Computer-Assisted DEM-Based Aero Photography Design

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Abstract  In aerial photography, the primary factor is terrain undulation. However, most of the external aerial photography software used for aerial photography design do not take terrain undulation influence into consideration. Therefore, the design result has comparative randomicity and “gaps” are expected. An aerial photography design system is developed by analyzing the terrain undulation influence to the design result with DEM data so that the forward overlap and side overlap can be justified according to the block terrain undulation to meet specifications or standards. The data designed by this system is compared with the real flying data. The results show that making use of DEM to assist in aerial photography design can ensure that the designed result fits the real terrain better.

Keywords  aerial photography design; digital elevation model; side overlaps; forward overlaps

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Introduction

The main responsibility of aerial photography design is to plot the coverage and carry out the flight line and the exposure laydown in the blocks. Some systems developed abroad can aid aerial photography design and navigation automation, such as the ASCOT and CCNS4. However, these have been produced much earlier and emphasize particularly on the navigation control. Therefore, the introduction of terrain feature to improve the accuracy of the resulting data has not been taken in account.

So far in China, a mature aerial photography design software has not yet materialized. Most of the design is done manually by calculating the defined primary scale topographic map, or utilizing the software incident on the camera. The manual work is very complicated, time-consuming, has low accuracy, and the randomicity can easily create aerial photography gaps. Therefore, the authors analyzed the manual technology design process, brought forward and systemically investigated the computer-assisted DEM-based aerial photography design, and contrived a set of software systems based DEM that can plan the aero photography, plot, technology design, check and accept, and manage the aero photography result data. This study discusses the factors and result of DEM-based aero photography design.

1 DEM-based aero photography design

The process of aerial photography design is to fix the plotting flight line and position of the principal point of the photograph, during which the terrain undulation has the greatest influence to the result, which mainly includes terrain undulation influence to flight height, forward/side overlap, and flight speed control, etc.
1.1 Influence of terrain undulation to photo’s overlaps

In aerophotography, the overlap between successive exposures in each strip is called forward overlap $q_x$, and the overlap between adjacent strips is called side overlap $q_y$, they are all in percents. In the datum of aero photography block, the overlap is defined as follows:

$$q_x = \frac{P_x}{L_x}, \quad q_y = \frac{P_y}{L_y}$$

where $P_x, P_y$ refer to the length and width of the overlap in the datum of each block, respectively; $L_x, L_y$ refer to the length and width of the coverage in the datum of each block, respectively.

The overlap area is used to form a stereomodel and link the photos, and in each strip there should be three overlap areas—the common overlap area of three successive photos are vital requirements of the aero photography design.

In fact, because of the terrain undulation, there will be a difference between the actual flight height and the one designed, and can largely affect the overlap. When the range of terrain is not wide, we can approximately represent the block terrain undulation directly using the average geoidal surface of each block, so that the block exposure laydown on the average geoidal surface can meet the demand of aero photography design. However, when the range of the terrain is very wide, the block exposure laydown on the average geoidal surface cannot ensure that the forward overlap or side overlap of the highest and the lowest elevation meet the requirement of aero photography design. Therefore, we must have an adjustment. Theoretically, the relation of forward overlap or side overlap to the terrain undulation can be shown like the following formulas:

$$q_x = q_x' + (1 - q_x')\Delta h / H$$

where $q_x$ is designed forward overlap on the block average geoidal surface; $q_x'$ is actual forward overlap; $\Delta h$ is terrain point elevation-datum elevation; $H$ is relative flight height to the block average geoidal surface.

$$q_y = q_y' + (1 - q_y')\Delta h / H$$

where $q_y$ is designed side overlap on the block average geoidal surface; $q_y'$ is actual side overlap.

The formulas mentioned above show the influence of terrain undulation. To meet the overlap $q_x'$ which is user specified, the overlap on the block average geoidal surface $q_x$ must be more than $q_x'$. That is, based on the user-specified overlap, add the overlap correction relevant to the terrain undulation. If the influence of the terrain undulation to the photo overlap is not taken into account, the overlap may not be enough and there will be a “gap” \cite{1,2}.

However, the photo overlap must also not be too much, because it will reduce the efficiency of the aero photography and the succeeding steps. Too little overlap will not lead to good quality result, and the succeeding steps will also not go down. The specification says: the forward overlap must reach 56%-75% ; and the side overlap must reach 13%-35\% \cite{3}. Therefore, we must correct and reasonably adjust the flight line and the designed position of the exposure according to the terrain undulation to the photo overlap to make sure that the overlap meets the demand. DEM can most effectively show the terrain undulation and make it convenient for fast calculation. This is also one of the peculiarities of the computer-assisted aero photography design system.

1.2 Influence of terrain undulation to flight height

Since there will be a hilly area or a plain with different undulation in one flight line, even if we adjust the average datum, it is still very difficult to ensure the overlap of the highest elevation. Therefore, we must separate one flight line into several and set different average datum. Afterwards, based on the different datum, design the process according to the required aerial photography scale. Thus, one flight line will have image points on different flight height, which can fulfill the flight design requirement.

2 Realization of DEM-based aero photography design

To realize this research and complete the main function of the aero photography design system, the research group adopted the GeoMap3.5, GeoStar4.0 series subassembly development technology devel-
oped by Wuda Geoinformatics Co., Ltd., and accomplished the DEM-based aero photography design system.

2.1 Workflow of DEM-based aero photography design

The flight line and the exposure laydown of DEM-based aero photography Design are shown in Fig.1.

2.2 Multisource data organization

In this research result, according to different functions, we adopted the integration of three database technologies and diversely organized the assistant data of the aero photography design (1:50 000 to 1:4 000 000 vector topographic data, 1:50 000 to 1:500 000 digital raster data, 1:10 000 to 1:250 000 DEM data, image data, national basic scale subdivision grid data, aero photography planning data, region classified data, aero photography camera type, etc.) Also, we add some functions for the DEM data to the development subassembly. For example, we obtain an elevation, the highest point or the lowest point of one region, the average altitude of one region and so on, to help realize the research result.

3 Experiment

The research group detected the design result of this system after it was developed, using the Yichun block as an example. The detection mainly contains three points: technology design, flight control, and contrast analysis.
3.1 Aero photography design

In terms of the requirement of the block technology parameter, adopting the plotting method and the technology design sub-system, the detection group implemented the aero photography design, which is composed of block plotting and aero photography exposure laydown.

The aero photography block plotting is shown in Fig. 2.

![Fig.2 Aero photography block plotting](image)

The coverage technology design parameters are shown in Table 1.

| Block No. | 1    | 2    | 3    | Sum   |
|-----------|------|------|------|-------|
| Area / km² | 1 735| 346  | 2 792| 4 873 |
| Scale / 1: | 25 000| 25 000| 25 000|       |
| Focal length / mm | 152 | 152 | 152 |   |
| The height elevation / m | 673 | 1 046| 1 075|   |
| Height of the datum / m | 320 | 500 | 510 |   |
| The lowest elevation / m | 210 | 245 | 191 |   |
| Flight height of the average plane / m | 3 800| 3 800| 3 800|   |
| Absolute flight height / m | 4 120| 4 300| 4 310|   |
| The highest point $Q_1$ / % | 17.91| 20.6 | 20.13|   |
| Datum $Q_1$ / % | 28 | 32 | 32 |   |
| The lowest point $Q_1$ / % | 29.93| 36.27| 37.57|   |
| Strip interval $D_1$ / km | 4.14| 3.91| 3.91|   |
| The highest point $P_1$ / % | 60.09| 59.13| 58.89|   |
| Datum $P_1$ / % | 65 | 65 | 65 |   |
| The lowest point $P_1$ / % | 66.03| 67.2 | 67.87|   |
| Base line $B_1$ / km | 2.013| 2.013| 2.013|   |
| Strip amount / bar | 10 | 6 | 11 | 27 |
| Strip length / km | 591.68| 181.13| 951.91| 1 725 |
| Photo amount / sheet | 304| 96| 484| 884 |
| The highest point $m$ / 1: | 22 627| 21 445| 21 313|   |
| Datum $m$ / 1: | 25 000| 25 000| 25 000|   |
| The lowest point $m$ / 1: | 25 676| 26 711| 27 129|   |
| Side cover factor / % | 50 | 50 | 50 |   |
| Forward cover factor(base line) | 2 | 2 | 2 |   |
| Historical snow line height / m | | | |   |

Via the analysis, the design result synthetically considers the altitude difference, terrain and others, in plotting the aero photography coverage, and according to different terrain (hilly terrain and upland) actualized different flight lines and photo exposure laydown. The block plotting is very reasonable, and the flight line and photo exposure laydown are also scientific and exact. Based on the DEM data, we calculated the actual forward overlap and side overlap and determined that the highest point and the lowest point are all inside the overlap tolerance.

The output of the aero photography design result is in ASCOT navigation system data format, provided aero photography units carry out standpoint exposure flight.

3.2 Aero photography flight

In the aero photography flight, the aero photography unit adopts the ASCOT navigation control system cooperating with an RC-30 aerial camera. Based on the dual-frequency GPS navigation, the dynamic ASCOT system can obtain high-precision GPS 3D coordinates, guide plane flight along the designed flight line, and control the aerial camera exposure at designed positions. According to the ASCOT work principle, when the plane is approximately at the same position as the designed photo exposure coordinates relative to the flight, if the level error is within the deviation, the exposure will take place; if it is beyond the level release closure distance, there will be no exposure. When the plane is running, we set the level release closure distance to be 300 m. The ASCOT system not only controls the exposure of the aerial camera, but also records the GPS camera station coordinates at the exposure moment, which can help check the aero photography flight result quality.

3.3 Comparison flight result and designed result

In every strip of block 3, the detection group compared each camera station coordinate to the designed exposure coordinate, and found that in the flight direction the biggest differential was within 0.39 s, approximately 12 m distance; in the level direction within 8.81 s, it was approximately 265 m distance.

To validate the correctness of the designed data and the flight result, combined with manual checking, the detection group sampled some aerial photo pair and
made a contrast, such as block 2 :21/22 (776/777) of strip 2, 37/38 (799/798) of strip 3, 53/54 (808/809) of strip 4.

The aero photography expert of the detection group manually did a conventional check on the Yinchun coverage, which includes forward overlap, side overlap, ap, angle of drift, slope angle, overlay and so on, and recorded the result to make a report. By strict and thorough inspection, each index agrees with the aero photography specification.

### Table 4 Flight quality

| Photo No. | Forward overlap | Side overlap range | Block coverage | Slope angle |
|-----------|-----------------|--------------------|----------------|-------------|
| 21/22     | 62%-66%         | 16%-32%            | Whole          | <2°         |
| 37/38     | 63.57           | 62.13              |                |             |
| 53/54     | 63.31           | 62.13              |                |             |
| 776/777   | 65.0            | 63.4               |                |             |
| 799/798   | 64.0            | 63.0               |                |             |
| 808/809   | 63.1            | 61.8               |                |             |

After comparing and analyzing each group of designed data, result data, and the manual measurement, the detection group elicited the following conclusions.

1) The coordinate differential of the aero photography design result under the Xi’an80 coordinate system and the one under the WGS84 system is inside 120 m, and the differential in the Y direction (longitude direction) is bigger, which can satisfy the flight navigation control request. At the same time, to export the aero photography design result into a navigation control system data format, such as ASCOT or CCNS, etc, the system adopted a special data process to improve the accuracy of the flight result and the designed result field coincidence.

2) Manual measurement is coincident to the designed data, which again validated its scientific nature and rationality.

3) Manual measurement is coincident to the system calculated data, which validated that the DEM-assisted flight can obtain steady and reliable result.

4) Using the DEM-based aero photography design result with GPS standpoint exposure mode, we can get high-quality images and improve the flight efficiency and save aero photography cost.

### 4 Conclusions

The DEM-based aero photography design presented in this paper synthetically considered the altitude difference and terrain for the block plotting. According to different terrain, different flight line and photo exposure laydown were actualized. The block plotting is very reasonable, and the flight line and photo exposure laydown are also scientific and exact. On the precondition of satisfying the aero photography overlap requirement and avoiding the aero photography gap, this system can reduce the flight time and exposure times to improve the flight efficiency and save aero photography cost.

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