

GENERALIZATION OF BUILDING POLYGONS EXTRACTED FROM IKONOS IMAGERY

Jie Shan D. Scott Lee

Geomatics Engineering, School of Civil Engineering, Purdue University, West Lafayette, IN 47907-1284, USA
jshan@ecn.purdue.edu

Working Group IV/3

KEY WORDS: Building extraction, Generalization, Shaping, Satellite Imagery, High resolution

ABSTRACT

Building extraction in this paper is treated as a classification guided image segmentation problem followed by a generalization operation. Initial building locations are first found by using supervised classification on IKONOS multispectral images. A supervised classification/cluster based approach is then used to segment the building image from its background and surroundings in the panchromatic image. A series of polygon operations are implemented to determine the best delineation of buildings based on the segmentation results. The delineated building polygons are subsequently refined by a two-step generalization process, distance-based generalization and curvature-based generalization. The distance-based generalization uses the classical Douglas-Peucker approach to remove redundant nodes in the building polygons, while a curvature-based approach is proposed to eliminate sharp and unrealistic angles in the building polygons. Results from IKONOS imagery are presented to show the implementation and efficiency of the proposed methodology.

1. INTRODUCTION

Building extraction from imagery has been a research topic in photogrammetry society for many years [Baltsavias, et al, 2001b; Grün et al, 1995; Grün et al, 1997; Mayer, 1999]. Many efforts use black and white images from air and space as the single data source. However, recent achievements suggest the combination of multiple data sources and the integration of photogrammetric tools with image processing and geographic information systems [Föstner, 1999; Haala, 1999; Huertas, et al, 1999; Huertas, et al, 2000; McKeown, et al, 1999]. As another experience gained in the past years, various building models have been introduced to facilitate and automate the building extraction procedure [Braun et al, 1995; Förstner and Pluemer, 1997].

Building extraction from high resolution satellite imagery has recently attracted increasing research interests. First results can be found in [Baltsavias, et al, 2001a; Fraser et al, 2001; Sohn and Dowman, 2001], where the geometric characteristics and potentials of IKONOS images are studied. Buildings extracted from IKONOS images are compared with those obtained from aerial photographs to evaluate the capabilities of IKONOS imagery [Fraser et al, 2001]. Lee et al [2002] report on their study on a classification-guided approach for automatic building extraction from IKONOS images. Related research efforts on IKONOS images include geometric accuracy study [Dial,2000], road extraction [Dial et al, 2001] and sensor modelling [Tao and Hu, 2001] for digital elevation model generation [Toutin, et al, 2001].

This paper will report on our recent experience gained in automatic building extraction from IKONOS imagery. Although the entire extraction process will be presented, the paper will be focused on the automatic delineation and generalization of building polygons obtained from classification results of multispectral IKONOS images. The objective is to refine the classification results to obtain accurate and realistic building boundaries. Our approach consists of following steps. First, the IKONOS multispectral images are classified into several

classes, including water, road, roof, tree, marsh, grass and sand based on the selected training sites. This step is carried out by using a Maximum Likelihood classifier. The resultant class maps are then vectorized to feature classes. Each vectorized building object will be used to define the searching area on the corresponding panchromatic image to delineate the building boundaries. This is accomplished by using image segmentation technique. A series of vector-based polygon operations are implemented to select the refined building polygons. The delineated building polygons will then be subject to a two-step generalization processing to obtain an accurate and realistic building boundary. For generalization, we first use Douglas-Peucker approach to eliminate the building polygon nodes that are within certain given threshold distance. Although this operation can remove a large amount of redundant nodes, rapid curvature changes still exist in the resultant building polygons, which contain high frequency zigzags and make the building polygon shape untrue. As for the second step generalization, we propose and implement a curvature-based approach to further refine the results. For each node in the building polygon, we calculate its curvature and label it as either convex or concave. Nodes whose curvature is beyond a given threshold and whose sign is different with its two immediate neighbouring nodes will be eliminated from the building polygon. In this way, the generated building polygons are closer in shape to real buildings and coincide with the building image well. This paper will present technical descriptions of our approach, shows details of the implementation and illustrate the principles by providing step by step intermediate results.

The rest of the paper is organized as follows. Section 2 briefs the data set used in the test and its classification. Section 3 describes the building delineation process on the panchromatic image guided by the classification results. Section 4 presents the technical details for the two-step generalization process. Sample results for each processing step are shown in every section. The paper concludes at Section 5 by summarizing the gained experience and prospecting the future work.

2. BUILDING CLASS GENERATION

The study area is located at Camp Lejeune and its surroundings (North Carolina, USA). The images used in this study are a single mosaicked IKONOS four band multispectral image and the corresponding IKONOS panchromatic image. The images are pre-rectified by the image vendor Space Imaging, Inc. The properties of the IKONOS images are listed below:

- Spectral resolution: 4 bands (Near IR/R/G/B), 11 bits/pixel
- Spatial resolution: 4 meters/pixel (multispectral) or 1 meter/pixel (panchromatic)
- Region: about 2.3*1.7 square kilometres
- Preprocessing from Space Imaging, Inc.: Standard Geometrically Corrected, Mosaicked
- Map projection: UTM Zone 18, WGS-84



Figure 1. Class map of supervised classification



Figure 2. Vectorized building class overlaid on the panchromatic image

As the first step of the study, the multispectral image is classified to several thematic classes, from which the building class is separated for further processing. In order to determine what classes should be used for the study, an unsupervised classification (clustering) based on the ISODATA (Iterative Self-Organizing Data Analysis Techniques) algorithm [Mather, 1999] is first carried out. A maximum of 12 clusters is specified for the clustering operation. A visual inspection of the clustering results leads to seven (7) primary classes: water, road, roof, tree, marsh, grass and sand. The class Road is used for

roads comprised of grayish and white or bluish-white pixels. The class Roof is used for gray, white and light blue rooftop pixels. The class Marsh is used for the reddish-brown areas adjacent to waterways. After the class category is determined, an ordinary maximum likelihood classifier is used to carry out the supervised classification. The classification is conducted with two packages, a campus-developed software Multispec [Biehl and Landgrebe, 1996] and the commercial image processing package ENVI, both yield essentially the same results. Figure 1 shows the class map resulting from the supervised classification as described above, whereas Figure 2 presents the vectorized building class overlaid over the corresponding panchromatic IKONOS image.

3. BUILDING DELINEATION

As shown in Figure 2, the original vectorisation of building classes contains many artefacts and non-building objects. The objective of building delineation is to obtain accurate building boundaries from the vectorisation results. This task consists of several steps.

Artefacts from the classification process need to be removed before further processing. After the building class is converted to vector form, each potential building will then be represented as a polygon object. Its primary geometric properties, such as length and area, are then calculated for each building polygon. Building polygons below given thresholds of areas and lengths are then regarded as artefacts caused by misclassification and eliminated from further processing. Our experience shows that a large percentage of classification artefacts can be eliminated through this process.

The next step is to precisely determine the building boundary on the panchromatic image guided by the classification results. The extension of the building polygon obtained from the classification is first used to define the working window for segmentation. Instead of using a conventional binary image segmentation approach [Otsu, 1976], we propose to use the unsupervised classification ISODATA approach to segment the panchromatic image window into several (> 2) classes [Lee et al, 2002]. In this way, multiple gray values in the working window can be taken into account and the difficulty in determining the segmentation threshold is avoided. This approach helps to separate buildings from multiple non-building backgrounds and results in satisfactory segmentation results. It is especially beneficial in low contrast areas where building and background have similar gray values. After the image window is segmented into several classes, the class polygon that has the maximum intersection area with the building polygon obtained from classification will be selected as the building delineation result from the panchromatic image. An algorithm is developed that calculates the intersections of the building class polygon from classification results with each polygon obtained with unsupervised classification on the panchromatic image. However, the selected maximum intersection polygon may contain small holes due to the sensor noise and uneven reflection of the building roofs. These unrealistic small holes need to be detected and removed from the building boundary polygon. An algorithm is developed that explodes a complex polygon with rings to its simple component polygons so that only the building polygon boundary is remained for further generalization processing.

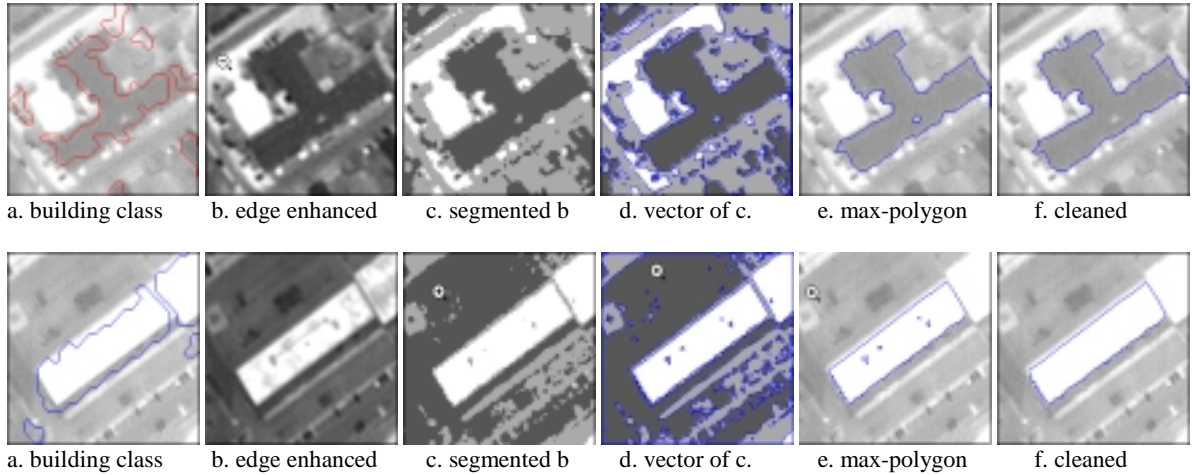


Figure 3. Two examples (in two rows) of building delineation process

Figure 3 presents sample results of building delineation process described above. Figure a shows the building class polygon obtained through classification. It is overlaid on the panchromatic image. The region is the working area defined by the extent window of the building class polygon. Figure b shows the enhanced image after a low pass smoothing filter is applied. This step is to ensure that the segmentation process will not return too many small meaningless polygons inside a building boundary. The segmentation result is shown in figure c, while figure d is the vector form of figure c. As shown in figure d, it contains many polygons that are potentially corresponding to the building class polygon (figure a). Figure e shows the polygon that intersects with the building class polygon with maximum overlap. The final delineation result is shown in figure f where the internal small holes are removed.

4. BUILDING POLYGON GENERALIZATION

The objective of this step is to obtain accurate boundary and shape of the delineated building polygons. As shown in Figure 3, the straight boundaries of the delineated building polygons are zigzagged. Besides, corners of building polygons are closed unrealistically. The building polygons may not be completed correctly. Some parts are missed and some are wrongly extended to backgrounds due to the shadow of building and trees. To solve this problem, a vector based two-step generalization procedure is proposed. As the first step, we use the conventional (distance-based) Douglas-Peucker (1977) approach to remove extra building points that cause the zigzag shape of a building boundary. In the second step, we propose a curvature or angle based generalization technique [Costa et al, 2001] to further remove the points that cause unrealistic sharp changes in the building polygon. This technique is outlined as follows.

As is shown in Figure 4, nodes of a polygon are ordered clockwise. The angle β_i at node of two consecutive edge vectors can be calculated by

$$\cos \beta_i = \frac{p_{i-1}p_i \bullet p_i p_{i+1}}{|p_{i-1}p_i| \cdot |p_i p_{i+1}|} \quad (1)$$

The cross product of the two edge vectors is calculated as follows

$$\Delta_i = \frac{p_{i-1}p_i * p_i p_{i+1}}{|p_{i-1}p_i| \cdot |p_i p_{i+1}|} \quad (2)$$

and can be used to obtain the interior angle α_i of two consecutive edge vectors at a node

$$\alpha_i = \pi + \text{sign}(\Delta_i)\beta_i \quad (3)$$

The convex and concave property of the node can then be determined by using the following determinant

$$\Delta_i \begin{cases} > 0 & \alpha_i \text{ concave, mouth} \\ < 0 & \alpha_i \text{ convex, ear} \end{cases} \quad (4)$$

A polygon node will be trimmed if its angle is beyond a certain threshold and its sign is different with its two immediate neighbouring nodes (one forward, one backward). In this way, sharp and unrealistic angles remained from the distance-based generalization can be removed.

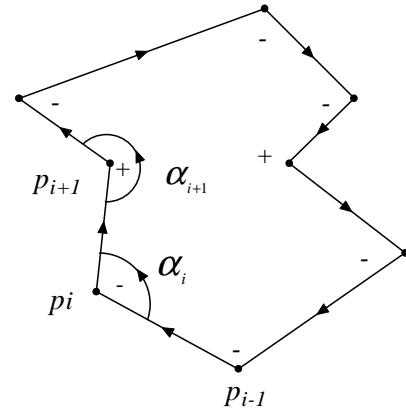


Figure 4. Curvature and convex determination

To generalize the building polygons, the distance-based approach and the angle-based approach are used sequentially. First, the nodes of a polygon are significantly reduced by using the distance-based generalization. Usually the reduction factor for the number of nodes can be as high as 2, namely half of the nodes in the delineation results can be removed. During this step, in order not to remove the building corner points, the generalization is carried out conservatively by giving a small distance threshold of not larger than one pixel (1 meter in this study). The angle-based generalization follows the distance-based approach. For each node in a building polygon, its interior angle is calculated using Equation (3). Beside, each

node will be labelled according to Equation (4) as concave and convex. A node will be removed or trimmed if it alternates the convex and concave property of its two immediate neighbours and is beyond a given threshold region, which is usually selected to keep right (90 degree) angles of a building polygon and eliminate its sharp turns. Sample results of the two step generalization are presented in Figure 5. In this figure, blue (at the bottom) is the original delineated building polygon, the red is the distance-based generalization polygon, the green one is obtained from angle-based generalization applied on the distance-based generalization results.

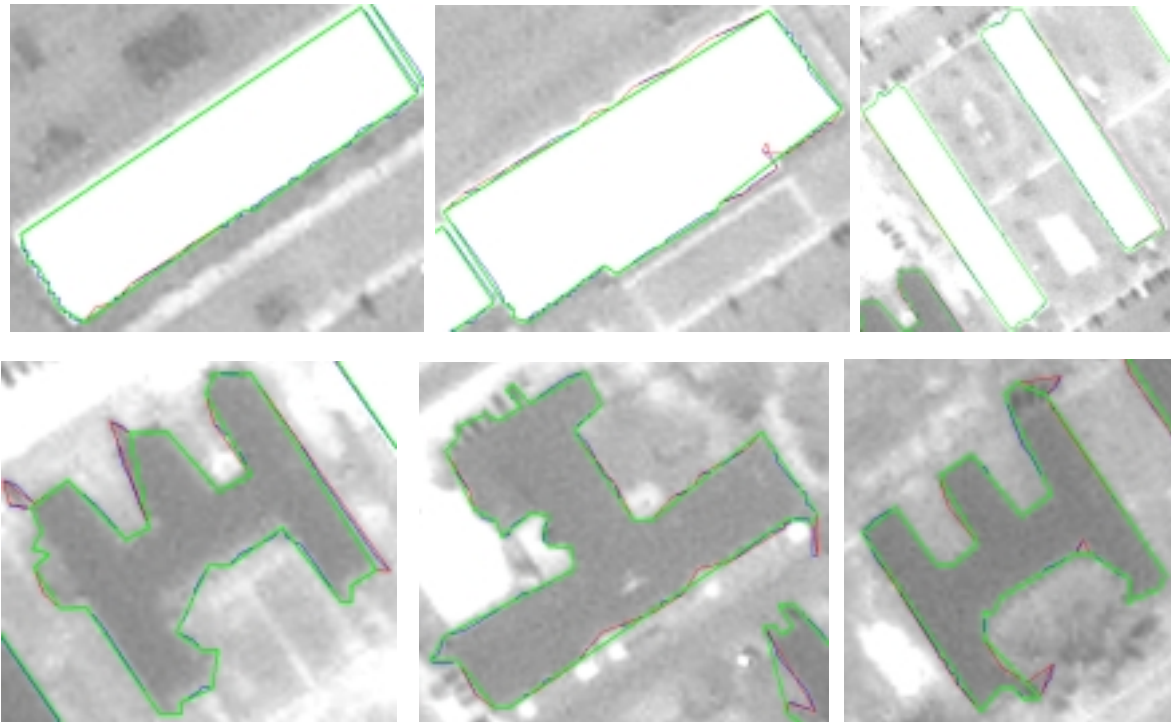


Figure 5. Generalized building polygons
Blue: delineated; Red: distance-based; Green: curvature-based (applied to the Red result)

5. CONCLUSIONS

The high resolution of recent IKONOS images makes the building extraction possible and is attracting increasing research interests. To automate this process and obtain reliable results, multiple data sources and advanced techniques are needed. The classification guided approach can utilize the properties of both multispectral and panchromatic images. The use of unsupervised classification/clustering to segment building class from its background and surroundings can avoid the difficulty in determining the threshold in classical binary image segmentation. The segmented buildings need to be further processed to obtain its realistic shape. The combination of distance-based and curvature-based generalization approaches provide a powerful tool to simplify, refine and shape the delineated building polygons obtained from image classification and segmentation. The distance-based Douglas-Peucker approach is effective to eliminate a large number of redundant nodes from the building polygon, whereas the subsequent curvature-based approach can then eliminate sharp and unrealistic angles based on polygon shape analysis. Further study will be focused on expanding this vector based shape analysis approach by introducing generic models, including straight and parallel lines and right angle to square the building

polygons. In this way, the effect caused by shadows and trees can also be remedied. The vector-dominant characteristic of the proposed approach will enable us to integrate it into GIS packages so that the powerful GIS vector analysis and operation capabilities can benefit the building extraction process, while the extracted buildings will be directly stored in GIS for database creation and visualization.

REFERENCES

- Baltsavias, E., Pateraki, M., Zhang, L., 2001a. Radiometric and geometric evaluation of Ikonos GEO images and their use for 3D building modeling, Proc. Joint ISPRS Workshop "High Resolution Mapping from Space 2001", Hannover, Germany, 19-21 September.
- Baltsavias, E., Gruen, A., Van Gool, L. (Eds.), 2001b. Automated Extraction of Man-Made Objects from Aerial and Space Images (III), Balkema Publishers, Lisse.
- Biehl, L. and D. Landgrebe, 1996. "MultiSpec - A Tool for Multispectral-Hyperspectral Image Data Analysis", Pecora 13, Sioux Falls, South Dakota, August 1996.

- Braun, C., Kolbe, Th., Lang, F., Schickler, W., Steinhage, V., Cremers, A.N., Förstner, W., Plumer, L., 1995. Models for Photogrammetric Building Reconstruction. *Computer & Graphics*, Vol. 19, No. 1, pp. 109-118.
- Costa, Luciano da Fontoura, Cesar, Roberto Marcondes Jr., 2001, *Shape Analysis and Classification, Theory and Practice*, CRC Press.
- Dial, G., 2000. IKONOS Satellite Mapping Accuracy, CD-ROM Proceedings of the ASPRS Annual Conference.
- Dial, G., Gibson, L., Poulsen, R., 2001. IKONOS satellite imagery and its use in automated road extraction. In: *Automated Extraction of Man-Made Objects from Aerial and Space Images (III)*, E. Baltsavias, A.Gruen, L. Van Gool (Eds.), Balkema Publishers, Lisse, pp. 349-358.
- Douglas, D., Peucker, T., 1973. Algorithms for the reduction of the number of points required to represent a digitised line or its caricature, *The Canadian Cartographer*, Vol. 10, No. 2, pp. 112-122.
- Förstner, W., Pluemer, L., 1997. Semantic Modeling for the Acquisition of Topographic Information from Images and Maps, Birkhaeuser.
- Förstner, W. 1999. 3D-City Models: Automatic and Semiautomatic Acquisition Methods, in Dieter Fritsch / Rudolf Spiller (Eds.), *Photogrammetric Week '99*, Wichmann, Heidelberg, pp. 291-303.
- Fraser, C., Baltsavias, E., Gruen, A., 2001. 3D building reconstruction from high-resolution IKONOS stereo imagery. In: *Automated Extraction of Man-Made Objects from Aerial and Space Images (III)*, E. Baltsavias, A. Gruen, L. Van Gool (Eds.), Balkema Publishers, Lisse, pp. 325-338.
- Gruen, A., Kuebler, O., Agouris, P., Eds, 1995. *Automatic Extraction of Man-made Objects from Aerial and Space Images*, Birkhaeuser, Basel, Switzerland.
- Gruen, A., Baltsavias, E., Henricsson, O. (Eds), 1997. *Automatic Extraction of Man-made Objects from Aerial and Space Images*, Birkhaeuser, Basel, Switzerland.
- Haala, R., 1999. Combining multiple data sources for urban data acquisition, in Fritsch and Spiller, 1999, pp. 329-340.
- Huertas, A., Kim, Z., Nevatia, R., 2000. Multisensor Integration for Building Modeling, *Proceedings of CVPR*.
- Huertas, A., Nevatia, R., Landgrebe, D., 1999. Use of Hyperspectral Data with Intensity Images for Automatic Building Modeling, *Proceedings of The 2nd International Conference On Information Fusion*, Sunnyvale, CA, July.
- Lee, D.S., Shan, J., Bethel, B., 2002. Classification-guided building extraction from IKONOS imagery, CD-proceedings of American Society for Photogrammetry and Remote Sensing, Washington DC.
- Mather, P., 1999. *Computer Processing of Remotely-Sensed Images: An Introduction*, 2nd Edition, John Wiley & Sons, Chapter 8.
- Mayer, H., 1999. Automatic object extraction from aerial imagery – a survey focusing on buildings, *Computer Vision and Image Understanding*, Vol. 74, No.2, May, pp. 138 – 149.
- McKeown, D., Jr., Cochran, S., Ford, S. McGlone, C., Shufelt, J., Yocum, D., 1999, Fusion of HYDICE Hyperspectral data with panchromatic feature extraction, *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 37, No. 3, May.
- Otsu, N., 1976, "A threshold selection method from gray-level histograms," *IEEE Transactions of Systems, Man, and Cybernetics*, vol. SMC-9, pp. 62-66, January.
- Sohn, G., Dowman, I.J., 2001. Extraction of buildings from high resolution satellite data, *Proceedings of the Third International Workshop on Automatic Extraction of Man-Made Objects from Aerial and Space Images*, 10. June - 15. June, Centro Stefano Franscini, Monte Verita, Ascona, Switzerland.
- Tao, C., Hu, Y., 2001, A Comprehensive Study of the Rational Function Model for Photogrammetric Processing. *PE&RS*, Vol. 67, No. 12, pp1347.
- Toutin, Th., Chénier, R. and Carbonneau, Y., 2001. 3D geometric modelling of Ikonos GEO images. *Proc. Joint ISPRS Workshop "High Resolution Mapping from Space 2001"*, Hannover, Germany, 19- 21, September.