Remote Sensing of Environment 201 (2017) 243–255

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Separate segmentation of multi-temporal high-resolution remote sensing images for object-based change detection in urban area

Xueliang Zhang, Pengfeng Xiao*, Xuezhi Feng, Min Yuan

Department of Geographic Information Science, School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing 210023, China
Collaborative Innovation Center of South China Sea Studies, Nanjing 210023, China
Jiangsu Center for Collaborative Innovation in Geographical Information Resource Development and Application, Nanjing 210023, China

ARTICLE INFO

Keywords:
High-resolution remote sensing
Object-based change detection
Multi-temporal segmentation
Spatial correspondence
Object-to-object change

ABSTRACT

High-resolution (HR) remote sensing images present geometric details of land surface. Object-based change detection (OBCD) provides an effective solution to reveal detailed changes of geographic objects in HR images. In OBCD, the separate segmentation strategy holds the potential of revealing specific object-to-object changes, but it is difficult to establish spatial correspondence between distinct multi-temporal segments. To overcome this difficulty, we proposed to first detect multi-temporal changed objects based on separate segmentations and then to establish spatial correspondence between changed objects at different phases. Three separate segmentation strategies, named as SIISeg, SAISeg, and SAOSeg, are compared to indicate the importance of associating separate segmentation procedures for successive spatial correspondence establishment. The experiments of detecting building changes in urban area are performed to demonstrate the success, benefits, and potentials of establishing spatial correspondence for object-to-object change detection.

1. Introduction

High-resolution (HR) remote sensing images provide a great amount of details of land surface, allowing detailed comparison of geographic objects at different phases. Detecting detailed changes of geographic objects is of great significance to map updating, urban planning and management, disaster management, and so on (Gong et al., 2008; Linke et al., 2009).

Since the geometric details of geographic objects are clearly presented, both thematic and geometric changes of geographic objects can be revealed from multi-temporal HR images, where the geometric changes involve the change of size, shape, position, number, and so on (Blaschke, 2005). Taking the buildings in urban area as an example (Fig. 1), different kinds of building changes, including the new, dismantled, and restored buildings, are presented with object-to-object geometric change in addition to thematic change. A single change map is able to describe the changed regions and the thematic changes in these regions. However, it cannot reveal the object-to-object geometric changes, which is important for understanding the changing process of geographic objects. The focus of this study is to achieve object-to-object change detection by comparing separate segmentations of multi-temporal HR images.

To detect changes of geographic objects from HR images, the object-based change detection (OBCD) has been demonstrated to be an effective method because: (1) image objects can delineate geographic entities better than pixels; and (2) OBCD can exploit abundant features of image objects for comparison (Blaschke et al., 2014; Chen et al., 2012; Hussain et al., 2013; Tewkesbury et al., 2015). Furthermore, OBCD shows a lower sensitivity to misregistration errors than pixel-based change detection (Chen et al., 2014; Dingle Robertson and King, 2011). Generally, OBCD is composed of image segmentation to generate image objects and successive change analysis on image objects to detect changed objects. The effectiveness of OBCD is highly dependent on the segmentation step by providing the same unit or different units for successive change analysis.

Providing the same unit means producing a single segmentation result from multi-temporal images. The solutions include: (1) only segmenting one image and directly assigning the segments to the other image (Comber et al., 2004); (2) stacking images at different phases and segmenting the stacked image (Bontemps et al., 2008, 2012; Conchedda et al., 2008; Desclée et al., 2006; Duveiller et al., 2008; Im et al., 2008; Park and Chi, 2008; Stow et al., 2008; Zhou et al., 2015); (3) separately segmenting images at different phases and fusing the segmentation results into one map by spatial intersection operation (Bruzzone and Prieto, 2000; Hall and Hay, 2003; Niemeyer et al., 2008); and (4) segmenting one image and then resegmenting the segments in

* Corresponding author at: 163 Xianlin Avenue, Nanjing, China.
E-mail address: xiaopf@nju.edu.cn (P. Xiao).

http://dx.doi.org/10.1016/j.rse.2017.09.022
Received 14 February 2017; Received in revised form 8 September 2017; Accepted 16 September 2017
Available online 25 September 2017

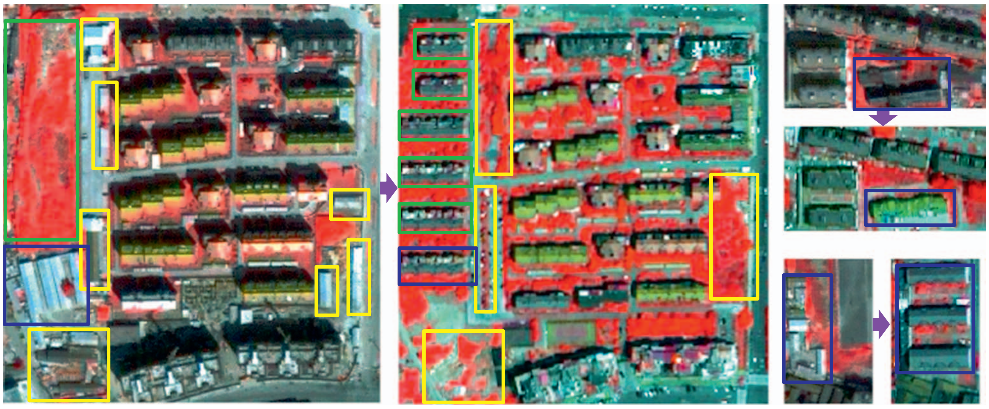

Fig. 1. Examples of changed buildings in urban area to illustrate thematic and geometric changes of geographic objects. New buildings, dismantled buildings, and restored buildings are marked as green, yellow, and blue rectangles at the corresponding positions in multi-temporal IKONOS images, respectively. The images are shown with the false-color composition of near infrared, red, and green. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

potentially changed regions for the other image (Li et al., 2009; Listner and Niemeyer, 2011). The main difference of the four segmentation solutions comes from the way of utilizing multi-temporal information. The effectiveness of them may depend on specific application tasks. Since the same unit is used for successive change analysis, it can only determine the changed regions and reveal the thematic changes in those regions. To reveal object-to-object geometric changes, the change analysis has to be performed on different units.

Providing different units for OBCD means to separately segment multi-temporal images to produce a segmentation result at each phase. The successive change analysis is then performed by comparing distinct multi-temporal segments associated with spatial correspondence. Since the segments hold the potential to represent diverse geographic objects at each phase, the geometric changes of objects can be revealed by comparing distinct segments at different phases, as shown in the blue rectangles in Fig. 2 for restored buildings. Furthermore, the separate segmentations hold a great potential of exploiting multi-temporal information for detecting thematic changes in two aspects: (1) the boundaries of changed objects can be accurately described by the separate segmentations, such as the marked changed buildings in Fig. 2; and (2) the shape change of multi-temporal segments could serve as an effective clue for determining changed objects.

Even though OBCD based on separate segmentations apparently holds theoretical advantages as described above, it faces the great challenge of establishing spatial correspondence between multi-temporal segments (Chen et al., 2012; Hussain et al., 2013; Tewkesbury et al., 2015). This is because in addition to the changed areas, the multi-temporal segments in unchanged areas also present apparent shape changes (Fig. 2), which could be caused by the contextual influence of the changed objects, the appearance change of the same geographic objects such as the material of roof and the phenology of vegetation, and the different imaging conditions such as the solar elevation, sensor angle, and atmospheric condition (Niemeyer et al., 2008). The shape changes of segments in unchanged areas make it difficult to distinguish the real shape changes from those caused by other factors rather than object changes. More importantly, a segment at one phase may overlap with multiple segments at the other phase, making it difficult to determine the spatially corresponded segments at different phases purely according to the geometric cues of segments, e.g. position, size, and shape.

Since the distinct segments in unchanged areas are the main disturbance to establishing spatial correspondence between separate segmentations, we need additional supports apart from geometric cues to suppress segments in unchanged areas and to highlight segments in changed areas. It should become relatively simple to establish spatial correspondence between distinct segments in only changed areas without the disturbance of those segments in unchanged area. Usually, the class labels of multi-temporal segments serve as an additional support. For example, we can first detect the objects of interest at each phase and then restrain to compare the detected objects for change analysis (Gong et al., 2008; Miller et al., 2005). In this case, it can naturally achieve object-to-object comparison by overlapping detected objects. However, the effectiveness is highly dependent on the object detection performance. Another possible solution is to first classify all the segments at each phase and then find changed objects with different class labels (Chen et al., 2013; Dingle Robertson and King, 2011; Gamanya et al., 2009; Lizarazo, 2012). However, at present, most studies still choose to determine changed objects on the intersections of classified objects (Dingle Robertson and King, 2011; Gamanya et al., 2009; Lizarazo, 2012). The intersection makes it degrade into change

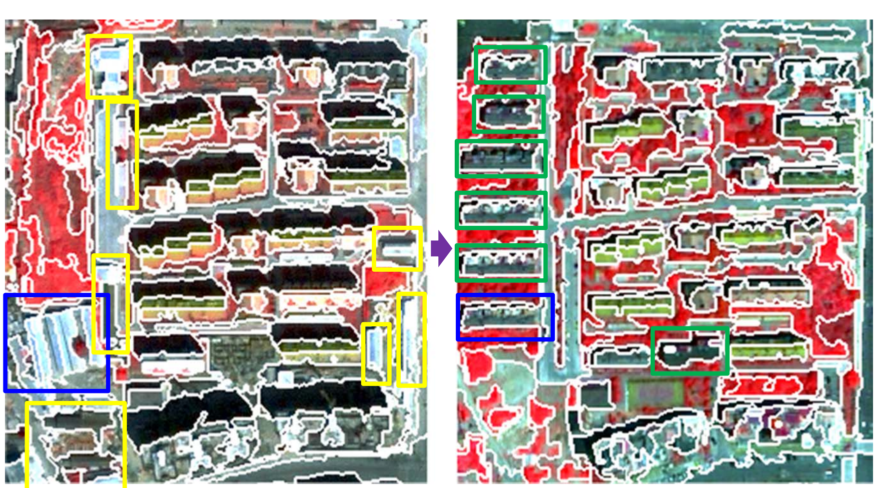

Fig. 2. Example of separate segmentations to illustrate its advantages of revealing geometric changes (such as the restored buildings in blue rectangles) and its difficulty of establishing spatial correspondence between distinct segments at different phases. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)