AUTOMATED 3D BUILDING GEOMETRICAL MODELING FROM DSM

Yan Li [a], Peng Gong [a,b] , MB. Babu[c]

[a] International Institute for Earth System Science, Nanjing University, Nanjing, Jiangsu, 210093,P.R.C. liyan@nju.edu.cn
[b] Institute of remote sensing applications, Chinese Academy of Sciences, LARSIS, gong@irsa.ac.cn
[c] PASCO Corporation, 1-1-2 Higashiyama, Meguro-ku, Tokyo, 153-0043, Japan, mb_babu@pasco.co.jp

KEY WORDS: Reconstruction, 3D, Building, Modeling, Polygon description

ABSTRACT:

This study focuses on building modeling from DSM. The objective is to develop a highly automatic system of 3D modeling. 3D reconstruction of buildings has been an active research topic in digital city and GIS applications. Various data types have been used in the researches, including multi-image, image integrated with GIS map or planning map, image integrated with DSM, etc. There are hardly commercial automatic systems for reconstruction of buildings due to the complexities of the reconstruction itself. In our study, the reconstruction algorithm is based on the polyhedral model because of the complex structure and shape of most of the modern buildings. The building modeling includes preprocessing, building detection, roof modeling and wall modeling. Edge preserved adaptive smoothing is employed to enhance the jump edges and outline of the buildings and remove the height noise within smooth regions. Outline and jump edge detection and Hough line extraction are carried out to the DSM to segment the ortho-roof plane. With DSM the 3D roof plane can be obtained. From the lines and relationships of lines and roofs the walls can be created and merged. The roofs and walls of a building are described as polygons with the vertices in anti-clockwise order. A case study is implemented to a DSM of a region of Tsukuba, Japan.

1. INTRODUCTION

3D reconstruction of buildings has been an active research topic in computer vision in recent years. 3D reconstruction of buildings from aerial images is becoming of increasing practical importance. Manual 3D processing of aerial images is very time consuming and requires highly qualified personnel and expensive instruments. Therefore, speeding up this process by automatic or semiautomatic procedures has become a necessity. The current state of automation in the reconstruction of buildings from aerial images is still surprisingly low. A lot of algorithms and systems have been proposed towards this problem. However, a versatile solution to the automatic reconstruction has not been found yet, with only partial solutions and limited success in constrained environments being the state of art. Most approaches have focused on the reconstruction of specific building models: rectilinear shapes (Noronha and Nevatia, 1997), (Roux and McKeown, 1994), flat roofs (Jaynes et al.,1997), (Lin et al, 1994) or parametric models (Fischer et al., 1998). But buildings show a much wider variety in their shape. Other approaches employ a generic roof model that assumes planar roof surfaces (Bignone et al., 1996), (Moons et al., 1998), (Schmid and Zisserman, 1997). These 3D roof planes are generated by grouping the coplanar 3D lines or corners computed from the images. From image pair combining to 2D GIS map and domain knowledge building is reconstructed from aerial image (Suveg et al). The domain knowledge is represented in a building library containing building primitives (flat, gable, and hip roof building). The current state of automation in the reconstruction of buildings from aerial images is still surprisingly low. A lot of algorithms and systems have been proposed towards this problem. However, a versatile solution to the automatic reconstruction has not been found yet, with only partial solutions and limited success in constrained environments being the state of art. The difficulty in obtaining a general solution to this problem can be attributed to the complexity of the reconstruction itself, as it involves processing at different levels: low level processing (feature extraction), middle level processing (representation and description of building models) and high level processing (matching and reasoning). Our research focus on building modeling from DSM. The objective is to develop a highly automatic system of 3D modeling.

2. METHODS AND TECHNIQUES

DSM first is reprocessed by adaptive smoothing and height-area threshold filtering. Then edge detection and extraction is implemented. After line fitting the line structure is constructed. On the base of line the planes with closed edges are labeled to construct planar structure and neighborhood between planes and lines is also obtained. Polygon description is made after on. Then edge line angles analysis gives the box direction of a building. The walls are created from line structure and DSM. The normals of all of the roofs and walls of a building are computed. For wall polygons and roof polygons, anti-clockwise vertices are recorded. Wall merging is at last implemented and the building is modeled.

2.1 Edge Preserved Adaptive Smoothing

Because DSM might has noise, we implemented smoothing to it. Adaptive smoothing proposed by Saint- Marc et al (Saint-Marc et al 1991) is a reformulation of the anisotropic diffusion method. In each iteration, a local 3×3 weighted average is computed at each DSM grid. The weights in the mask are inversely proportional to its likelihood of being an DSM edge.

$$C^{(n)}(x_{j'}) = e^{-\frac{\left|\nabla x_{j'}^{(n)}\right|^2}{2K^2}}$$

(1)

$$x_j^{(n+1)} = x_j^{(n)} + \frac{1}{\sum\limits_{j'\in N_j} C^{(n)}(x_{j'})} \sum_{j'\in N_j} C^{(n)}(x_{j'}) x_{j'}^{(n)}$$

(2)

where $\nabla x_{j'}^{(n)}$ denotes the gradient modulus computed with a 3×3 mask. Our goal is to smooth the small height fluctuation and to obtain uniform regions as result. What we need to preserve is big height discontinuity rather than the higher order discontinuities, therefore height difference based adaptive smoothing is enough to satisfy our target. The equations of Marc are modified as following(Li and Peng 2001). A moving weight window sized 3×3 is used in the adaptive smoothing. Let $f(m,n,t)$ denote the $t'th$ iteration of the grid (m,n), and $w(m,n,t)$ denote the weight of (m,n) in the $t'th$ iteration, then the $t+1'th$ iteration of the grid (m,n) is described as

$$f(m,n,t+1) = \frac{1}{w(m,n,t) + \sum_{(j,k)\in\varepsilon(m,n)} w(j,k,t)} \left(w(m,n,t) f(m,n,t) + \sum_{(j,k)\in\varepsilon(m,n)} w(j,k,t) f(j,k,t) \right)$$

(3)

where $\varepsilon(m,n)$ denotes the neighborhood of (m,n). The weights of the smoothed grid and its neighbors construct a filtering mask. a Gaussian is chose to represent the relation of weight and the measurement.

$$w(j,k,t) = e^{\left(-\frac{d(j,k,t)^2}{2*K^2}\right)} \quad (4)$$

with $d(j,k,t)$ representing the edge measurement and

$$d(j,k,t) = \max\{f_{\max}(j,k,t) - f(j,k,t), f(j,k,t) - f_{\min}(j,k,t)\} \quad (5)$$

where,

$$f_{\max}(j,k,t) = \max_{(u,v)\in\varepsilon(j,k)} \{f(u,v,t)\}, \quad (6)$$

$$f_{\min}(j,k,t) = \min_{(u,v)\in\varepsilon(j,k)} \{f(u,v,t)\} \quad (7)$$

$\varepsilon(j,k)$ is a neighborhood of 3×3 of (j,k) here.

2.2 Outline And Jump Edge Extraction

We used a gradient based detection technique to extract 2D building outlines and jump edges. Firstly, a Sobel operator is taken to compute the local gradient of the heights. The DSM is segmented as a binary image by taking a threshold to the gradient. Then the edge image is obtained by thinning the binary edge image to a single pixel edge image of contours and jump edges of the buildings. Because of the preprocessing, DSM yields the continuous edges with almost no broken. Regions is naturally generated by closed edges.

Due to the fact that buildings are man-made objects, it should have enough height and size. Using a height threshold can remove objects with lower height such as cars, and a size threshold will remove some smaller objects such as single trees. However, there still has a tough problem left: the larger vegetation area or vegetation connected with buildings cannot be removed using height or size criteria. Some researchers (http://icrest.missouri.edu/Projects/NASA/FeatureExtraction-Buildings/) suggest to separate them based on geometric shape characteristics because vegetation and building have significantly difference in geometric shape. Their approach is similar with Brunn and Weidner: to discriminate vegetation and building based on roughness of surface measured by differential geometric criteria (Brunn and Weidner, 1998). We found it has limit help in our project. We have tried using local gradient deviation to determine the surface roughness of DSM and separate trees from buildings. This method is effective for some cases, but not for all. Other techniques should be developed in future work.

2.3 Line Fitting And Square Modeling

Hough transformation is used in line fitting. We defined a line structure describing the feature of a line and the relations between them. First, Line fitting is implemented to all the jump edges. The joints of jump edges are remained after removing of the edge points corresponding to the lines. The connecting relation between edges and joins is then created. Line terminals are recomputed and more lines may be created if the distance or angle between two connecting edges beyond the certain values. A neighboring line structure array is generated. From this structure, the joint coordinate of each pair of connecting lines can be computed and recorded as the terminals of the lines. For convenient of the following computation, the lines are split so that each line is connected with others with one of its terminals.

Now the angles of lines are directly computed from Hough transformation and linear regress. For a building, the most jump edge should be with the same two angles orthogonal with each other. Thus square modeling is taken here. The gross deviation of the angles of all the lines of a building from a varying pair of orthogonal angle is computed and the pair of orthogonal angle *Theta* and *Theta* +90, *Theta*>0 and <90, corresponding to the minimum deviation is the box angles to this building. *Theta* is called as rectify angle. After then, the parameters of the lines are recomputed and the line structure and neighboring line structure are adjusted.

2.4 Roof Planes And Polygon Description

From the result of the last stage, a building in DSM is actually separated from the background and into several regions corresponding to roofs with their own heights. All we have to do is to label these roof planes and calculate their parameters. A planar structure is created recording the area, normal vector of a roof plane. To describe the plane as a polygon we need to know the coordinates of the vertices for each polygon. Therefore a series of reasoning is carried out to the plane and lines. The algorithm distinguishes the hole from the out contour. It includes vertices tracing, out contour description, vertices reversion. The polygon relation with lines is first found and recorded in the polygon structure. The sequential vertices of the polygon are determined and recorded using a searching algorithm for sequential vertex we proposed. Finally, a reversing procedure is taken to check the direction of the vertex chain and reverse the clockwise ones and adjust them in the polygon structure. The third coordinate, ie. the height, of a vertex of a polygon is computed by the parameters of the polygon. The procedure is illustrated in Figure 1.

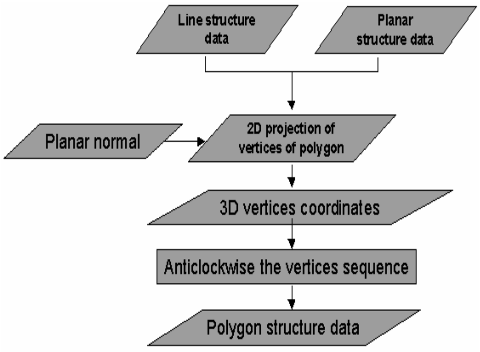


Figure 1 The steps of polygon description

2.5 Wall Creation

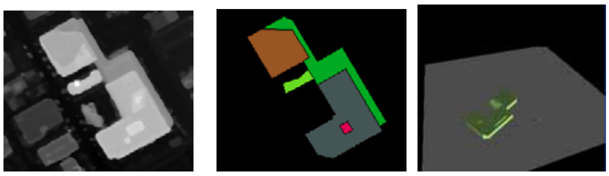
The walls are supposed as vertical. Thus they can be generated by the lines of outline and jump edges. Since splitting algorithm is adopted in line extraction stage, it is possible for a line to be separated into several segments according to the definition of the line structure, the wall creation procedure is composed of three steps. First, each line creates a wall with four vertices, 2 of one neighboring planar, 2 of the other neighboring planar. The coordinates of the vertices directly come from the planar structure of the corresponding planes to the line. The walls are also taken as the spatial planes and the parameters of them are computed and new planar structure data for them are added. The vertex chain is of either clockwise or anti clockwise order at last. Then, a reversing process different with that for polygon description is implemented to the vertex chain of clockwise order of a wall according to the planar height comparison in both side of the line corresponding to the wall, so that in front of the wall the vertex sequence is anticlockwise. Last, wall merging step is taken. The connecting walls with the same parameters are taken as one wall. The vertices of them are rearranged and inserted to the polygon description data of the upper or left one.

2.6 Building Modeling

A building is modeled as an assembly of polygons. We use the sequential 3D vertices to describe a polygon. For all buildings, and all polygons of the buildings, the 3D coordinates of the vertices of it are output to a data file. From these data, the normal and location of each polygon can be calculated and the building can be reconstructed. In our job, we use OpenGL to display the building models.

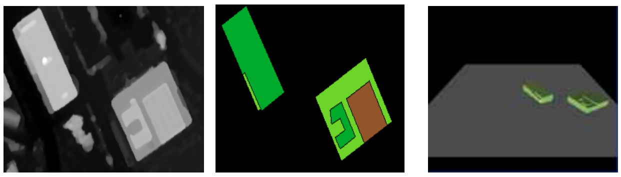
3. RESULTS AND DISCUSSION

A case study is implemented to a DSM which is generated by ADS40 image pair with spatial resolution of 1m. The research field is Tsukuba, Japan. We used several patches of a whole DSM to testify our approach of 3D building modeling. Because the thresholds of height and size effect the result and the thresholds are set for a patch, the models of a certain building will be different if it is in different patch. For the same reason, we suggest that it is better to carry out the building modeling for a patch including similar size and height of buildings. We selected several single building patches, which are usually with higher height and greater size, as well as more complex structure. The tree if there is any is easily to be removed through proper thresholds. By our approach the models of them are quite good. Figure 2(a) and figure 3(a) illustrate a DSM patch including one or two buildings with certain structures respectively. Figure 2(b) and figure 3(b) map the orthogonal roof planes of the buildings in figure 2(a) and figure 3(a) respectively. Figure 2(c) and figure 3(c) illustrate the 3D models of them respectively. The models are well reconstructed for the buildings in the two patches. When the patch includes more buildings, especially the distribution of them is complex, the result is not ideal. Some roofs or walls may be lost, as illustrated in figure 4(c). The problems might happen in box modeling, plane-line relation, or wall creating or the mix of them. When there are only buildings with simple structures in the patch, the modeling is satisfied, as shown in figure 5.



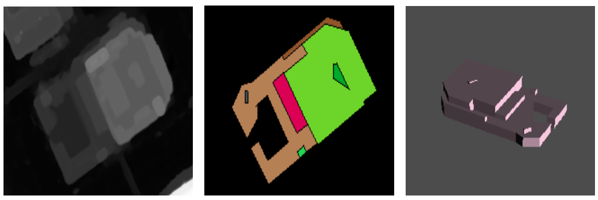
(a) (b) (c)

Figure 2 3D modeling of a building



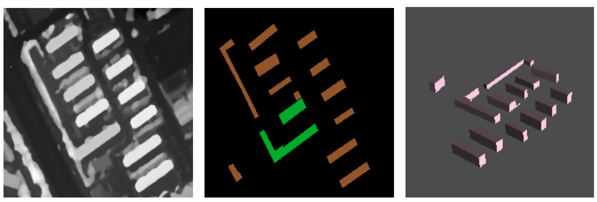
(a) (b) (c)

Figure 3 3D modeling of two buildings



(a) (b) (c)

Figure 4 3D modeling of a building



(a) (b) (c)

Figure 5 3D modeling of a group of buildings with simple structures

4. CONCLUSION

As conclusion, we employ a reasoning scheme to create 3D model of the building from DSM. The works from edge detection to polygon description depend on line structure. Normal vector of the roof plane or wall plane is computed to create the 3D coordinates of the vertices of the corresponding polygon. The most important parts of the approach are the creation of various relationships including relations between the lines, relations between the planes, and relations between the planes and lines. The research cannot be said perfect at this stage. Some algorithms were not robust enough. A little change somewhere may get better results for some buildings, but worse for others. We have to do more efforts in the future. The image data ought to be combined with DSM, for example.

REFERENCES

Bignone F., Henricsson O., Fua P., Stricker M., 1996, Automatic extraction of generic house roofs from high resolution aerial imagery, *Computer Vision - ECCV*'96, Springer Verlag, vol.1, pp. 85-96.

Brunn A., Weidner U. 1998, Hierarchical bayesian nets for building extraction using dense digital surface models, *Journal for Photogrammetry & Remote Sensing*, 53(6), pp. 296 - 307.

Fischer A., Kolbe T.H., Lang F., Cremers A.B., Förstner W., Plümer L., Steinhage V., 1998, Extracting buildings from aerial images using hierarchical aggregation in 2D and 3D, *Computer Vision and Image Understanding*, 72(2), pp.185-203.

Jaynes C., Marengoni M., Hanson A., Riseman E., Schultz H., 1997, Knowledge-directed reconstruction from multiple aerial images, *Proc. ARPA Image Understanding Workshop, New Orleans, LA*, Vol. II, pp. 971-976.

]Li Y., Peng J., 2001, Feature extraction and recognition of harbor contour, *Image Extraction, Segmentation, and Recognition, Proc. Of SPIE*, vol.4550, pp. 234-238.

Lin C., Huertas A., and Nevatia R., 1994, Detection of buildings using perceptual grouping and shadows, *Proc. CVPR, IEEE Computer Society Press*, Los Alamitos, CA, pp. 62-69.

Moons T., Frere D., Vandekerckhove J., Gool L., 1998, Automatic modeling and 3D reconstruction of urban house roofs from high resolution aerial imagery, *Proceedings European Conference on Computer Vision '98 (ECCV98)*, pp. 410-425.

Noronha S., Nevatia R., 1997, Detection and description of buildings from multiple images, *Proc. CVPR*, pp.588-594.
[9]Roux M., McKeown D. M., 1994, Feature matching for building extraction from multiple views, *Proceedings of the ARPA IUW*, Menterey, CA, pp.331-339.
Saint- Marc P., Chen J., and Medioni G., 1991, Adaptive smoothing: A general tool for early vision, *IEEE trans. on PAMI*, 13(6), pp.514-529.

Schmid B., Zisserman A., 1997, Automatic line matching across views, *Proc. CVPR*, pp. 666-671.

Suveg I., Vosselman G., 2001, Automatic 3D building reconstruction by map based generation and evaluation of hypotheses,
http://www.bmva.ac.uk/bmvc/2001/papers/12/12.html

http://icrest.missouri.edu/Projects/NASA/FeatureExtraction-Buildings