Research on route planning of aerial photography of UAV in highway greening monitoring

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Abstract. UAV (unmanned aerial vehicle) image technology has the advantages of wide shooting range, large inventory space, strong timeliness and so on, when it is used in highway detection. In addition to the basic parameters such as image quality, resolution and overlap, the safety of flight routes should also be taken into account in aerial photography of highways in operation. Optimal route planning is the premise and guarantee for the application and promotion of UAV in the field of highways. By adopting appropriate shooting form, flight height and angle, the actual road condition information can be collected to ensure high accuracy of data information. This provides great convenience for the actual situation of highway green belt, the confirmation of the location of plant growth and other aspects. It plays an important role in promoting the maintenance efficiency and level of highway green belt. This paper quantitatively analyzes and studies the optimal aerial route planning for unmanned vehicles in highway field.

1. Quantification of factors influencing the quality of UAV aerial images

1.1. Classification of UAV photography

UAV aerial photography can be divided into three categories in general, namely vertical photography (side angle ± 3 °), tilted photograph (side angle is greater than ± 3°, but less than ± 30°) and oblique photography (side angle is greater than 35 °, but less than 55 °). Vertical photography is the most commonly used of the three modes of photography. In vertical photography, an aerial camera is used to image objects perpendicular to the ground[1]. Due to the actual flight of the UAV and other factors, such as mechanical vibration, aerial camera doesn't perpendicular to the ground condition in the actual process of aerial. There will be a smaller side angle (less than ± 3 °) usually. Therefore, vertical photography also includes photography with a small side view angle in practice. The image ground coverage of aerial image refers to the actual surface coverage corresponding to the image. The imaging range is determined by camera parameters (focal length and physical size of sensor) and aerial photography flight height using (1). Where $A_{im}$ is the image imaging area, $Im_{w}$ and $Im_{h}$ are the width and height of the image imaging area respectively, $A_s$ is the area of the sensor, $H_f$ is the flying height of aerial photography, $f$ is the focal length, $S_w$ and $S_h$ are the width and height of the sensor.

$$A_{im} = Im_{w}\times Im_{h} = A_s \times \left(\frac{H_f}{f}\right)^2 = (S_w \times S_h) \times \left(\frac{H_f}{f}\right)^2 \tag{1}$$

When the image imaging range is related to the sensor size, the actual surface distance represented by each pixel on the sensor can be further obtained, that is, the image resolution or ground sampling
distance (GSD) [2] (2). Where, \( P_w \) and \( P_h \) are pixel in the sensor width and length direction respectively, and \( D \) is the distance from the camera to the object. The essence of GSD is to use the actual ground distance unit to represent the pixel size. The larger the GSD is, the larger the actual ground distance represented by the pixel is, and the lower the image accuracy will be. During GSD calculating, the object furthest away from the camera should be selected for specific calculation of GSD. At this time, the GSD obtained is its maximum value to ensure the accuracy of the image meets the requirements.

\[
GSD = \frac{S_w}{P_w} \times \frac{D}{f} \quad \text{or} \quad \frac{S_h}{P_h} \times \frac{D}{f}
\]

(2)

1.2. Quantification of image overlap
In order to obtain high-quality mosaic images and 3D reconstruction results (digital surface model and 3D point cloud) [3], aerial images need to have a certain degree of image overlap. Image overlap includes forward overlap (Endlap) and side overlap (Sidelap) [4] (Fig 1). Forward overlap refers to the overlap between two adjacent images in the direction of the airline. The schematic diagram of forward overlap and side overlap are shown in Figure 1, where distance \( B \) is air base, which refers to the distance between adjacent image centers, and Endlap is the longitudinal coverage length. The air base \( B \) has the following relationship with aerial photography flight speed \( v \) and photography interval \( t \) (3). \( O_{\text{forward}} \) refers to the overlapping of images on adjacent airline lines, in which the distance \( SP \) is the distance between adjacent airline lines and sidelap is the sideline overlap length (4). Then, the sideline overlap degree \( O_{\text{side}} \) can be calculated by (5), image coverage width \( Im_w \) and image coverage height \( Im_h \) are shown in the Figure 1.

\[
B = v \times t
\]

(3)

\[
O_{\text{forward}} = \frac{Im_h - B}{Im_h} \times 100\% = \frac{Im_h - vt}{Im_h} \times 100\%
\]

(4)

\[
O_{\text{side}} = \frac{Im_w - SP}{Im_w} \times 100\%
\]

(5)

2. The development process of aerial photography plan
The parameters to be calculated for the establishment of aerial photography plan include the number of routes, the number of aerial images, flight speed and altitude. The information required to calculate these parameters includes the pixels, physical size and focal length of the aerial photograph camera’s sensor, accuracy requirements (GSD), longitudinal and lateral coverage, preset flight speed, and the length and width of the aerial photograph’s target area. The specific process is shown in Figure 2. For general aerial photography projects, longitudinal and lateral overlap requirements are greater than 75% and 60%, respectively. For aerial photography of forest, high-vegetated area or farmland, vertical and lateral overlap degrees are usually required to be greater than 85% and 70% respectively.
2.1. Aerial photography route development
When making the aerial photography plan, first of all, the route should be parallel to the long side of the aerial photography coverage area, that is, the short side of the aerial photography coverage area should change the course to reduce the number of routes and the number of course changes. In Figure 3 (A), the red one-way arrow represents the route and course, and the black border is the target area of aerial photography. The route is parallel to the target area of aerial photography, and the course is changed on the short side of the target area of aerial photography (red two-way arrow). By setting the photosensitive sensor (CCD array) or the long edge of the image perpendicular to the route direction, the side coverage range of aerial image can be increased, thus reducing the number of routes. In Figure 3A, the blue rectangle represents CCD array or image whose long side is perpendicular to the airline line.

2.2. Calculation of the number of routes
The number of routes that should be set is calculated according to the side-overlap degree and the width of the target area of aerial photography. First, calculate the interval between routes (SP, Figure 3B), then the number of routes \(N_{f1}\) to be set can be calculated based on (6) and (7). Where, the ceiling is the integer function, and the WIDTH is the width of the target area of aerial photography.

\[
SP = (1 - O_{\text{side}}) \times Im_w
\]

\[
N_{f1} = \text{ceiling} \left(\frac{\text{WIDTH}}{SP} + 1\right)
\]

2.3. Calculation of the number of images acquired in the aerial photography program
When the number of routes is set, the number of images needed to cover the entire target area of aerial photography should also be calculated. First calculates the air base length \(B\), then calculate the number of images on every route \(N_{it}\). Finally, calculate total number of images required \(N_{it}\). In the process of the actual route planning, aerial coverage should be slightly bigger than the target area, to ensure that the target area image at the edge of the area have enough coverage, thus improve the reconstruction precision of the edge of the area. Therefore, two images can be added at both ends of the long side direction of the aerial photography target region (blue dots outside the central region in Figure 3B). In the direction of the short side of the target area of aerial photography, another route can be added on the outside of the route.
\[ B = (1 - O_{\text{forward}}) \times W_g \]  
\[ N_{it} = \text{ceiling}(\frac{\text{LENGTH}}{B}) + 1 \]  
\[ N_{it} = N_{it} \times N_{fl} \]

3. Quantitative results of flight path parameters

3.1. Aerial photo setup and road central green belt imaging

The safety of landing flight is fully taken into account in the route planning. Based on the above quantitative calculation method, the parameters of formation flight on both sides of the road avoiding the road surface and single-aircraft flight on one side of the road edge are calculated for different levels of highway. The statistical analysis results only show the double-lane for the 1-3 class highways. In order to avoid the UAV’s emergency landing on the highway lane, the route is set above the edge of both sides of the road. The preset flight speed is 10 m/s, the shooting interval is 1 s, and the longitudinal and lateral overlap degrees are 70% and 80%, respectively\[6\].

3.2. Highways and first class highways

Taking ZENMUSE X5 camera as an example, parameters of aerial photography plan under different aerial configuration are calculated. The physical size of the sensor is 17.3 \times 13.0 mm, the maximum resolution of the image is 4608 \times 3456 (16 million pixels), and the focal length is 15 mm. In China, the total width of the highway from the height highway to the first grade highway is 40~70 m, and the average value is 55 m as the distance between the routes. In the case that the flight height under 150 m does not take GSD into account (Table 1), the vertical and lateral coverage do not meet the preset requirements.

| \(H_f\) (m) | GSD (cm) | \(I_m\) (m) | \(I_m\) (m) | \(O_l\) (%) | \(O_L\) (%) | \(H_f\) (m) | GSD (cm) | \(I_m\) (m) | \(I_m\) (m) | \(O_l\) (%) | \(O_L\) (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20.0 | 0.5 | 23.1 | 17.3 | 42.2 | -138.4 | 140 | 3.5 | 161.5 | 121.1 | 91.7 | 65.9 |
| 30.0 | 0.8 | 34.6 | 25.9 | 61.5 | -58.9 | 150 | 3.8 | 173.0 | 129.8 | 92.3 | 68.2 |
| 40.0 | 1.0 | 46.1 | 34.6 | 71.1 | -19.2 | 160 | 4.0 | 184.5 | 138.4 | 92.8 | 70.2 |
| 50 | 1.3 | 57.7 | 43.3 | 76.9 | 4.6 | 170 | 4.3 | 196.1 | 147.1 | 93.2 | 71.9 |
| 60 | 1.5 | 69.2 | 51.9 | 80.7 | 20.5 | 180 | 4.5 | 207.6 | 155.7 | 93.6 | 73.5 |
| 70 | 1.8 | 80.7 | 60.6 | 83.5 | 31.9 | 190 | 4.8 | 219.1 | 164.4 | 93.9 | 74.9 |
| 80 | 2.0 | 92.3 | 69.2 | 85.6 | 40.4 | 200 | 5.0 | 230.7 | 173.0 | 94.2 | 76.2 |
| 90 | 2.3 | 103.8 | 77.9 | 87.2 | 47.0 | 210 | 5.3 | 242.2 | 181.7 | 94.5 | 77.3 |
| 100 | 2.5 | 115.3 | 86.5 | 88.4 | 52.3 | 220 | 5.5 | 253.7 | 190.3 | 94.8 | 78.3 |
| 110 | 2.8 | 126.9 | 95.2 | 89.5 | 56.7 | 230 | 5.8 | 265.3 | 198.9 | 94.9 | 79.3 |
| 120 | 3.0 | 138.4 | 103.8 | 90.4 | 60.3 | 240 | 6.0 | 276.8 | 207.6 | 95.2 | 80.1 |
| 130 | 3.3 | 149.9 | 112.5 | 91.1 | 63.3 | 250 | 6.3 | 288.3 | 216.3 | 95.4 | 80.9 |

\(H_f\): flight height  
GSD: ground sampling distance  
\(I_m\) : Image coverage width  
\(I_m\) : Image coverage height  
\(O_l\) : Longitudinal overlap (%)  
\(O_L\) : Lateral overlap (%)  

3.3. The secondary roads

The total width of the road ranges from 30 m to 60 m, and the average value of 45 m is taken as the distance between routes. The vertical and lateral coverage do not meet the preset requirements when the flight height under 120 m, which does not take GSD into account (Table 2).

| \(H_f\) (m) | GSD (cm) | \(I_m\) (m) | \(I_m\) (m) | \(O_l\) (%) | \(O_L\) (%) | \(H_f\) (m) | GSD (cm) | \(I_m\) (m) | \(I_m\) (m) | \(O_l\) (%) | \(O_L\) (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 0.5 | 23.1 | 17.3 | 42.2 | -95.1 | 140 | 3.5 | 161.5 | 121.1 | 91.7 | 72.1 |
| 30 | 0.8 | 34.6 | 25.9 | 61.5 | -30.1 | 150 | 3.8 | 173.0 | 129.8 | 92.3 | 74.0 |
3.4. Highways and first class highways (High resolution camera)

Choose a camera with higher resolution (take Canon 5Ds R camera as an example) to calculate the parameters of aerial photography plan under different aerial photography configurations. The physical size of the camera's sensor is $36 \times 24$ mm, the maximum resolution of the image is $8688 \times 5792$ (50 million pixels), and the focal length is 24 mm (depending on the lens). The quantitative parameters for the configuration of dual-route aerial photography routes of expressways and first-level highways are shown in Table 3. The longitudinal and lateral coverage of the flight height under 120 m do not meet the preset requirements when GSD is not taken into account.

Table 3. Dual route configuration of expressways and first-class highways (High resolution camera).

| $H_f$ (m) | GSD (cm) | $Im_w$ (m) | $Im_h$ (m) | $O_l$ (%) | $O_ll$ (%) | $H_f$ (m) | GSD (cm) | $Im_w$ (m) | $Im_h$ (m) | $O_l$ (%) | $O_ll$ (%) |
|----------|----------|-----------|-----------|---------|-----------|----------|----------|-----------|-----------|---------|-----------|
| 20       | 0.4      | 30        | 20        | 25.0    | -83.3     | 140      | 2.4      | 210       | 140       | 89.3    | 73.8       |
| 30       | 0.5      | 45        | 30        | 30.0    | -22.2     | 150      | 2.6      | 225       | 150       | 90.0    | 75.6       |
| 40       | 0.7      | 60        | 40        | 42.5    | 8.5       | 160      | 2.8      | 240       | 160       | 90.6    | 77.1       |
| 50       | 0.9      | 75        | 50        | 70.0    | 26.7      | 170      | 2.9      | 255       | 170       | 91.2    | 78.4       |
| 60       | 1.0      | 90        | 60        | 75.0    | 38.9      | 180      | 3.1      | 270       | 180       | 91.7    | 79.6       |
| 70       | 1.2      | 105       | 70        | 78.6    | 47.6      | 190      | 3.3      | 285       | 190       | 92.1    | 80.7       |
| 80       | 1.4      | 120       | 80        | 81.0    | 54.2      | 200      | 3.5      | 300       | 200       | 92.5    | 81.7       |
| 90       | 1.6      | 135       | 90        | 83.3    | 59.3      | 210      | 3.6      | 315       | 210       | 92.9    | 82.5       |
| 100      | 1.7      | 150       | 100       | 85.0    | 63.3      | 220      | 3.8      | 330       | 220       | 93.2    | 83.3       |
| 110      | 1.9      | 165       | 110       | 86.4    | 66.7      | 230      | 4.0      | 345       | 230       | 93.5    | 84.1       |
| 120      | 2.1      | 180       | 120       | 87.5    | 69.4      | 240      | 4.1      | 360       | 240       | 93.8    | 84.7       |
| 130      | 2.2      | 195       | 130       | 88.5    | 71.8      | 250      | 4.3      | 375       | 250       | 94.0    | 85.3       |

$H_f$: flight height

GSD: ground sampling distance

$Im_w$: Image coverage width

$Im_h$: Image coverage height

$O_l$: Longitudinal overlap (%)

$O_ll$: Lateral overlap (%)

4. Conclusions

The UAV platform is used to monitor the highway green belt. Considering the emergency landing of UAV, the route setting must be set directly above the edge of both sides of the road surface. If the overlap degree of the adjacent images meets the requirements, the resolution of the camera and the width of the road will affect the flight height in the course setting. In the range of appropriate aerial photography height, highways and first-class highways need higher resolution cameras to obtain more accurate reconstruction results. This paper quantitatively analyzes the influencing factors of aerial photography route design in the application of UAV in highway field, so as to further clarify the influence of each UAV flight parameter on image acquisition. Combined with the width of the road surface to be monitored for different grades of roads, the optimal route planning suitable for the...
monitoring of different grades of roads is studied. This paper provides a feasible and optimal route setting method for the application and promotion of UAV in highway field.

Acknowledgements
We would like to acknowledge Bangyou ZHENG (CSIRO) for his generous help with the photography and software used for 3D reconstruction, Wei GUO (The University of Tokyo) for his help in image interpretation algorithm. This study is supported by the National Key Research and Development Program of China (2017YFC0804904) and National Natural Science Foundation of China (31771678).

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