Building extraction from high resolution satellite imagery based on multi-scale image segmentation and model matching

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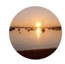

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Building Extraction from High Resolution Imagery based on Multi-scale Object Oriented Classification and Probabilistic Hough Transform

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Abstract—**In this paper, we developed a new building extraction system applied on high resolution remote sensing imagery based on multi-scale object oriented classification and probabilistic Hough transform. This can be divided into two different phases: building roof extraction, and shape reconfiguration. For the first phase, the multispectral and panchromatic high resolution satellite imageries are firstly fused for spatial resolution improvement and color information enhancement. The multi-resolution image segmentation is applied on the fused image, resulting in the formation of the different level of polygon primitives at different space scale, providing different view of the scene at different resolution. In addition to the spectral information, the tone, texture, shape, context information is evaluated in an object oriented manner. The classification is based on a fuzzy rule decision tree classifier. By fuzzy evaluating of the shape, texture, context and spectral information, building roofs are extracted by reconstruction and classification from an appropriate space scale of roof polygon primitives. For the shape reconfiguration phase, we adopt the probabilistic Hough transform to delineate the roof dominant line which shows the major orientation of the specific building roof. According to the dominant line, a building squaring algorithm is applied based on rectilinear fitting of the building boundary. It is shown by our experiment that most rectangular building roofs can be correctly detected, extracted and reconfigured, demonstrating the potential application of the method.**

Keywords – building extraction; object oriented classification; hough transform

I. INTRODUCTION

Recent advancement of satellite remote sensing technology, e.g. the successful launch of Ikonos, QuickBird, provides global, accurate, very high resolution multispectral imagery (around 1 meter or better after fusion of the panchromatic with multispectral bands) to individuals, commercial organizations and governments for urban development applications. Particularly, the extraction of building information from high resolution imagery has been one of the most interesting topics for remote sensing and computer vision scientists.

In general, current building extraction methods could be classified as two categories:

The first kind of methodology is investigated most extensively and deeply, which extracts buildings by using image information combined with altitude information, either derived from stereo images or from other sources. For example, Fraser *et al*. (2002) present results on building extraction from Ikonos stereo images. Some operational methods have also been established, e.g. CSG method, and have been implemented on some commercial software systems.

The other kind of method relies only on satellite remote sensing imagery. It combines new image processing algorithm with new methods from pattern recognition, machine vision and artificial intelligence fields, to extract the roof of building semi-automatically or automatically. The method doesn't need height information and other prior knowledge. Compared with the first method, it has a more extensive application area but currently there are still some technical difficulties which should be overcome.

Zheltov (2001) adopts the linear extraction method proposed by Burns *et al*. (1986) and combines with the rectangular building model to extract building information from aerial images. Sohn and Dowman (2001) extract the polygon of building based on Fourier Transform and Binary Space Partitioning tree and combined with Building Unit Shape knowledge. Stassopoulou (2000) combines multi-scale region segmentation based on canny operator with edge segmentation to extract regional features (geometry shape, radiation characteristic, context information), and extracts building features by Bayesian network. Lin and Nevatia (1998) derives the analytic geometric relationship between building margin line and building shadows according to general illumination model to analyze the relationship of different ground features.

These methods normally combine specific edge detection, edge linking algorithm with semantic analysis of the relationship among detected lines, surfaces and their contexts. They have shown relatively good result on airborne photograph because of its high signal noise ratio (SNR). However on high resolution satellite imagery, the low spatial resolution and low SNR substantially increases the difficulties to locate and identify the exact building roof edges.

Lee (2003) utilizes ECHO classifier on multi-spectral IKONOS images classification and extracts the building shapes using Hough transform. Baaze and Schäpe (2000) put forward a new method that combines the multi-scale region segmentation with object-oriented decision tree classifier to classify the target features by investigating the spectral, texture and context information. A comparatively good result is obtained when this method is used in high resolution image for land use classification. The method could also be used in extraction of typical man-made features, such as building, arable land etc.

In this paper, we presents a new automated building extraction system applied on high resolution satellite imagery based on multi-scale object oriented classification and probabilistic Hough transform.

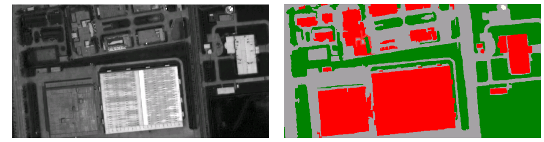
II. Methodology

1) General procedure

The approach developed consists of the following steps. First, original high resolution panchromatic image is fused with the low resolution multispectral imagery (green, red, and near infrared bands) by a HIS fusion technology so that the color and texture information of the ground objects are enhanced. Second, a multi-resolution segmentation algorithm is applied on the fused image. Object primitives which have homogeneous color, similar texture, and constrained shape are created on given space scale levels, thus provide us different view of the scene at different resolution. Third, an object oriented classifi-cation rules are constructed and are applied on the previously generated object primitives based on the spectral, tone, texture, shape, context information. The classification is based on a fuzzy rule decision tree classifier. This step will result in a well classified urban land use map. Specifically, the classification results can successfully distinguish building classes from other objects such as vegetation, road, water, and small vehicles. The created building classes are then merged together to create a binary-coded building mask image. Finally, each building unit in the building mask image is subjective to refine its shape by applying a probabilistic Hough Transform (HT) and rectilinear fitting. The probabilistic Hough transform is adopted to delineate the roof dominant line which shows the major orientation of the specific building roof. According to the dominant line, a building squaring algorithm is applied based on rectilinear fitting of the building boundary.

2) Multi-resolution segmentation

The multiresolution segmentation algorithm adopted here is a bottom up region-merging technique proposed by Baatz and Schäpe (2000). Starting with one-pixel objects and in its numerous iterative steps, smaller image objects are merged into bigger ones based on the differences of neighborhood objects' spectral information, tone, texture, shape, and context information. This pair-wise clustering process minimizes the heterogeneity of resultant building object primitives, and maximizes the heterogeneity between building primitives and other objects.



(a) (b)

Figure 1. Object-oriented classification of the high resolution remote sensing imagery: (a) Original QuickBird imagery after HIS fusion enhancement; (b) Classified buildings (red), road (gray), and vegetation (green).

3) Object-oriented classification

The methodology proposed in this paper is based on a new, object oriented approach to image classification technology. In contrast to traditional classification methods, the basic processing units of object oriented classification are image objects or segments, rather than single pixels. The motivation for the object oriented classification approach is the fact that the expected result is the extraction of real world building units, proper in shape and proper in category. This expectation cannot be fulfilled by common, pixel-based approaches.

Object-oriented classification of the urban land cover is conducted under the commercial remote sensing image processing software eCognition 3.0. The classification is based on a fuzzy rule decision tree classifier. Semantic relationships are used as prior knowledge for classification, e.g., the relationship between building primitives and shadows, between buildings road, and yards. Different decision rules are constructed based on the intrinsic features, topological features, and context features of the previously multi-resolution segmented object primitives.

The resultant urban land use classification map can be used to distinguish building classes from other objects such as vegetation, road, water, and small vehicles. The created building classes are then merged together to create a binary-coded building mask image.

4) Progressive Probabilistic Hough Transform

The Hough Transform (Duda and Hart, 1972) is a powerful image processing tool which has been extensively used for extraction of linear features from remote sensing imagery, e.g., road/runway, dam, roof edges, etc. Due to the computational complexity of the standard Hough transform algorithm, the Progressive Probabilistic Hough Transform (PPHT) was applied to minimize the proportion of points that are used in voting while maintaining false negative and false positive detection rates almost at the level achieved by the standard Hough Transform, thus providing a improved way of detecting building roof edges with high efficiency.

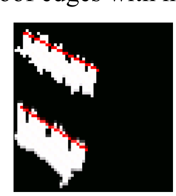


Figure 2. Detection of roof dominant lines with Progressive Probabilistic Hough Transform (PPHT): white area represents building roofs classified from Quickbird imagery; red line shows detected roof dominant lines

Below is an outline of the algorithm used, as described in Matas, *et al*. (1998):

1. Check the input image, if it is empty then finish.
2. Update the accumulator with a single pixel randomly selected from the input image.
3. Remove pixel from input image.
4. Check if the highest peak in the accumulator that was modified by the new pixel is higher than threshold l. If not then goto 1.
5. Look along a corridor specified by the peak in the accumulator, and find the longest segment of pixels either continuous or exhibiting a gap not exceeding a given threshold.
6. Remove the pixels in the segment form input image.
7. Unvote from the accumulator all the pixels from the line that have previously voted.
8. If the line segment is longer than the minimum length, add it into the output list.
9. Goto 1.

In this paper, the PPHT is adopted to detect the roof dominant line which is used as the baseline of the rectilinear fitting of the roof shapes. Here, the roof dominant line is defined as the straight line composed of the greatest number of points lying on each roof's boundary. Fig.2 shows the result of the detection roof dominant lines from Quickbird imagery. In which, white areas are classified building roofs, the detected roof dominant lines are shown as two red lines, each for one building roof. From Fig. 2 we could see that, the roof dominant lines could be well detected by this algorithm from previous classification results.

5) Roof Shape Fitting

Before roof shape fitting, coordinates of each pixel in the image plane, including the roof dominant lines, are transformed to a new object plane according to its roof dominant line by using the following Coordinate transformation equations:

$$\begin{aligned} x &= g + X\cos(\alpha) - Y\sin(\alpha) \\ y &= h + X\sin(\alpha) + Y\cos(\alpha) \end{aligned} \qquad (1)$$

where, (x, y) represents original coordinate of each pixels in image plane，(X, Y) represents transformed coordinates in the new plane. α is the rotation angle, (g, h) is the old coordinates of the origin in the new plane.

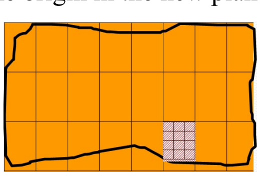


Figure 3. Delineation of roof shapes from irregular building boundaries: bold black curve shows the irregular boundary of classified building unit; the brown yellow cell is the minimum fitting unit; small pink cells represent individual pixels.

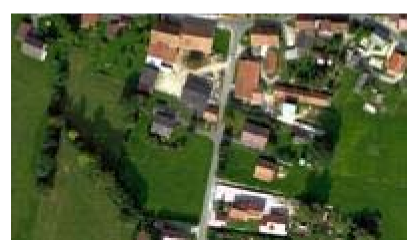
In this study, the building model of rectilinear boundaries is assumed. It can be described that each building are composed of straight lines that meet at 90-degree angles. We adopt this model because it is the most commonly existed roof shape and relatively easy to be dealt with. Building squaring is used to refine and shape the building extraction results from the object oriented classification.

The delineation based on object-oriented classification result in irregular building boundaries as shown in Figure 3.

Firstly, all lines parallel and perpendicular to the dominant line are obtained with equal spacing (in Fig. 3 it is 5x3 pixels), namely side length. After this step, the orthogonally crossed lines will form a set of rectangular cells aligning with the walls of the building. In the third step, each cell is overlaid upon the binary building mask imagery obtained from segmentation and classification. The percentage of building pixels within each cell is computed. A cell is retained if it contains a specified percentage (e.g., 40 percent) or more of building pixels. The final delineation is obtained by tracing the boundary of the retained cells. The tracing step retains only the corner points of the building, i.e., the minimum set of points necessary to define the 2D building contour. The result is a building outline composed entirely of orthogonal edges.

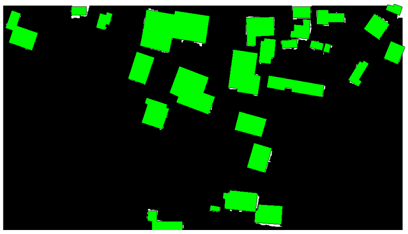
III. EXPERIMENTAL RESULTS

A true color airborne photograph subset from eCognition tutorial dataset is chosen for our experiment. Fig 4a shows the true color imagery. Fig. 4b shows the object-oriented classification results of the land use, in which white areas show extracted building masks by object-oriented classification. Other land use class, e.g., yards, trees, and roads are not shown here. Fig. 4c shows rectilinear roof fitting of the building masks, where green areas represents the final delineated building roof polygons.



(a)

(b)



(c)

Figure 4. Experimental results of building extraction from imagery: (a) original airborne photograph; (b) white areas show extracted building masks by object-oriented classification; (c) rectilinear roof fitting of the building masks, green areas show the final delineated building roof polygons.

IV. Discussion and Conclusion

In this paper, we proposed a building extraction system applied on high resolution remote sensing imagery based on multi-scale object oriented classification and progressive probabilistic Hough transform. It is shown by our experiment that major rectangular building roofs can be correctly detected, extracted and reconfigured, demonstrating the potential application of the method.

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