SEMI-AUTOMATIC BUILDING EXTRACTION BASED ON LEAST SQARES MATCHING WITH GEOMETRICAL CONSTRAINTS IN OBJECT SPACE

Zuxun ZHANG, Jianqing ZHANG
Wuhan Technical University of Surveying and Mapping, P.R.China
zxzhang@supresoft.com, jianqing@supresoft.com

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ABSTRACT

Building extraction is one of the critical problems in digital photogrammetry. This article describes a semi-automatic way based on the object space. According this method the building extraction is converted into a procedure of leaner template matching with geometrical constrain. For it's potential use in the DPW the approximate positions of the building which are needed for least adjustment are pointed out by operator on the aerial photos. The space coordinates of roof's corners can be calculated by forward intersection. The error equations of least squares image matching are created between image and templates of straight line, and the unknowns are the corrections of the space coordinate of roof's corners. The geometric constraints include right angle、parallel、same height (horizontal) condition and etc. This method is suitable for the houses with flat or gabled roof. From the experiments the method proposed in this paper has been proved to be very accurate and quite robust enough to the noisy.

1. INTRODUCTION

As the result of the great progress of Digital Photogrammetry within last decade, many commercial digital photogrammetric workstations (DPW) have been developped and applied into practical production; and they are progressively replacing the disappearance of the traditional photogrammetry equipment. Until now, with the development and consummation of the theory and algorithm of image matching, most of the functions of digital photogrammetric workstations, such as orientation (mainly inner orientation and relative orientation), DEM generation, orthophoto creation and mosaic, pass point transformation and measurement in areatrianglation, have reached high automation (Zhang, 1998). But there is still rather a long way for us to accomplish in the practice application of automatic and semi-automatic man-made feature extraction. For the sake of application, we shall select an ideal "semi-automatic" mathematical model firstly, and then expand its "semi-automatic" part steadily step by step, and finally achieve the automatic man-made feature extraction. That means: an ideal "semi-automatic" mathematical model should be open and expansible. According to our experience and understanding, automation of man-made feature extraction could be divided into three parts. ① Recognition and segment, divided the feature we would extract, for example, houses, from its background, and then distinguish its type, (such as houses-- the types of their roofs); ②Set the initial value, for example, set the seed points of road, or corner point of houses; ③Accurate positioning. And we may find out that automatic recognition is rather easy for people, especially to recognize from the aerial image under the condition of stereo measurement; and on the other hand, it is rather difficult and accurate positioning is relatively easy for computer.

Although there has been a great deal of study in automatic house extraction, for example, using digital surface model (DSM) to recognize or to set the initial value of houses (Balstavias, 1995; Huertas, 1989; Kim, 1996; Trinder, 1995), but it is still rather difficult in the city block crowded with buildings. In order to give prominence to emphasis and for the sake of possibility of application, this paper would be centralized in the discussion of accurate positioning and mathematical model of houses, which have been manually recognized and based on manually setting type of house and initial value of roof boundary.

The mathematical model of house accurately positioning is the least squares matching (Heipke, 1992) with the geometric constraint conditions in the object space. Namely, the beeline template and boundaries are used in the least squares matching in order to get the space coordinates of house-corners directly, under certain geometric constraint conditions.

2. MATHIMATICAL MODEL

2.1. Least squares Adjustment model

As shown in the figure 1, the initial values of house corners （i =1、2、3、4）have been gained, but there are still errors（ΔX_i、ΔY_i、ΔZ_i）. Admittedly, the errors in object space shall cause the errors of the corner points in image:

$$dx_i = f_x(\Delta X_i, \Delta Y_i, \Delta Z_i)$$
$$dy_i = f_y(\Delta X_i, \Delta Y_i, \Delta Z_i)$$

Because each straight edge of the house connects to two neighbor corner points (for example: i, j), the position of every point in the straight edge shall be affected by the errors of two corner points:

$$dx = \varphi_x(dx_i, dy_i, dx_j, dy_j)$$
$$dy = \varphi_y(dx_i, dy_i, dx_j, dy_j)$$

The shifts (dx, dy) of the image point can be detected by a beeline template. Suppose gray level of beeline template is

$$g_m(x, y)$$

And gray level of image is

$$g(x, y)$$

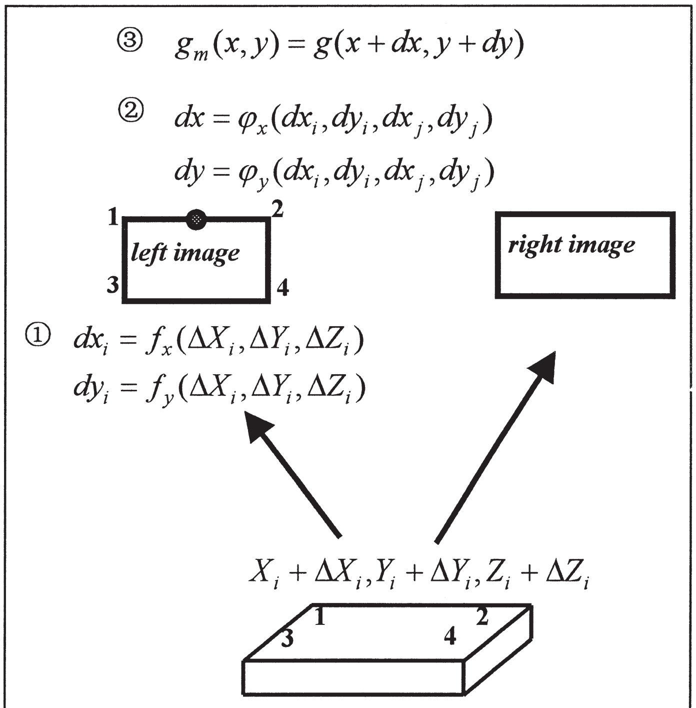


Figure 1. Adjustment model

Then the shifts of the image point can be detected by template matching:

$$g_m(x, y) = g(x + dx, y + dy)$$
$$v(x, y) = g'_x(x, y)dx + g'_y(x, y)dy - [g_m(x, y) - g(x, y)]$$

Replacing (dx, dy) with the object-space-coordinate correction values (ΔX、ΔY、ΔZ) of corner points i、j, the least squares adjustment model of the precise position of the house can be acquired:

$$v_g(i, j) = a_{1,i,j,k}\Delta X_i + a_{2,i,j,k}\Delta Y_i + a_{3,i,j,k}\Delta Z_i + a_{4,i,j,k}\Delta X_j + a_{5,i,j,,k}\Delta Y_j + a_{6,i,j,k}\Delta Z_j - \Delta g(i, j, k) \qquad (1)$$

The adjustment model does not consider the error from absolute orientation of the stereo model.

2.2. Geometrical constraint

There are very strict geometric constraint conditions for the house in object space. If the geometric constraint conditions are used, the stability and accuracy of the solution will be greatly increased. That is why the solution scheme is based on object space. The geometric constraint conditions depend on the type of houses. Some main geometric constraint conditions of houses are described bellow:

① **Orthogonal (right-angle) constraint condition**

As illustrated in Figure 2, three corner points of the house consist of a right angle $\theta = 90°$

$$dx = l_x = 0$$
$$(X_{i+1} - X_i)\cos\theta + (Y_{i+1} - Y_i)\sin\theta = 0$$

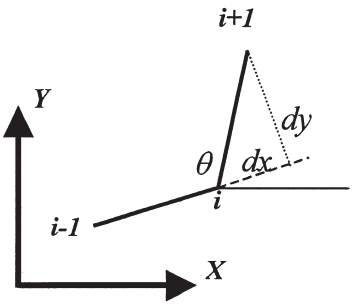


Figure 2. Orthogonal constraint

Finally the orthogonal constraint condition is:

$$(X_i - X_{i+1}) \cdot \Delta X_{i-1} + (X_{i+1} + X_{i-1} - 2X_i) \cdot \Delta X_i + (X_i - X_{i-1}) \cdot \Delta X_{i+1} + (Y_i - Y_{i+1}) \cdot \Delta Y_{i-1} + (Y_{i+1} + Y_{i-1} - 2Y_i) \cdot \Delta Y_i + (Y_i - Y_{i-1}) \cdot \Delta Y_{i+1} - L_{Xi} = 0 \tag{2}$$

② Collinear constraint condition of three points

As illustrated in the Figure 3, the projections of the three points, i-1、i、i+1, of the gable roof on the XY plane should be in the same line. That is they are collinear:

$$dy = l_y = 0$$

$$-(X_{i+1} - X_i)\sin\theta + (Y_{i+1} - Y_i)\cos\theta = 0$$

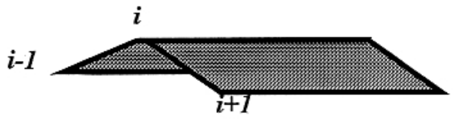


Figure 3. Collinearity

The collinear condition of three points is:

$$(Y_i - Y_{i+1})\Delta X_{i-1} + (Y_{i+1} - Y_{i-1})\Delta X_i + (Y_{i-1} - Y_i)\Delta X_{i+1} + (X_{i+1} - X_i)\Delta Y_{i-1} + (X_{i-1} - X_{i+1})\Delta Y_i + (X_i - X_{i-1})\Delta Y_{i+1} - l_y = 0 \tag{3}$$

③ Equal height constraint condition

No matter the houses with flat roof or gable roof, there should be some roof point, which have the same height, then they should be under the condition of equal height:

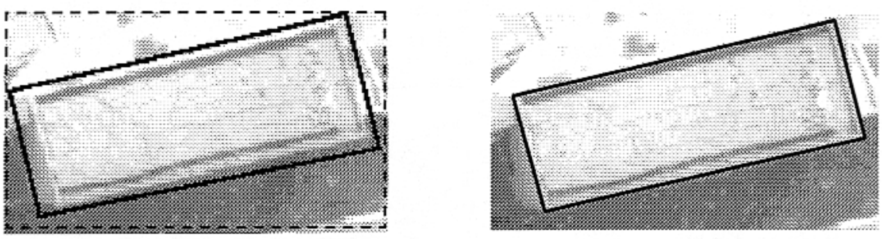
$$Z_{i+1} - Z_i = l_z = 0$$

$$\Delta Z_{i+1} - \Delta Z_i - l_z = 0 \tag{4}$$

Listed above are some basic geometric constraint-conditions for houses. According to the different types of houses, some other relative geometric conditions can be added. Combining the adjustment model (1) with the geometric constraint condition (2), (3) and (4), the least squares matching model, which is based on geometric constraint condition in object space, could be used in the extraction of houses.

3. The results of implementation

The initial values could be detected by DSM, or to be determined by the rectangle, which is parallel to the (x, y) coordinate axes of image, as illustrated in the Figure 4a. In order to examine the validity of the model mentioned above, the initial values are determined by the polygon parallel to the boundary of the house, just like the rectangle with black line in Figure 4a. Figure 4b is the result of the adjustment model mentioned above.



a b

Figure 4. Result of the precise position of the flat floor house.

The initial values of gable roof are determined by pointed out the approximate position of the roof boundary, as illustrated in the Picture 5a. The result of the adjustment model mentioned above is shown in Fig 5b. The superposition of the original scanned image enlarged to 4 times and the result of precise position is illustrated in Figure 6. It shows that the result of precise matching could be perfect and satisfying, because of using optimal matching with all information of house boundary and combining the geometric conditions.

a

b

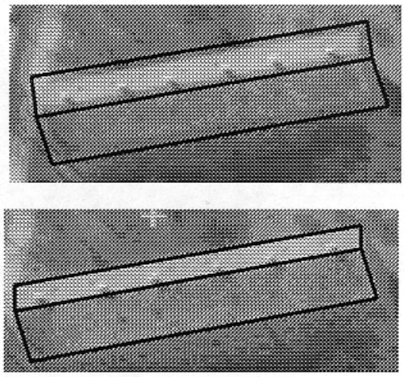


Figure 5. Precise position result
of gable roof

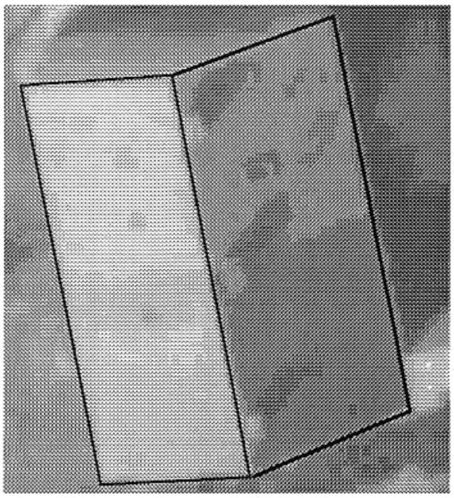


Figure 6. Enlarged image and the result
of precise position

4. Conclusion

Through the preparatory test, the mathematical model of semi-automatic house extraction has been approved as correct. Besides its perfect geometric accuracy, its geometric constraint condition in object space enables it to prevent the noise. For example, neither the boundary or individual corner point in shadow, nor the low contract of some boundaries of houses (weak boundary), could affect the final results.

In next research work, besides the improvement of the mathematical model mentioned above, the ability and range of automation should be increased, in order to consummate the semi-automatic house extraction step by step. These will be the most important content of the study for digital photogrammetry workstation.

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