THREE DIMENSIONAL RECONSTRUCTION AND VISUALIZATION OF REGULAR HOUSES AND THEIR TEXTURE FROM IMAGE PAIR

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ABSTRACT

Three-dimensional reconstruction and visualization of houses with their texture rendering are very useful in urban planning, communication and tourism etc. An automation of house reconstruction is tested. The digital surface model (DSM) is first created by image matching, based on hierarchical relaxation, and the approximate positions of houses are extracted by detecting the lumps or hills. Within these areas single image analysis and perceptual organization are made to detect the boundaries of house. A mathematical model based on least squares matching with geometrical constrains in object space has been used to recover the house. Finally, texture rendering of visual surface on the buildings is achieved based on the complete 2.5D triangulated irregular network (TIN) of house surface. The real landscape of urban is constructed.

The theory and method used in the reconstruction procedure mentioned above are introduced in this paper, and the relative experiment results are shown and analyzed in each parts.

1. I NTRODUCTION

Current methods of photogrammetry have solved most parts of the problem in automatic aerial triangulation and automatic digital elevation model (DEM) acquisition. Nevertheless, because of the limitation of visual computational theory and the hardware equipment as well as the complexity of the image data, the research work of the automatic measurement for space objects is in the primary stage. The existing research results demonstrate that the problem of automatic measurement for space objects is difficult to be fully solved at current stage. It is a bottleneck in full automation of digital photogrammetric systems. In view of this situation, researches on the methods of semi-automatic measurement for space objects have invited much attention. And these researches have achieved some progress and paved the way for the final solution to the problem.

The paper introduces some elementary experiments of automatic extraction, 3D-reconstruction ad visualization of houses with the basic procedures as follows: Using VituoZo digital photogrammetry system to begin stereo matching of stereo image pairs and acquiring digital surface model (DSM), sequentially Extracting the approximate range of the houses. Secondly, analyzing the single image and extracting the boundaries of the houses. Then, reconstructing 3D geometrical models of houses by least squares matching with geometrical constraint conditions in object space (Zhang, 2000). And finally realizing the reconstruction of visible surface texture based by considering the full 2.5D triangular irregular network (TIN) in the building surface and based on the original image, and creating real 3D landscape of a city.

2. GENERATION OF DSM AND DETERMINATION OF APPROXIMATE LOCATION OF HOUSE

2.1 Image Matching and DSM Generation

The use of DSM and DEM in house detection is getting more and more important（Baltsavias, 1995; Haala, 1995; Weidner, 1997）. Image matching, which is a process to search homologous images in two images of stereo pairs, is a key technique to DSM generation. Generally, it may adopt feature-based matching or area-based matching. However, the isolated single point matching, no matter whether feature-based or area-based matching, results in a rather low reliability. Hence, more researches are focused on global matching （Heipke 1992. The generation of DSM presented in the paper is realized in VirtuoZo, a commercial digital photogrammetry system (DPW).

VirtuoZo DPW is an image matching system based on image space, adopting the technique of pyramid data structure and multi-level global image matching. It is a global matching algorithm with probability relaxation based on the bridge-mode.

First, by using the correlation coefficient ρ , select n candidate points of homologous image in neighbor image: j_1, j_2, …, j_n. Compute the initial probability of each candidate point:

$$p^0(i,j) = \rho(i,j) \Big/ \sum_{j=0}^{m} \rho(i,j)$$

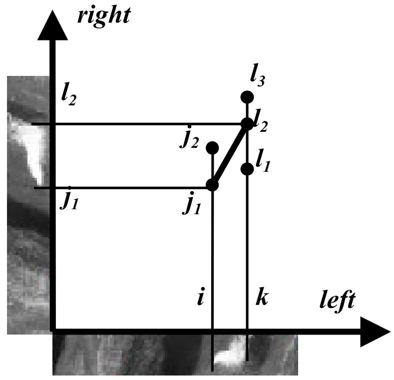


Figure 1. Bridge mode

Then, considering the relation between image point i and its neighbor point k, for instance, calculate the compatible coefficient *C(i, j, k, l)* between them. As demonstrated in figure 1, the horizontal axis represents the left image while the vertical the right. Based on the principle of local maximization of correlation coefficient, compute for two image points (i and k) in the left image their candidate points of homologous images in the right image (j_1, j_2) (l_1, l_2, l_3). If (i, j_1) and (k, l_2) are the right two of homologous point pairs, the similarity of image segments between the left and the right image is in accordance with the compatible coefficient: $C(i,j;k,l) \propto \rho(ik, j_1l_2)$. It may render an efficient calculation of geometrical distortion of the homologous points, which is the essence of the bridge-mode method; that is, it connects all the matching points between i and its neighbour points (set k), which is a set of neighbour points. The probability $p^r(i,j)$ is modified with the method of probability relaxation in an iterative procedure.

$$q(i,j) = \sum_{k=1}^{n(k)} \left(\sum_{l=1}^{m(l)} C(i,j;k,l)\right) \cdot p^{r-1}(i,j)$$
$$p^r(i,j) = p^{r-1}(i,j) \cdot (A + B \cdot q(i,j))$$
$$p^r(i,j) = p^r(i,j) \Big/ \left(\sum_{j=0}^{m} p^r(i,j)\right)$$

The algorithm has a full consideration of global relation of image matching and enhances significantly the reliability of the result. Figure 2 shows DSM of the urban area generated by VirtuoZo, in which the houses are appearing as lumps.

Figure 2. Urban DSM

2.2 Detection of Local Prominence Area

The above analysis tells that houses are shown at ‘lumps’ in DSM. And the so-called detection of local prominence area (LPA) is a process of separating the lumps from DSM and extracting the boundaries. The paper adopts a heuristic searching method based on the principles of maximalization of gradient differences and minimalization of height difference（Qiu, 1997）, which reguires that the boundaries of local prominence area should be placed where gradient difference of DSM is largest and where the height difference (or parallax) of two neighbouring points in the the boundaries should be minimal.

If s(x,y) is the slope value of the point(x,y), then the module G(s(x,y)) of the slope difference rate is:

$$G(s(x,y)) = [(\partial s/\partial x)^2 + (\partial s/\partial y)^2]^{1/2}$$

And the parallax between point I and point j is :

$$\Delta p = \left\| p_i - p_j \right\|$$

The cost function from point *i* to *j* is acquired:

$$C(i,j) = \gamma \cdot [G(s(x_i,y_i)) + G(s(x_j,y_j))] \big/ (\Delta p + 1)$$

According to the criterion:

$$C(i,j) = \max$$

The LPA, where the house may be exist, can be extracted.

Besides, the extraction can be by mathematical morphology: A simple low-pass filtering is used for DSM first. Then, the algorithm of extracting the peak point by mathematical morphology is adopted to extract all local peak-points of 3d DSM. The LPA is generated by region growing, based on the peak-points as the seeds. Finally, the boundary of LPA is extracted by edge following algorithm. The result is similar as the heuristic searching mentioned above.

3 Boundary Extraction and 3D Reconstruction of Regular House

3.1 Extracting for Roof of the Simple Regular House

The extraction of the roof boundary is the so-called feature extraction by considering the intrinsic properties of the house structures. It is well know that roof is consisting of boundaries, which are straight lines usually. Therefore extraction of the straight lines is a major component of it. However, the structure of the house roof is complicated and of various types. It’s hard to give a general description of roofs’ intrinsic properties. Thus, it is difficult to give a general extraction algorithm of the house boundary extraction. Hereafter, we only discuss the boundary extraction of simplest regular house with the widest application. That is the boundary extraction of the roofs with flattop and fastigium house.

The method discussed in the paper is composed of two parts: a). Image processing, which includes straight-line extraction and area construction. b). Perceptual organization, which consists of organizing the fragmented and low-level information into higher level descriptions (Hericsson 1995). As shown in Figure 3. First, extract straight lines (Figure 3.b) from image windows (Figure 3.a) partitioned from original images. Analyze these broken straight lines and remove those not orienting to the housing main direction and fragmented lines (Figure 3.c). Extend the lines and compute their intersections to construct an area (Figure 3.d). Give a comprehensive analysis of the information about the straight lines and the area. Branch the areas and then merge them to acquire the boundary of the flat top house (Figure 3.f).

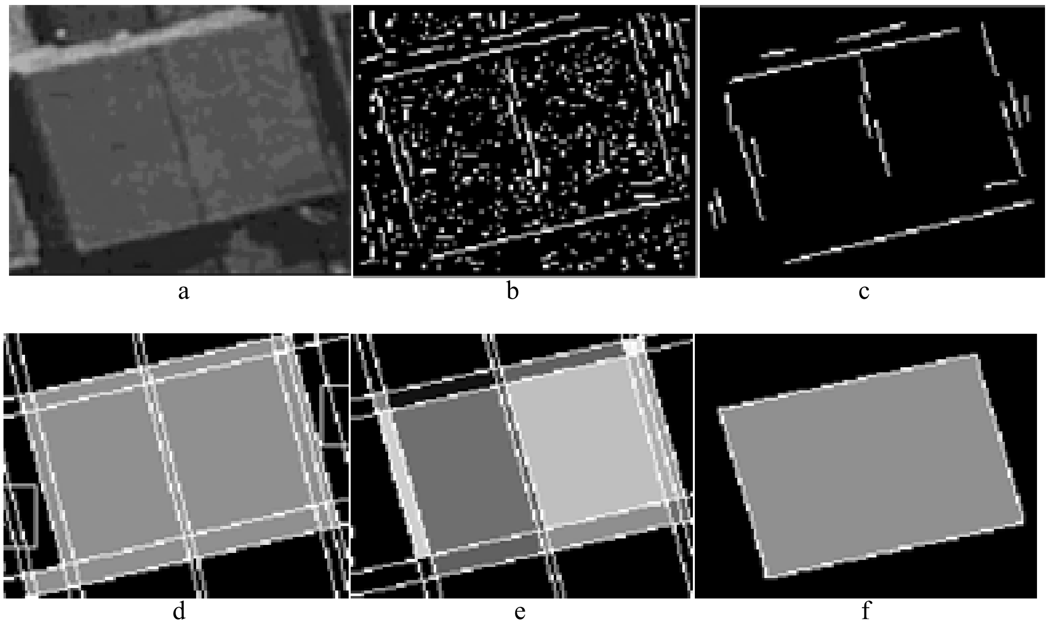


Figure 3. Extraction procedure of flattop

The algorithm of flattop extraction, mentioned above, is also suitable for the extraction of “L” shaped houses, as shown in Figure 4. Above scheme can be alternated and extended in order to apply to fastigium house. Considering the fact that fastigium house generally has its main direction, the lines in the main direction can firstly be extracted and then the lines nearly perpendicular to them section by section. The extraction result of fastigium house is shown in Figure 5.

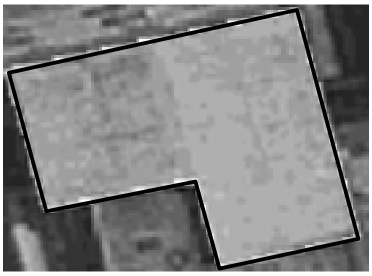


Figure 4. Extraction result of flattop

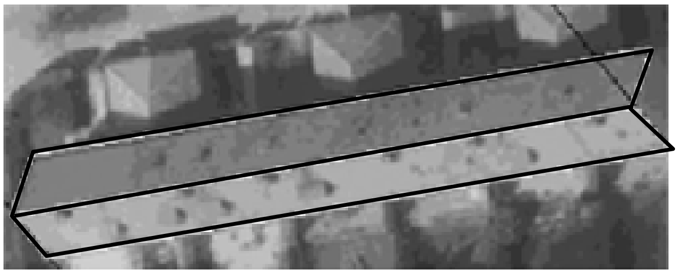


Figure 5. Extraction procedure of fastigium house

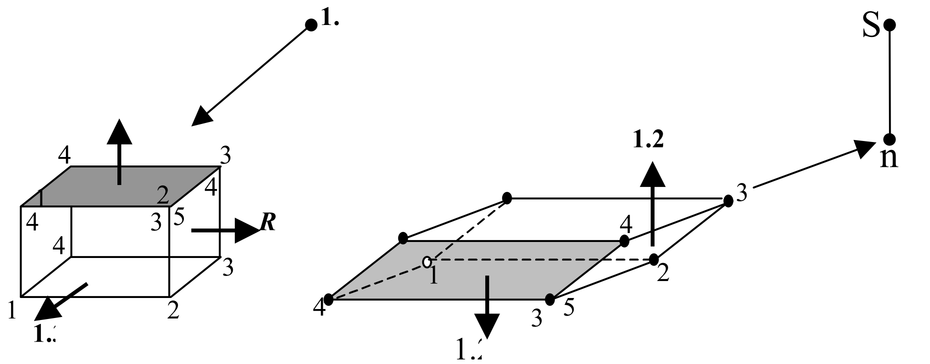
3.2 3D Reconstruction of House

The extraction scheme of housing boundary mention above is based on the analysis of single image. House could be reconstructed in object space through extracting the corresponding house boundaries in the left and right image. But, the paper adopts the scheme based on the least squares matching with geometrical constraints in object space (Zhang, 2000). Based on the least squares matching of straight-line template, the scheme introduces the geometrical constraints in object space, which not only ensures the accuracy of the house reconstruction but also improves the reliability with the features of good noise resistance.

4. Restoration of the visible surface texture of the house

4.1 Determination of Visibility of Wall Surface

Because the aerial image is central projection, the roof of the house is generally visible. But for the walls, some of them are visible, called visible walls. Some are shadowed, called invisible walls. The texture of the former can be extracted form the image while not of the latter. Therefore, it’s necessary to determine the visibility of the walls to extract their texture (Figure 6).



(a) Object space (b) Image space

Figure 6. Determination of Visibility of Wall Surface

The corner points on each surface of the house (roof or wall) should be numbered in certain order, to ensure that the normal of each surface points to the outside of the house according to right-hand rule. Figure 6 (a) indicates that both normal F of the front wall and normal R of the right wall point to the outside of the house. When these wall points are projected into the image, the numbers of them should keep unchanged (Figure 6(b)). Now, the normal R of the projection face of right wall surface on image is upward, towards the projection center, and thus it is visible. The projection normal F of the front wall on image is downward, away form the projection center, and thus it is invisible.

4.2 Extracting the Surface Texture of the House

In object space, each surface of the house consists of TIN. The original image contained in each triangle of the house's TIN corresponds to the triangles' texture of the visible surface TIN in 3D object-space.

In OpenGL and 3D studio, after determining 3D coordinates of the vertex of a polygon and its correspondent 2D coordinates in certain texture piece, a 3D-polygon surface with texture map is constructed. The length and width of the 2D-texture piece must be power series of two, and the texture coordinate adopts normalization relative value (0.0-1.0). To form a texture map, the paper adopts the following way to designate the 2D texture coordinates of the triangle's vertex.

Figure 7 shows that point A; B and C are three vertexes of triangles on the invisible sides. The circumscribed rectangle is determined by their 2D coordinate. And the lengths of the rectangles' sides are extended into the power series of two. The gray level, or trichromatic value RGB, in the range of the circumscribed rectangle of the triangle ABC are extracted in the aerial image. Add the texture coordinates of the triangle's 3 vertexes A, B and C are assigned as A:((x1-x0)/wt,(y1-y0)/ht);B:((x2-x0)/wt,(y2-y0)/ht);C:((x3-x0)/wt,(y3-y0)/ht).

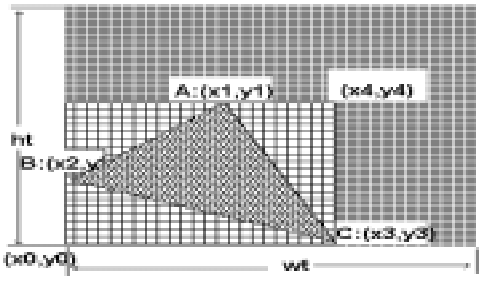


Figure 7. 2D texture coordinates of triangle vertexes

Every triangle of the house's 3D-surface TIN is projected into the left and right images. The texture extracting from the visible triangle with larger areas and to better the boundary extraction of complex housing. Figure 8 and Figure 9 show the example of reconstruction and visualization of regular houses and their texture from the black-white aerial images, created by the method mentioned above, and Figure 10 shows a 3D model of urban area from the color aerial images.

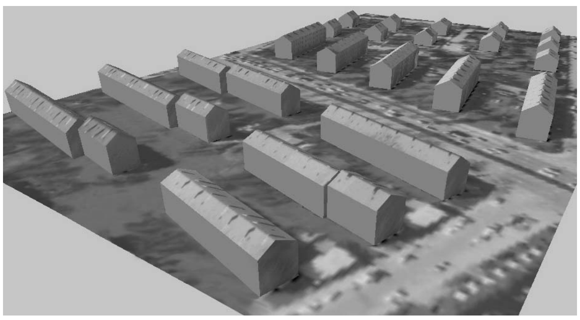


Figure 8. Black-white 3D urban model

Figure 9. Another view of same area as in Figure 8.

Figure 10. Color 3D urban model

5. CONCLUSIONS

Urban 3D modeling and visualization are important components of virtual realism (VR) technology, which can be realized by using digital photogrammetry. The experiment, introduced in this paper, which includes the image matching, automatic extraction of DSM, image segment by Using DSM, separation of the house from the background of image, single image analysis of the left and the right image, extraction of the housing boundary, reconstruction of the house's geometric model by employing line template least squares matching with geometrical constrains and the whole procedure of automatic extraction of roof and wall texture on images, is beneficent and successful. The method proposed in the paper has the features of high automation and efficiency. However, further efforts are required to improve the reliability of image matching in urban areas especially those with highly-dense houses, to increase the quality of DSM and to be better the boundary extraction of complex housing.

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