Establishment of High Precision Terrain Model of Eroded Gully with UAV Oblique Aerial Photos

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Abstract. Taking the example of aerial modeling of erosion gullies in Shenmu county of northern Shaanxi in China, with oblique aerial photos acquired by a COTS (commercial off-the-shelf) UAV (unmanned aerial vehicle) (DJI INSPIRE-1) and 30 high-precision pre-deployed ground control points (GCPs) measured by FIFO A30 RTK (real-time kinematic). Establish the high-resolution measured 3D terrain model with the aid of high-precision ground control points, the efficiency of airphoto and modeling is relatively high, it indicates that eroded gully modeling and monitoring relying on UAV has good application prospect.

1. Introduction

UAV aero photogrammetry has developed rapidly in recent years [1-4]. Though most COTS (commercial off-the-shelf) products can provide ordinary precision GPS positioning data, due to low precision camera posture information, the conveyed commercial digital camera cannot provide precise intrinsic parameters, it is hard to have high precise three dimensional checking conditions. Therefore, high precision ground control points (GCPs) are needed to obtain reliable aerial survey results. Pointing at this, this paper adopts oblique aerial photos (the camera's pitch angle is less than 90 degrees) to conduct gully terrain model. The traditional oblique photogrammetry method is to obtain the multi-angle oblique image of the target object by carrying a professional multi-lens tilt camera on the flight platform. However, the professional tilt camera and the flight platform are expensive, and SfM-MVS method does not limit the the taking angle and direction of the aeronautical chart on the principle. Kaiser [5] directly adopts to hold the digital camera by hand, manually take to obtain grounding photos with different viewing angles on the ground, high resolution three dimensional modeling of eroded gully by using SfM-MVS.

2. Material and Method

2.1. Experiment plan

(1) Aerial photographic acquisition: include route planning, camera setting, and camera calibration.
(2) Ground control points measuring: usually adopt live deployment control points and high precision measurement to obtain control points.

(3) POS information processing: extract POS information taken by the aero photography from UAV's GPS recorded files or aero photography's EXIF information.

(4) The camera's internal and external parameters solving: obtain the initial estimation of the camera's internal and external parameters according to the aero photography and POS information by adopting SFM method.

(5) The ground control point's remark: according to the initially calculated aero photography's direction and camera parameters, identify and mark each aeronautical chart's ground control points under the epipolar constraint.

(6) Connection points editing and trimming

(7) Camera's parameters optimization: through high precision ground control points and trimmed connection points, make optimal estimation on the camera's parameters, especially the internal parameters to improve the precision of the modeling.

(8) Model precision evaluating: according to the reserved ground control points, conduct quantitative evaluation on the precision, if the precision is low, repeat to trim the connection points and optimize the camera's parameters until the expected precision is reached.

(9) Model's spatial registration: for the established spatial model, shift to the required geographic coordinates through the ground control points.

(10) Spatial model generation.

2.2. Experimental area

The experimental area is located in the Shegeda village, Liudaogou, Shenmu County, Yulin city, Shaanxi province. The monitored object is a typical gully, which located in 38°47′46.33″N, 110°22′04.56″E, 1182. 376 m above sea level.

2.3. Aero photography acquisition

Aerial image is collected by Dajiang Inspire-1 integrated UAV system. This paper adopts oblique aerial images (the camera's pitch angel is less than 90°) to construct gully terrain, set a square 34 m×34 m in the task area of the gully, and the direction is along the development direction of the gully. The flight height is set to be 15m, the degree of overlap is 80%, and the total length of the flight route is 528m. Adopt double zigzag route template, the camera's angel is set to be 70°, totally obtain 194 aerial maps. The gully airway shooting consists of two zigzag airways that are perpendicular to each other, and six airways are evenly distributed in the vertical direction and the horizontal direction.

(1) Control points measuring

As shown in figure 1, 30 ground control points are evenly arranged along the independent gully. The flag points in the rectangular box in the picture is no.25 ground control points, and nearby is the RTK base station.
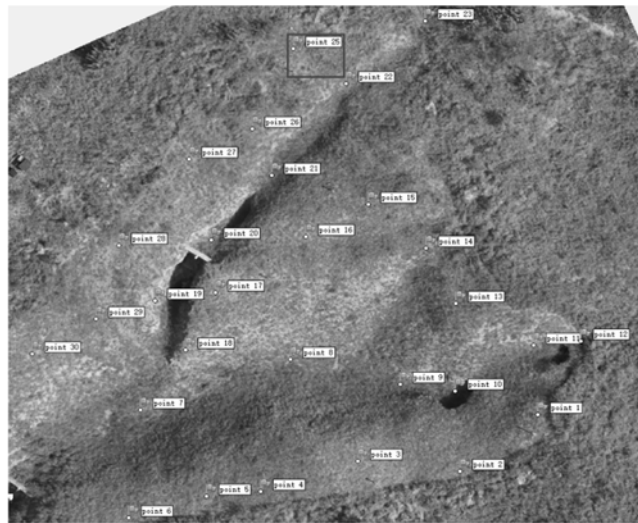
Figure 1. The gully's control points distribution diagram

There is a fixed steel pipe inserted into the ground at the base station. Place a disc on the top of the steel pipe during the UAV aerial survey, the center of the disc coincides with the center of the steel pipe. After the complement of aerial survey, connect the RTK host to the short pole and then directly insert into the steel pipe to be fixed as the base station. Additionally use another RTK host to respectively measure the central coordinates of the disc at each control points, and obtain the coordinates of ground control points with reference to the base station. Number the control points in order, and edit the measured longitude, latitude and altitude into CSV files and import into PhotoScan software, then select multiples of 3, i.e., 3, 6... No. 30 ground control points as check points, which do not take part in space matching calculation and are used for precision evaluation of modeling results. The rest 20points are reference points and the base of space matching.

(2)   The camera's parameter solving

The camera's internal parameter modeling adopts the adaptive optimization method to estimate to obtain the connection points and sparse points cloud. However, due to ground control point's error, the initial obtained sparse points modeling has 0.235 longitude error, 0.609m latitude error, 10.33m altitude error on the actual ground control points. Obviously the precision of the ground control points is greatly larger than that of the result, therefore it is necessary to use the ground control points to optimize the camera parameters.

(3)   Control points marking

First, import control points measurement coordinates into the software, establish control points; then directly mark each control points is marked directly in the sparse points cloud or orthophotomap, according to the previously evaluated camera's parameters and control points of the model, PhotoScan can obtain the evaluated position of each aerial chart through beam project; finally, check and correct each control point's evaluated location on the aerial chart, mark the correct image location, obtain the complete and right control points system.

(4)   Camera's parameters optimization

Through four optimization, the aerial survey control point's projection error will be reduced to about 0.538 pix, the mean square root projection error of the connection points will also be reduced to about 0.51 pix. The max projection error will be reduced to about 7.8 pix.

3. Result and analysis

3.1. Precision evaluation and analysis

Table 1 and table 2 are respectively the reference point's error and check point's error. It can be seen that the ground check points X error is 6cm, Y error is about 7cm, Z error is about 1.8cm, and the overall error is about 10cm. It is visible that each error of the check points is close to the ground reference points. It indicates that the error of the check points can reflect the overall error.

Table 1. The error of the ground control points (reference points)

No.	overall error/m	X error/m	Y error/m	Z error/m
point 1	0.161191	0.123929	-0.102224	0.013206
point 2	0.039888	0.001235	-0.03751	0.013509
point 4	0.078411	0.000605	-0.073852	0.026342
point 5	0.081865	0.053454	-0.05765	0.022827
point 7	0.162863	0.075758	0.138823	0.038902
point 8	0.095691	0.076878	0.056463	0.007639
point 10	0.071555	-0.047243	-0.052793	-0.010052
point 11	0.039372	0.004507	0.038915	0.003931
point 13	0.025231	0.001284	0.014053	-0.020916
point 14	0.142656	-0.113635	0.084021	-0.019452
point 16	0.091962	-0.025335	0.088207	-0.005888
point 17	0.100695	0.021766	0.098215	-0.004421
point 19	0.138637	-0.136782	0.018724	0.012664
point 20	0.054012	-0.014334	-0.052072	-0.000549
point 22	0.079778	0.019213	-0.064894	-0.04224
point 23	0.133973	0.049942	-0.124283	-0.002849
point 25	0.089551	-0.085775	-0.00894	-0.024125
point 26	0.094532	-0.081331	0.044886	-0.017516
point 28	0.090798	0.090277	0.009635	-0.001252
point 29	0.024977	-0.014335	-0.017635	0.010361
overall error	0.098649	0.067177	0.069749	0.018816

Table 2. The error of the ground control points (check points)

| No.	overall error/m	X error/m	Y error/m	Z error/m
point 3	0.162269	-0.129594	-0.097143	0.010002
point 6	0.092623	0.017127	-0.08436	0.034191
point 9	0.060918	0.055298	-0.015566	0.02027
point 12	0.088498	-0.030584	-0.082782	0.006614
point 15	0.081789	-0.057462	0.057059	-0.011482
point 18	0.154773	0.084942	0.128585	0.014329
point 21	0.020639	0.01473	-0.004886	-0.013606
point 24	0.085277	0.06402	-0.055942	-0.006633
point 27	0.030733	0.013245	0.008722	-0.026325
point 30	0.136496	-0.110837	0.07698	0.020508
overall error	0.1021622	0.0695514	0.072521	0.0184486

Through statistical analysis of the error of ground control points, the statistical indicators of X error, Y error, Z error and overall error are obtained as shown in table 3.

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Table 3. The statistical indicator of the error of the gully control points

error type	control points type	statistical indicator/m						
		mean value	variance	min	first quartile	median	third quartile	max
X error	1	3.9E-6	0.06892	-0.13678	-0.03629	0.00126	0.0517	0.12393
	2	-0.00791	0.07284	-0.12959	-0.05746	0.01399	0.0553	0.08494
Y error	1	4.45E-6	0.07156	-0.12428	-0.05522	3.475E-4	0.05067	0.13882
	2	-0.00693	0.07609	-0.09714	-0.08278	-0.01023	0.05706	0.12859
Z error	1	6.05E-6	0.0193	-0.04224	-0.01378	-9.005E-4	0.01294	0.0389
	2	0.00479	0.01878	-0.02633	-0.01148	0.00831	0.02027	0.03419
overall error	1	0.08988	0.04171	0.02498	0.06278	0.09017	0.11733	0.16286
	2	0.0914	0.04811	0.02064	0.06092	0.08689	0.1365	0.16227

Note: Control point's type 1 is the reference points, control points type 2 is the check points.

The table shows that the mean error values in the three directions of X, Y and Z are all in millimetre level, indicating that the generated model has no significant systematic error. The box plot for generating the upward error based on the statistical indicators is shown in Figure 2. It can be seen from the figure 2 that the median error of the reference point and the checkpoint in each direction is substantially close to the mean. The error of the reference point is basically symmetrically distributed, and the error of the checkpoint has a certain positive and negative offset. All errors have no abnormal values.
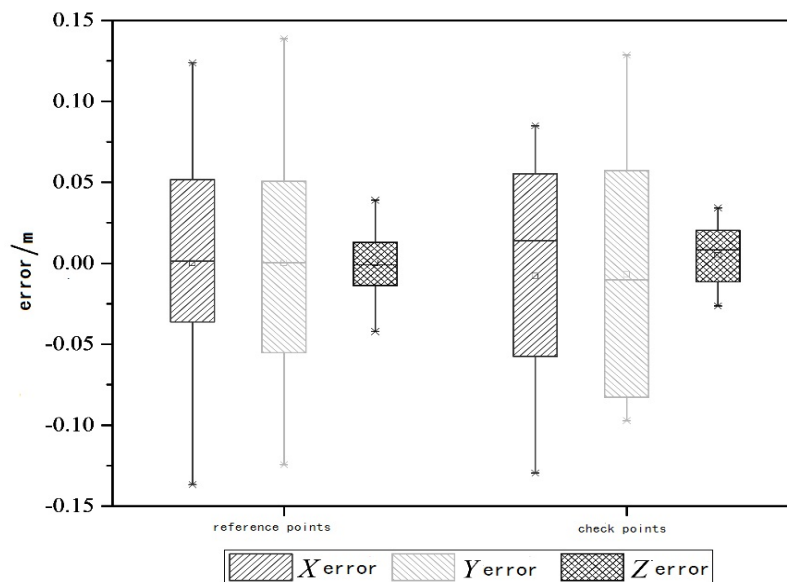
Figure 2. Gully error boxplot

The horizontal error of the independent gully is the mean square root of error X and error Y. The plane position error XY=0.071051716 is got from error X = 0.0695514, error Y=0.072521. Therefore, the precision of ground control points meets the requirements of 1:500 scale digital line drawing (class

B) and orthophotomap drawing (class B). The elevation error is Z error error Z=0.0184486, which also meets the requirements of the elevation annotation and contour marking of 1:500 scale digital line drawing (class B).

3.2. Dense points cloud construction

According to the optimized camera's parameters and each aerial chart, the dense points cloud model of the aerial photography area can be constructed. The mass parameter of dense points cloud is set as High and the filtering method is Aggressive. A dense point cloud with 16494336 points is obtained (figure 3). It can be sees from the figures that the dense points cloud detailed reflects the surface form of the gully, and the point density is relatively high and the distribution is basically uniform, except the small regional cavity in the gully, there is no obvious cavity in the gully bank and the gully head.
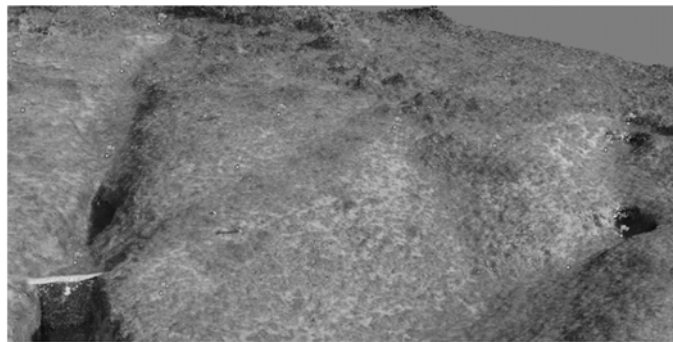

Figure 3. Stereo view of dense points cloud

3.3. Three dimensional points cloud results analysis

Use interpolation of dense points cloud to construct the DEM model with the size of 5190 x 4275, the resolution is 1.09 cm/pix. Use the dense points cloud to construct TIN model. Use the independent gully TIN model to construct the orthophotomap, the generated size is 9744×8315, the resolution is 5.47 mm/pix. Comparing it with Microsoft's Bing satellite image, the resolution of the orthophotomap is much higher than that of the satellite image, which can describe detailed the shape of the independent gully.

4. Conclusion

With the aid of the high precision ground control points, high-resolution measured three dimensional topographic model is constructed, which is helpful to research the eroded gully, the research result shows that:

(1) The error in the plane position of the gully calculated from the ground error control points is 0.07 m. The precision of ground control points meets the requirements of 1:500 scale digital line drawing (class B) and orthophotomap drawing (class B). The elevation error is 0.018m, which also meets the requirements of the elevation annotation and contour marking of 1:500 scale digital line drawing (class B). What's more, due to the adopted oblique image, compared with the traditional modeling method based the orthographic aerial chart, this method in the paper has advantages of high precision.

(2) Use the dense points cloud to construct TIN model, the model is basically consistent with the real terrain, and the included concave gully head and the gully bank can be modeled correctly.

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