

Object-based extraction of buildings from very high resolution satellite images: A case study of Ho Chi Minh City, Viet Nam

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Abstract: A new object-based extraction approach based on area morphology is developed and tested on an old dense residential and commercial area of Ho Chi Minh City, Viet Nam. It aims to extract the building features from very high resolution (VHR) satellite images for the update of building inventory database. This new approach analyzes the spectral information across the scale space built on area morphological filtering. By this way, not individual pixel is concerned but an object as it appears at a specific range of scales. As a result, the extracted buildings are readily used in GIS database. The test result shows successful extraction of most commercial buildings and big residential buildings. The success in extraction of a building highly depends on how its spectral signature differs from the surroundings. In a very dense residential area, small houses are often merged as a block. It infers that the method will be successful in newly developed city areas. Employment of VHR satellite image at the first step of updating process prior to the field survey and input database can reduce lots of labor cost and processing time. Thus, it is a promising cost-effective approach.

Keywords: Very high resolution satellite image, object-based analysis, features extraction, building inventory database.

1. Introduction

For decades, as satellite sensors provide rather coarse images like 30-meters Landsat, or 10-meters SPOT images, etc. for land applications, it was unable to be employed in establishing and updating geospatial database of urban areas. The conventional routine of updating building database is mainly visual interpretation of aerial photographs prior to inputting other attributes collected from field surveys. This process is time-consuming and tedious. The recent commercialization of IKONOS and QuickBird, called very high resolution (VHR) satellite images in general, which capture equal to or better than 1-meter spatial resolution images, allows the capability of employing satellite images in this urban application. More importantly, it is possible to speed up the process of updating building database since satellite images have lower image distortion and cover larger area than the aerial images (Meinel et al. 1998). In addition, the revisit cycle of those high resolution sensors can be as short as 1-3 days so that the frequent update of the building database can be achieved.

The VHR satellite images virtually provide enough detailed information for updating building inventory. However, their complexity is a big obstacle to develop either an automatic or a semi-automatic updating the database (Kressler et al. 2004). Pixel-based or texture-based methods cannot exploit all information possessed in a VHR image. Those methods commonly introduce the intra-region errors in classification or segmentation, i.e. a building is smashed into fragments. Object-based methods which concern the context information in the neighborhood of every pixel entity during the analysis have been realized as a potential solution. Nevertheless, a few object-based methods are available today. Its employment in processing images for updating a building database is also limited. Most recent efforts show quite good extracted results in sparsely distributed areas (Kressler et al. 2004, Liu et al. 2005).

This paper presents a newly developed object-based method for feature extraction in general. Its application focuses on the extraction of buildings for updating a building database. The method was developed based on area morphology (Vincent, 1992), which is briefly described in Section 2. Based on area morphology, scale-space (Lindeberg, 1993; Petrovic et al. 2004) is generated as the framework for extraction/segmentation. Description of the proposed method is given in Section 3. The method was tested on dense residential and commercial areas of Ho Chi Minh City, Viet Nam using QuickBird images. The results in Section 4 illustrate the capability of the method and also to achieve another objective of this study, i.e. to check the capability of VHR images in updating building databases of very dense Asian cities.

2. Area morphological scale space

The binary area opening is defined (Vincent, 1992) as follows; Let set X is a subset of set $M \subseteq R^2$ and $\{X_i\}$ is all the connected components of X . The area opening of parameter s ($s \geq 0$) of X , represented as $\gamma_s^a(X)$, is the union of the connected components of X with an area greater than s . The area closing of parameter s ($s \geq 0$) of X , represented as $\phi_s^a(X)$, is then defined as area opening of parameter s on the complement of X in M .

Vincent (1992) then extended the definition of binary area opening or closing to grayscale area opening or closing. A grayscale image can be defined as a mapping $f : M \rightarrow R$. The grayscale opening of f is described as follows. The image M is firstly threshold with all the possible h and the binary opening $\gamma_s^a(T_h(f))$ is found. Subsequently, supremum, i.e. a lowest upper bound, is applied to all the recently found $\gamma_s^a(T_h(f))$. It is similarly extended to grayscale closing by duality. Area morphological filtering does not depend on the shape of structural elements as the conventional one. Therefore, it can effectively remove noise and simultaneously retain thin or elongated objects.

Applying area opening followed by area closing with a parameter s , named *AOC* operator, on an image is hence, like flattening this image by parameter s . This performance segments an image into the flat zones of similar intensity or isolevel sets, in other words. Therefore, a scale-space can be generated by iterative applying *AOC* with increasing s . The desirable properties of a scale space like fidelity, causality, Euclidean invariance, are hold by *AOC* scale-space (Acton and Mukherjee, 2000). Theoretically, the scale-space is generated by an infinite number of scales. For the discrete dimension of an image, the number of scales increases one each as a window (area) size increases from one pixel to the image size. However, it is time-consuming to concern all the area values. Practically, a scene contains a limited number of sizes. Horizontal and vertical granulometry analyses (Vincent, 1994) are carried out to find the potential patterns contained in an image. The local maximum found in horizontal and vertical dimensions can be used to compute the possible areas of objects in the image.

The *AOC* presented above for grayscale images was extended to process multi-spectral images for more practical uses. Firstly, granulometry analysis is carried out on the first component of Principle Component Analysis (PCA). The parameters found from this analysis will be used for all bands. In addition, digital numbers representing the spectral reflectance can be re-scaled to be a smaller number of grayscale values. It is to speed up the computational time and mitigate the differences between different parts of a building due to sun light. The scale-space of each band is separately generated as illustrated in Figure 1. Figure 1a shows the original false color composite (FCC) of a QuickBird scene acquired over Bam city, Iran. It is represented on scales $s = 50, 100, 1000$ as shown in Figure 1b, 1c, and 1d, respectively. Each big building or vegetated area is clearly shown as one object on scale 1000. The smaller buildings disappear on this scale but clearly shown on the smaller scales. Spectral signature is then grouped separately on each scale by K-mean clustering. Spectral indexes are assigned to land-cover types such as building, vegetation, shadow, water body, etc. and stored in a database for further analysis.

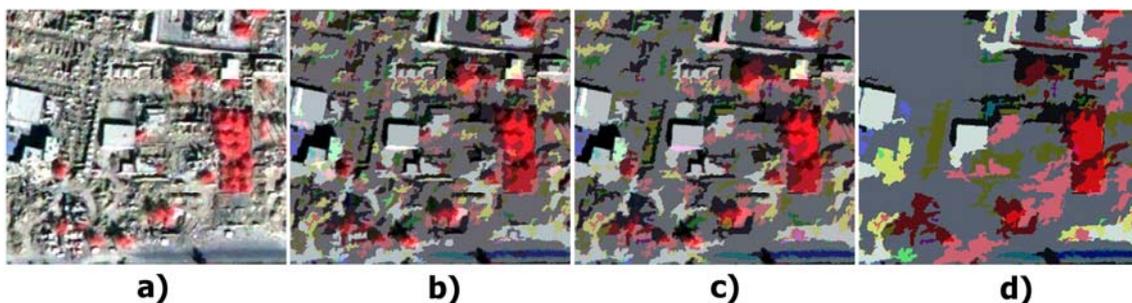


Figure 1. The illustration of scale-space generation for a multi-spectral image: a) original FCC image and on three scales b) $s = 50$, c) $s = 100$, d) $s = 1000$.

3. Scale-space feature extraction

Across the scale space from coarse to fine, an object follows the process of creation and split. Depending on its spectral index, a newly created object might be a child of the current object which this new object falls into. If not, the current scale is called “root” scale of this object. An object can be extracted at its “root” scale. The links between objects across the scale space are demonstrated in Figure 2. Let assume that we are considering three-scales space with $S1$ is the

coarsest and S3 is the finest one. On the current scale S2, there are two newly created objects named A and B. While A has similar intensity to the bigger one at scale S1, B has different intensity. As a result, B can be extracted at this scale S2 with its two-levels tree and A is associated with its father at S1 and two children at S3 to form a three-levels tree.

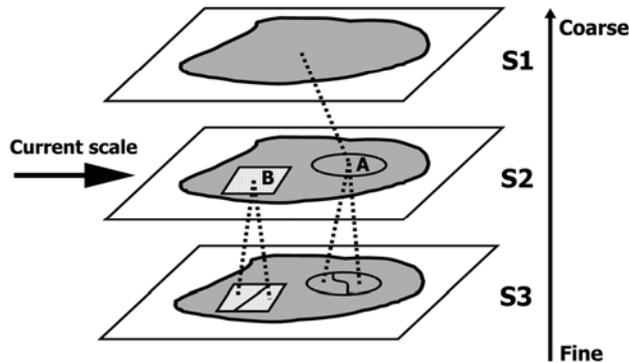


Figure 2. Illustration of object linking across the scale space.

All objects are linked and their relationships are stored in a database. However, focusing on building features, other classes are ignored in the extraction. The linking is started at the finest scale. The attributes of each object are

- SCALE: the current scale in which it exists,
- ID: the identified number on the current scale,
- AREA: object’s area,
- X0, Y0: image coordinates of the starting point of an object,
- X, Y: image coordinates of the centroid; this point will be shifted to an arbitrary location inside the object if it is a concave object,
- SHAPE: to indicate an object is convex or concave,
- SPECTRAL: spectral class,
- SUPERID: the identified number of the object’s father on the next coarser scale, this number equals 0 if the scale is the root of this object. It is the cue for the extraction.

4. Test results

Two dense residential and commercial areas (Figure 3) of Ho Chi Minh City were used to test the proposed scheme of feature extraction. A QuickBird image was acquired on June 1, 2004. There is sparse distribution of buildings in Test A area. However, there are several very complex structures interspersed in vegetation-covered areas. On the contrary, in Test B area, there is very dense distribution of residential buildings. Many small houses with similar roof material tightly stand next to others.



Figure 3. Two test areas in Ho Chi Minh City, Vietnam.

Firstly in Test A, all of big buildings, even very complex structures could be extracted (Figure 4). Figure 4b collected only the extracted buildings on 3 biggest scales for clear presentation. As total 7 scales were concerned, the small buildings in Test A were successfully extracted on the smaller scales. A typical example of the complex structures is Reunification Palace as shown in Figure 5. A problem introduced is how to combine all components of this complex structure into one due to the differences in their sizes and spectral signatures. Perhaps, more context information is needed. This problem will be concerned in further improvement.

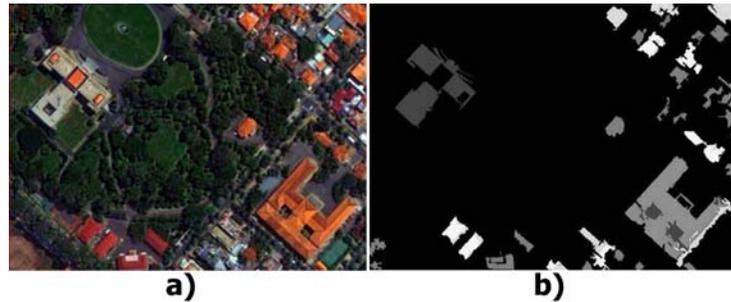


Figure 4. Illustration of successful extraction of big buildings in Test A: a) original RGB and b) extracted results with black for background.

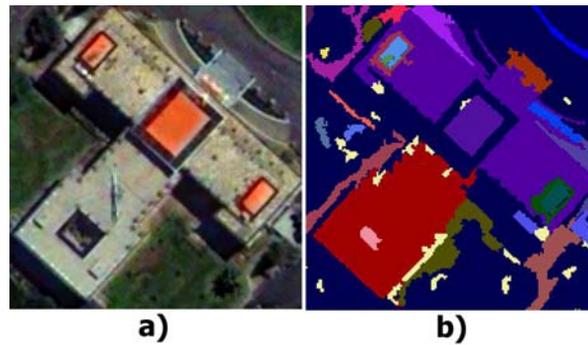


Figure 5. Reunification Palace. a) original RGB and b) extracted result with dark blue for background.

Secondly, the extracted results on 3 biggest scales of Test B are shown in Figure 6. Big buildings with different spectral signatures in comparison with the surroundings were successfully extracted. Other extracted results were building blocks, combining several neighboring buildings with similar spectral signatures. The extraction was very sensitive to the intensity. Even though the digital numbers were re-scaled to reduce the spectral difference, the difference still retains. Besides the contrast to the surroundings, in order to successfully reconstruct the exact shape of a building, all components of a building must have very similar signatures. Sun condition at the acquisition time is the affected factor. A typical example is the red-roof house at the bottom-right of Figure 6a, only one side of the roof was reconstructed.

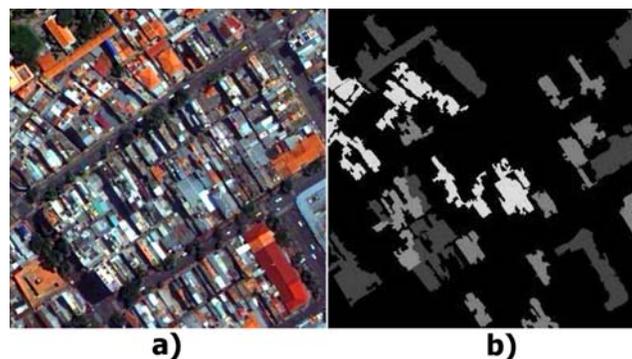


Figure 6. Illustration of successful extraction of big buildings in Test B: a) original RGB and b) extracted results with black for background.

Focusing on a dense area of small houses (Figure 7), how a small building could be extracted? Similarly as big buildings, small buildings with much different spectral signatures were quite successfully extracted. Some others whose spectral signatures are similar as the ground's were unsuccessfully extracted like a block on the right side of Figure 5a. In this testing, the smallest size concerned was 10 pixels which equal 3.6 m². However, the houses which are larger than this size were also missed or combined to others due to the low contrast of spectral signature. It infers that much better than 0.6-meter spatial resolution images are required to extract such small houses in a dense area. It is also recommended that the improvement of the method should deal with different roof material for better separation. The next question is whether 4 bands of VHR images are enough and how many categories of spectral information should be defined in the clustering?

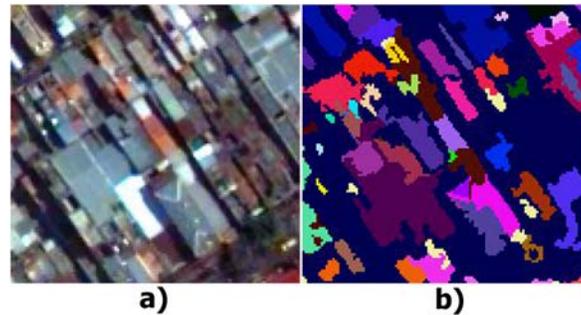


Figure 7. A dense area of small houses: a) original RGB and b) extracted result with dark blue for background.

5. Conclusion

A new object-based feature extraction method built based on area morphological filtering was introduced and implemented. As it successfully extracted most of buildings except small and low contrast buildings, this method is very promising to extract newly constructed buildings. It is applicable to quickly update the building database for such fast-growing cities of developing countries. It is recommended to use a better spatial resolution image for extraction of small houses in very dense areas. Further improvement should include more context information to group different parts of a complex structure into one and to separate the small houses from a block. Categorizing the roof material will be also concerned in further works.

Acknowledgement

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