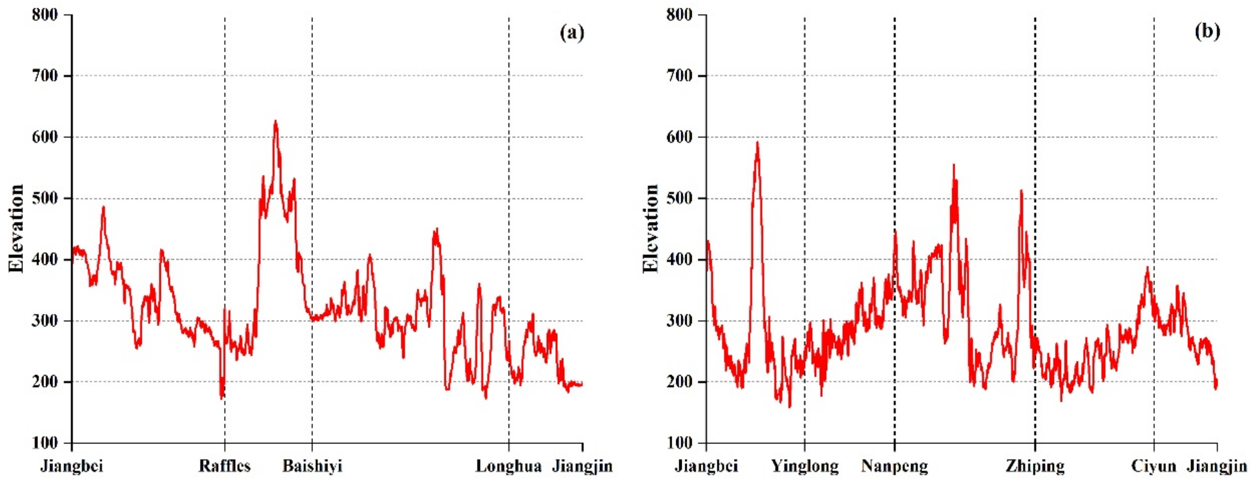

Fig 3. Topographic profile with minimum (a) and maximum (b) time impedance

To sum up, the optimal route of this helicopter rescue flight task (Fig. 4) is Jiangbei Airport→ Raffles →Baishiyi Town→ Longhua Town→ Jiangjin Helicopter, and the time taken is 23.818 minutes.

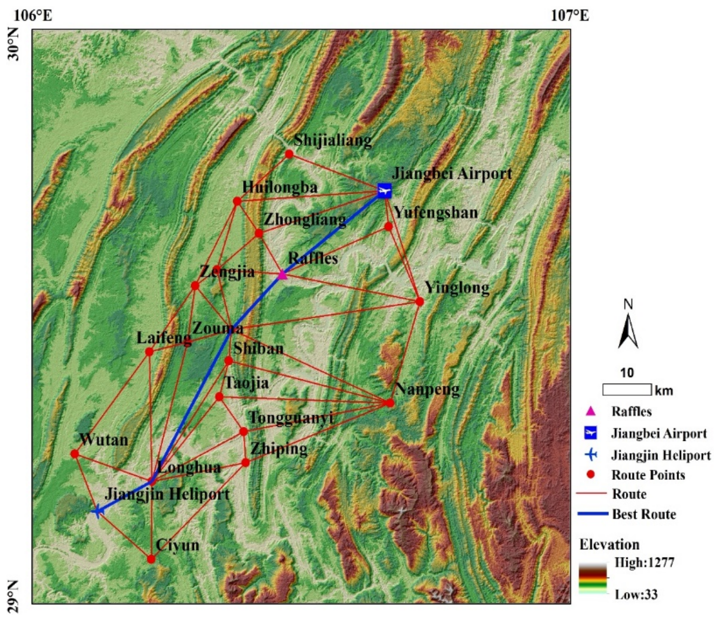

Fig 4. The best path of helicopter rescue

4. Conclusion

In this paper, taking the complex terrain area of Chongqing as an example, a digital visual aeronautical map is generated, and the optimal path of helicopter rescue flight is analyzed with the flight time as impedance and the total length of the route is short and the overall terrain fluctuation is small, which verified the feasibility of combining GIS technology with Dijkstra's algorithm. However, this paper does not consider the influence of factors such as bad weather and high-voltage lines in the actual route on the helicopter flight, which may lead to certain deviations in the results, and further research is needed in the future.

At the same time, we should also think about how to quickly determine the emergency rescue track under the influence of many complex factors, and build a complete complex terrain helicopter emergency rescue path planning theory and method. Especially when receiving emergency rescue instructions, if we can quickly provide pilots with reasonable flight path, the shortening of the take-off preparation time and the timely dispatch of the police to carry out rescue will make our country's helicopter rescue capability greatly progress. At present, the key technical problem is how to give full play to the helicopter's performance in view of complex terrain and combined with digital aeronautical charts, and at the same time how to use the heuristic intelligent optimal path search algorithm to search for the optimal track according to its obstacle-surmounting ability.

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