STUDY ON THE HEIGHT MEASUREMENT OF CULTURAL FEATURE BASED ON THE SINGLE AERIAL PHOTO

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ABSTRACT:

As an important property information, the height information of buildings possesses quite high utilizing value in the civil fields. The traditional method to get the heights of artificial buildings is to carry on the measurement on stereopairs, This method acquires work departments to have stereometers and professional workers, further more, it calls for advanced software and hardware, so it disagreed with those non-professional surveying and mapping departments. This paper studied how to ensure the height information of buildings by the projection error on single aerial cartographic photography. The technology could not need costly software and hardware to measure on stereopairs, depressed the speciality ability of workers, and make the technology approach to obtain the height information of buildings more broadly. Further more, the projection error on images is corresponding to the vertical edge of culture features which passes photo nadir points, it's easy to carry on automatic extraction to the vertical edge, so this method owns very large potential to the direction of robotization. This paper has implemented experiments and precision analysis to the method and proved that its feasibility and high precision.

1. INTRODUCTION

Along with the continuous development of the city construction, the amount of the high buildings and large mansions grows day by day, so the high buildings' height information becomes to be an necessary parameter in the activity of city planning, economic decision-making. The traditional method to get the heights of artificial buildings is to carry on the measurement on stereopairs. This method acquires work departments to have stereometers and professional workers, further more, it calls for advanced software and hardware, so it disagreed with those non-professional surveying and mapping departments. This paper studied how to ensure the height information of buildings by the projection error on single aerial cartographic photography. The technology could not need costly software and hardware to measure on stereopairs, depressed the speciality ability of workers, and make the technology approach to obtain the height information of buildings more broadly.

In Photogrammetry, there are three main methods to get the height information of the buildings: the height information extraction based on the single aerial photo, the height information extraction based on the stereopairs and the height information extraction based on the multi-source data. In our country the researchers have made great study on the method based on the stereopairs, these years, people begin to study the height extraction method based on the laser radar data, there is little study on the height information extraction based on the projection error, besides, there is great potential to extract the height information automatically(On the aerial photos, the projection error of an image point corresponds with the vertical line of the building, the photo nadir point is on the vertical line, so it is relatively easy to extract the vertical line). So, study on the method of height information extraction based on the single aerial photo has great significance.

2. THE BASIC PRINCIPLE OF THE HEIGHT INFORMATION EXTRACTION METHOD BASED ON THE SINGLE AERIAL PHOTO

In photogrammetry, the projection error is an important conception. It is caused by the terrain relief and is on the radial line. Based on the traditional photogrammetric theory, the rigorous formula of the projection error is:

$$\delta h_\alpha = \frac{\Delta h}{H} r_n \left[\frac{1 - \frac{r_n}{2f}\sin\varphi \sin 2a}{1 - \frac{\Delta h}{2Hf} r_n \sin\varphi \sin 2a} \right] \tag{1}$$

Based on the above formula, we can get the formula to compute the height information as follows:

$$\Delta h = \frac{2fH}{r_n(2f - r_n \sin\varphi \sin 2\alpha)/\delta h_\alpha + r_n \sin\varphi \sin 2\alpha} \tag{2}$$

For tilt imagery, approximate altitude difference formula:

$$\Delta h = \frac{\delta h_\alpha}{r_n\left(1 - \frac{r_n}{2f}\sin\varphi \sin 2\alpha\right)} H \tag{3}$$

For plane imagery, altitude difference formula:

$$\Delta h = \frac{\delta h}{r} H \tag{4}$$

In the above formulas r_n, δh_α, H, Δh, f, α, φ separately represents radicalization distance of photo nadir point, projection error, relative flying height, height of culture feature, focus of aerial camera, tilt angle of photography and bearing of radicalization distance of photo nadir point .

From above formulas, radicalization distance r_n, projection error δh_α, relative flying height H, focus of aerial camera f, tilted angle of photography α and bearing of radicalization distance of photo nadir point φ should be needed in order to get the height information of culture feature Δh. The solving process of these parameters involves the interior orientation, space resection and other methods.

3. THE METHOD AND PROCESS OF THE HEIGHT INFORMATION EXTRACTION METHOD BASE ON THE SINGLE AERIAL PHOTO

3.1 The interior orientation and space resection for the digital image

In the height solution formula, the radicalization distance r_n、projection error δh_α are the distances under the photo coordinate system, the processed images are digital ones, so it is necessary to carry through the interior orientation to get the relationship between the scanning coordinate system and the photo coordinate system, we can use the formulas as follows:

$$\begin{cases} x = a_0 + a_1 \cdot I + a_2 \cdot J \\ y = b_0 + b_1 \cdot I + b_2 \cdot J \end{cases} \quad (5)$$

In above formula, x and y are the photo coordinates of the fiducial marks, I and J are the corresponding scanning coordinates. With the four photo coordinates and the corresponding scanning coordinates of the fiducial marks, we can get the six parameters($a_0, a_1, a_2, b_0, b_1, b_2,$) with the adjustment method.

In the formulas of (2), (3), (4) the relative height H is equal to Zs-Z (Z is the height of the building bottom point, Zs is the height of the camera station). If we want to get the height H, we should take the space resection to get the elements of exterior orientation, in the formula (4), the tilt angle of photography can be calculated with the elements of exterior orientation, besides, the coordinates of the nadir point can also be calculated with the elements of exterior orientation. So it is necessary to take the space resection to get the elements of exterior orientation with a quantity of GCPs.

3.2 The calculation of the nadir point coordinates

In order to get the radicalization distance of photo nadir point, we should get the nadir point coordinates on the image, we can use the following methods:

(1) When the image is horizontal or approximately horizontal, we can consider the photo nadir point and the principal point of photograph are concurrent, so the nadir point coordinates are (0, 0).

(2) When the image tilted, there are two methods to calculate the nadir point coordinates:

①We can use the collinearity condition equation to deduce the nadir point calculation formula:

$$\begin{cases} x_n = -f \dfrac{c_1}{c_3} \\ y_n = -f \dfrac{c_2}{c_3} \end{cases}$$

Then with the interior orientation parameters, we can get the nadir point coordinates under the scanning coordinate system.

②When the image is tilted, because the projection error is on the radial line of the nadir point, so if we get some vertical lines of the buildings, the nadir point coordinates can be calculated with these lines. To ensure the precision, to the best of our abilities, we should capture the vertical lines of the tall buildings, because these vertical lines are clear, the captured precision is high.

For these two methods, the first method is suitable for the condition that the exterior orientation parameters are known or can be calculated. The second method is suitable for any condition, but it needs to capture the vertical lines manually, so the precision is not high, when we cann't get the precise exterior orientation parameters, we can use this method.

3.3 The relative height calculation of the bottom point of the vertical line

The relative height H is equal to Zs-Z , Z is the height of the building bottom point, Zs is the height of the camera station, so it is necessary to calculate Z with the monoposition theory with the help of the DEM, the monopositon theory is described as figure 1:

$$\begin{cases} X - Xs = (Z - Zs)\dfrac{a_1 x + a_2 y - a_3 f}{c_1 x + c_2 y - c_3 f} \\ Y - Ys = (Z - Zs)\dfrac{b_1 x + b_2 y - b_3 f}{c_1 x + c_2 y - c_3 f} \end{cases}$$

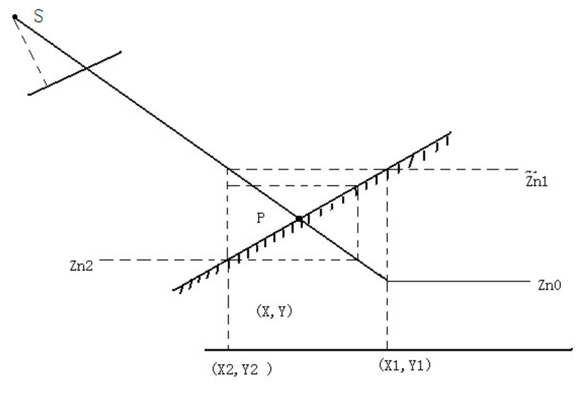

Figure.1 The Principal of the Monoposition Theory

3.4 The building height calculation

When the radicalization distance, projection error, relative flying height are all calculated, we can use the formula (2) to get the building height. When we use the formula (3) or (4), it is necessary to calculate the tilted angle of photography and bearing of radicalization distance of photo nadir point.

The calculation formula of the parameter $\sin\varphi$ can be analyzed with the following Figure 2:

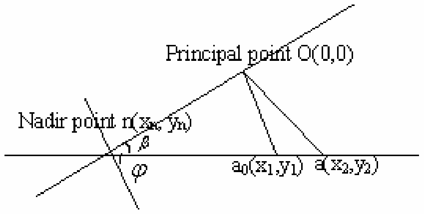

Figure.2 The triangulation relationship for the bearing of radicalization distance of photo nadir point φ

$$\sin\varphi = |\cos\beta| = \left|\frac{\vec{s_1}\cdot\vec{s_2}}{|\vec{s_1}|\cdot|\vec{s_2}|}\right| = \left|\frac{x_n(x_1-x_n)+y_n(y_1-y_n)}{\sqrt{x_n^2+y_n^2}\cdot\sqrt{(x_1-x_n)^2+(y_1-y_n)^2}}\right|$$

With the help of the spin matrix relationship, we can get the formula: $\cos\alpha = c_3$, so,

$\sin 2\alpha = 2\sin\alpha\cdot\cos\alpha = 2\cos\alpha\sqrt{1-\cos^2\alpha} = 2C_3\sqrt{1-C_3^2}\ (\sin\alpha > 0)$ The coordinates X and Y of the bottom and top point of the buildings are same, so the height of the top point can be calculated with the formula: $Z' = Z + \Delta h$ (Z is the height of the bottom point), then we can get the three-dimensional coordinates of the top point.

4. EXPERIMENT RESULTS

In the experiments, the scale of the image is: 1/3750, the focus is 152.908mm, collimating marks distance is 212mm, the flying height is about 575m, the exterior parameters are :

$$X_s = 511826.68$$
$$Y_s = 4145628.60$$
$$Z_s = 572.793 \text{(unit:meter)},$$
$$\alpha_x = 0.00194005$$
$$\omega = 0.007211$$
$$\kappa = -0.0646547 \text{(uinit:radian)}.$$

The partial experiment results are listed in the table.1 and table .

Index	Height	Projection error	Radiation distance	Horizontal	Error 1	Titled 1	Error 2	Titled 2	Error 3
1	18.74	0.3053	10.8696	15.9327	-2.8073	15.9384	-2.8016	15.9383	-2.8017
2	19.35	1.6049	48.7857	18.6603	-0.6897	18.6973	-0.6527	18.6961	-0.6539
3	2.35	0.3322	84.0154	2.2260	-0.124	2.2282	-0.1218	2.2281	-0.1219
4	17.13	2.7183	89.1277	17.3172	0.1872	17.3913	0.2613	17.3891	0.2591
5	21.87	3.3841	89.1363	21.5578	-0.3122	21.6168	-0.2532	21.6146	-0.1554
6	49.40	9.7975	112.9627	49.2436	-0.1564	49.4334	0.0334	49.5169	0.1169
7	17.27	3.5224	115.1690	17.3675	0.0975	17.4651	0.1951	17.4621	0.1921
8	17.27	3.8548	127.0017	17.2349	-0.0351	17.3425	0.0725	17.3392	0.1692
9	19.35	2.3895	71.5043	18.9543	-0.3957	19.0071	-0.3429	19.0054	-0.3446
10	2.55	0.3322	84.0154	2.3260	-0.224	2.3282	-0.2218	2.3281	-0.1219
11	17.13	2.7183	89.1277	17.3172	0.1872	17.3913	0.2613	17.3891	0.2591
12	21.87	3.3841	89.1363	21.5578	-0.3122	21.6168	-0.2532	21.6146	-0.1554
13	17.13	2.7289	89.8093	17.2527	0.1227	17.3272	0.1972	17.3249	0.1949
14	49.40	9.7975	112.9627	49.2436	-0.1564	49.4334	0.0334	49.5169	0.1169
15	49.40	9.8528	113.8897	49.1183	-0.2817	49.3103	-0.0897	49.2936	-0.1064
16	17.13	3.5939	117.5893	17.3556	0.2256	17.4553	0.3253	17.4523	0.3223

Table.1 The experiment results when we consider the nadir point is the principal point of photograph

Index	Height	Projection error	Radiation distance	Horizontal	Error 1	Titled 1	Error 2	Titled 2	Error 3
1	18.74	0.3060	10.9174	15.8967	-2.8433	15. 8975	-2.8425	15.8974	-2.8426
2	18.74	0.5658	18.2346	17.6014	-1.1386	17.6162	-1.1238	17.6158	-1.1242
3	18.74	0.7428	24.0134	17.5466	-1.1934	17.5635	-1.1765	17.5630	-1.1770
4	18.74	0.9623	30.7724	17.7387	-1.0013	17.7578	-0.9822	17.7572	-0.9828
5	18.74	1.3299	41.5118	18.1724	-0.5676	18.1973	-0.5427	18.1965	-0.5435
6	19.35	1.6052	49.8017	18.2821	-1.0679	18.3220	-1.028	18.3207	-1.0293
7	18.74	1.6823	52.2102	18.2772	-0.4628	18.3023	-0.4377	18.3015	-0.4385
8	19.35	2.2913	69.5359	18.6897	-0.6603	18.7332	-0.6168	18.7318	-0.6182
9	19.35	2.3896	72.2990	18.7466	-0.6034	18.7932	-0.5568	18.7916	-0.5584
10	2.35	0.3323	84.0363	2.2416	-0.1084	2.2462	-0.1038	2.2461	-0.1039
11	21.87	3.3596	86.0195	22.1772	0.3072	22.2569	0.3869	22.2538	0.3838
12	17.13	2.7289	89.8093	17.2527	0.1227	17.3272	0.1972	17.3249	0.1949
13	49.40	9.8530	113.2326	49.4045	0.0045	49.5617	0.1617	49.5480	0.1480
14	17.27	3.5225	116.2019	17.2136	-0.0564	17.3026	0.0326	17.2999	0.0299
15	17.13	3.5939	118.6099	17.2063	0.0763	17.2962	0.1662	17.6934	0.1634
16	17.27	3.8548	128.0410	17.0951	-0.1749	17.1932	-0.0768	17.1902	-0.0798

Table.2 The experiment results for the nadir point

The Tab.1 lists the experiment results when we consider the nadir point is the principal point of photograph, The Tab.2 lists the experiment results for the nadir point. In the two tables, the "Horizontal" represents the height results calculated with the formula (4), the "Titled 1" represents the height results calculated with the formula (3), the "Titled 2" represents the height results calculated with the formula (2), the "Error 1" ,"Error 2", "Errir 3" separately represent the error between the calculated height with the the formula (4),(3),(2) and the true height value. The unit of the "Height", "Horizontal", "Titled1","Titled 2","Error 1","Error 2","Error 3" is meter, and the unit of the projection error and the radiation distance is millimeter.

The error analyzation of the two group data is drawn on the Figure 3, in the figure, the horizontal ordinate and the vertical ordinate separately represent the radiation distance and the "Error 1". The continuous line represents the results when we consider the nadir point is the principal point of photograph, the imaginary line represents the results for the nadir point. Through the experiment results, we can conclude that:

(1) The precision of the results for the nadir point of photograph is higher than the results for the principal point of photograph;

(2) When the image is approximately horizontal, we can use the principal point of photograph to substitute the nadir point to calculate the buildings' height.

(3) When the radiation distance and the projection error are great, the precision of the height calculation is higher;

(4) When the image is approximately horizontal, the calculation results with the formula (2), (3), (4) are approximately equal.

5. CONCLUSIONS

In the paper we developed the method to calculate the building height with the projection error formula with the help of DEM, the calculation process is simple, convenient and the precision is very high. The vertical line of the buildings on the image can be extracted with the line extraction operator to substitute the captured process manually, we will introduce the research achievements in other papers.

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