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VARIOUS METHODS FOR PRODUCING ORTHOPHOTO OUT OF CENTRAL PERSPECTIVE IMAGERY

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ABSTRACT:

DEM(Digital Elevation Model)-based digital differential rectification is a very popular method for producing Digital Orthophoto Model(DOM) out of central perspective imagery. However, it is by not the unique way. Three other non-DEM methods are proposed and discussed technically in the paper. (1) If central perspective-sensed images are in the form of stereopair, then parallax can be computed by stereo-image matching and directly applied to differential rectification. Thus, the procedure of making DEM is bypassed. (2) If multi-centered perspective images do not meet the requirements of stereopair constitution, but certain spatial distances exist among the centers, then by using the mathematical formula derived in paper, parallax-based differential rectification on the basis of image matching can be done. The figure and formula illustrate that such ill geometrical condition does not seriously affect the results quality. (3) If topographic data, such as DRG (Digital Raster Graphics) or DLG (Digital Line Graphics), of the area distributed with dense objects, are available, then orthorectification can be implemented by registering the feature lines out of DRG or DLG with those extracted from a single frame of image. Besides, a new method, based on mathematical morphology, used for the matching of feature lines, is also presented.

1. INTRODUCTION

It is generally believed that the production of Digital Orthophoto Model(DOM) out of perspective imagery must adopt DEM(Digital Elevation Model)-based digital differential rectification method with collinear equations as the mathematical model. So, DEM is indispensable besides a certain number of control points. DEM can be created out of stereopair by analytical photogrammetry or image matching in digital photogrammetry. DEM can also be produced by the digitization of contour lines in topographic maps of corresponding scale, then interpolating. Although the DEM-based digital differential rectification method for producing DOM has become very complete and popular through practical applications, it is by no means the unique way. Three other non-DEM methods that are in connection with various conditions of perspective imagery are discussed technically in the following parts.

2. NON-DEM METHOD IN STEREOSCOPTIC PHOTOGRAMMETRY

In stereoscopic photogrammetry, central perspective-sensed images are in the form of stereopairs. The parallax between left and right image of a stereopair can be calculated out by image matching of digital photogrammetry. With the parallax, differential rectification can be done directly to obtain DOM, and the procedure of computing DEM is excluded.

As illustrated in fig.1, the images P_1、 P_2 taken separately from left and right station have been rectified by exterior orientation elements (or orienting epipolar rays) to turn into the state of vertical imaging. Terrain point A has h as its height, Its coordinates in respective horizontal images are x_1、x_2, which can

be got by using image matching method. Let B stands for baseline, f for camera's principal distance and H for flying height. Their values are all known. The following formula is then derived:

$$\begin{cases} \Delta L = x_1(\dfrac{H}{f} - \dfrac{B}{x_1 - x_2}) \\ \Delta R = x_2(\dfrac{H}{f} - \dfrac{B}{x_1 - x_2}) \end{cases} \quad (1)$$

Where, ΔL and ΔR is A's projective correction in left and right image. They determine A's orthophoto position A_O.

The above process avoids the path of computing height h to make DEM. In one way, it simplifies computation. In another, the points failed in matching (correlation) are not interpolated by height, but by parallax. This has more advantage. Because parallax is based on coordinates in image, in practical operation, image features (road, river, lake, forest, grassland, sand beach etc.) can easily be extracted manually or automatically, and then interpolation can be done along them. Therefore, the blindness of interpolation is evaded and better interpolation result is obtained; Moreover, when the left and right image is rectified simultaneously, then both rectified images can be utilized to perform image re-matching to check and evaluate result precision. Since now only remaining errors are left in the rectified image, larger matching area (target zone) can be used. Through this, matching precision will be increased step by step, result quality will be improved by iterating computation.
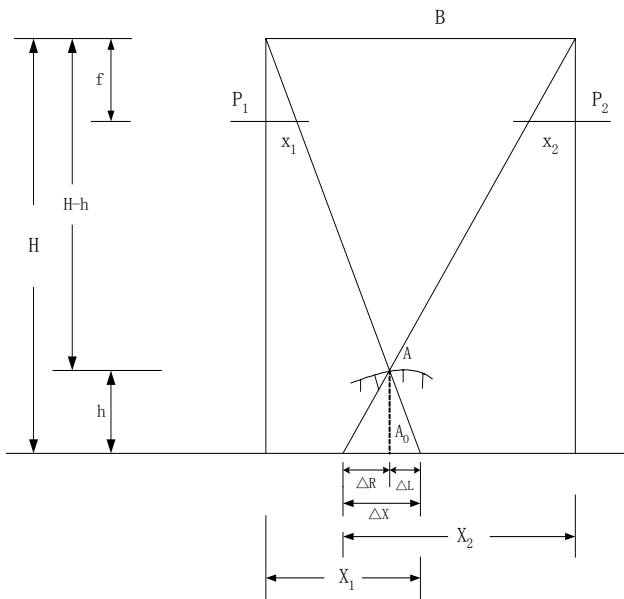
Figure 1.

3. MAKING DOM OUT OF MULTI-CENTERED PERSPECTIVE IMAGES

Not all multi-centered perspective images can form stereopair. But if there are certain spatial distances among those image centers, it is still possible to make DOM utilizing them.

Fig. 2 shows a typical case that two frames of image captured with a same camera or two cameras at different elevation. Obviously, they are unable to be used to constitute stereopair to measure terrain height and produce digital terrain module. However, the issue of producing DOM is not equal to the mathematical issue of making DEM. Differential rectification does not necessarily require DEM. This principle is clearly illustrated in the geometrical figure 2., and mathematical formula can be prudently educed:

$$X = (H_A - H_B)\frac{tg\alpha \bullet tg\beta}{tg\alpha - tg\beta} = x_a x_b (H_A - H_B) \Big/ (f_b x_a - f_a x_b) \qquad (2)$$

Where X is the coordinates of DOM to be solved, f_a, f_b are camera's principal distance, H_A, H_B are flying height, x_a, x_b are coordinates of terrain point P in its respective image.

To note that when terrain point is approaching nadir point, both x_a and x_b are approaching towards zeroes. At the moment, the infinitesimal level of numerator in formula (2) is higher than that of denominator. Hence, X is approaching towards zero. Such mathematical analysis has remarkable photogrammetric meaning that the influence of height errors to differential rectification is small at where near to nadir point. Therefore, even the used multi-centered images are not in the form of stereopair, so ill the geometrical state does not seriously affect the result quality. In practical operation, within the area near to nadir point, big block image matching is employed to solve

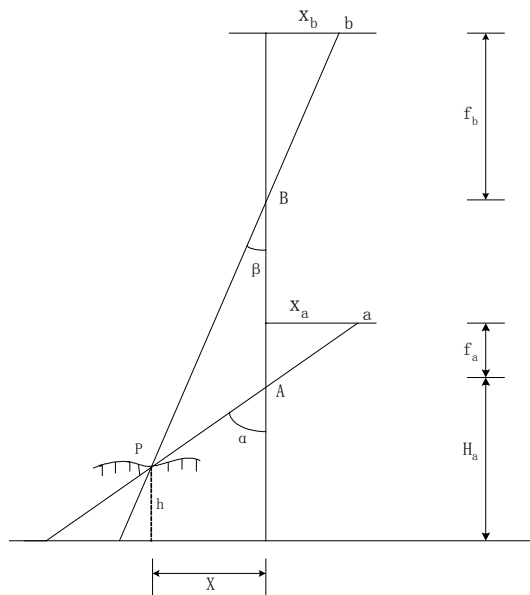parallax by least square matching method or multi-points matching method.

Figure 2.

It is quite meaningful to discuss the mathematical unity of the above two non-DEM methods. The synthetical situation of fig.1 and fig.2 is as fig.3 shows：
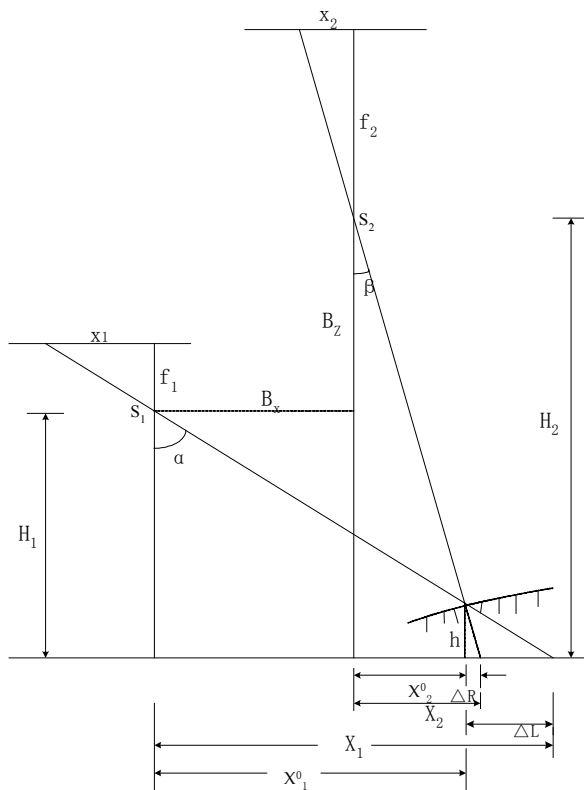
Figure 3.

In Fig.3, two camera's main focal length f_1、f_2, two imaging heights H_1, H_2 and baseline's heft B_X, B_z are all known. Suppose that images have been rectified into horizontal state, x_1, x_2, as the coordinates of the same terrain point in images, can be measured. Now what to be solved is the correction value to the projective error in projection plane ΔL、ΔR or the coordinates of projection X^0_1、X^0_2. The following computational formula are educed:

$$
\begin{cases}
\Delta L = x_1 f_2 (x_1 \dfrac{H_1}{f_1} - x_2 \dfrac{H_2}{f_2} - B_X)/(x_1 f_2 - x_2 f_1) \\
= (H_1 tg\alpha - H_2 tg\beta - B_X)/(1 - \dfrac{tg\beta}{tg\alpha}) \\
= tg\alpha(H_1 tg\alpha - H_2 tg\beta - B_X)/(tg\alpha - tg\beta) \\
\Delta R = x_2 f_1 (x_1 \dfrac{H_1}{f_1} - x_2 \dfrac{H_2}{f_2} - B_X)/(x_1 f_2 - x_2 f_1) \\
= (H_1 tg\alpha - H_2 tg\beta - B_X)/(\dfrac{tg\alpha}{tg\beta} - 1) \\
= tg\beta(H_1 tg\alpha - H_2 tg\beta - B_X)/(tg\alpha - tg\beta)
\end{cases}
\quad (3)
$$

$$
\begin{cases}
X^0_1 = X_1 - \Delta L = H_1 tg\alpha - \Delta L \\
X^0_2 = X_2 - \Delta R = H_2 tg\beta - \Delta R
\end{cases}
$$

It can be noted that when $H_1 = H_2$, $f_1 = f_2$, $B_Z = 0$, formula (3) will be simplified into formula (1). While $B_X = 0$, $B_Z = H_1 - H_2$, fig. 3 will be simplified into fig.2. Then formula (4) ,in nature, is the same to formula (2) At this moment, $X = X^0_1 = X^0_2$.

4. USING DRG OR DLG TO DO IMAGE RECTIFICATIONTRAN

If the topographic data, such as DRG (Digital Raster Graphics) or DLG (Digital Line Graphics), of the area distributed with dense objects, are available, then orthophoto rectification can be implemented by registering the feature lines out of DRG or DLG with those extracted out of a single image.

The essential element of this method is to cut image apart into feature units according to the common visible character both in image needed to rectify and in map, to substitute collinear equations for polynomials (normally, only second or first level equations are used) in each small unit to achieve local rectification. This method is able to offer rather satisfactory result in the area of smooth relief and dense objects. In fact, when solving DEM by using sterescoptic image matching method, it is mainly the ground feature image that play the essential role. Elevations in the area of lean feature are gained through interpolation. There is another case that the aim of image rectification is not to get the orthophoto whose absolute coordinates are very precise, but to superpose image and existing special map to make application analysis. Here the original geometric error of the special map is to be accepted and rectified forcefully over the special map base, then this method has to be employed.

The technical key to this method is the registration of feature lines in image with those in map. In order to reach precise registration with automatic matching method, the following procedure is taken:
(1) To extract homologous feature lines both in image and map by man-steering edge extraction, then to binarize those feature lines

(2) To skeletonize the extracted binary feature lines and then expand them.(the operations are defined in mathematical morphology). The skeleton is given the maximum grey value G_{max} (e.g. G_{max} =100), the other parts formed by dilation step by step are given decreased grey values by ΔG in turn (e.g. 95,90,85,⋯⋯). Then homologous feature lines in both map and image are as fig.4 shows.
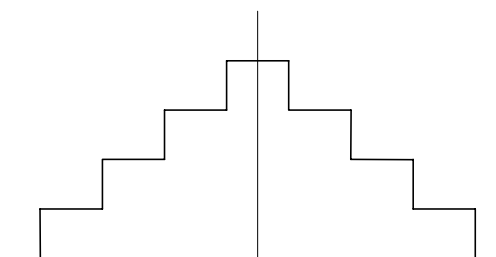

Figure 4.

(3) To match those feature lines by least square mathching. Since the skeleton of feature lines is dilated, gradient effect functions when two homologous lines are close. So the solutions to least square matching are surely convergent. (See fig.5).
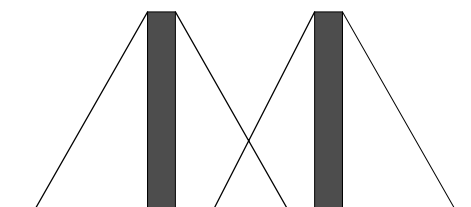

Figure 5.

(4) To transform image by rectification parameters obtained by least square matching so that the image is rectified.

5. CONCLUSION

The three methods proposed in this paper are supplements to the present DEM-based differential rectification way. Such supplements are necessary because (1) they expand the path of DOM making and suit for flexible combination of methods so that they are easily adapted to different production conditions and kinds of application requirements (2) Most of satellite images are non-stereopairs. If data of this type are used to make DOM, the rate of their utilization is greatly increased.

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