ISPRS Journal of Photogrammetry and Remote Sensing 130 (2017) 202–216

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

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

Technical design and system implementation of region-line primitive association framework

Min Wang [a,b,*], Jinjin Xing [a], Jie Wang [a], Guonian Lv [a,b]

[a] Key Laboratory of Virtual Geographic Environment (Nanjing Normal University), Ministry of Education, Nanjing, Jiangsu 210023, PR China
[b] Jiangsu Center for Collaborative Innovation in Geographical Information Resource Development and Application, Nanjing, Jiangsu 210023, PR China

ARTICLE INFO

Article history:
Received 11 November 2016
Received in revised form 30 March 2017
Accepted 6 June 2017

Keywords:
Region-line primitive association framework
Object-based image analysis
Image segmentation
Region
Straight line
High-resolution remote sensing
Information extraction

ABSTRACT

Apart from regions, image edge lines are an important information source, and they deserve more attention in object-based image analysis (OBIA) than they currently receive. In the region-line primitive association framework (RLPAF), we promote straight-edge lines as line primitives to achieve powerful OBIAs. Along with regions, straight lines become basic units for subsequent extraction and analysis of OBIA features. This study develops a new software system called remote-sensing knowledge finder (RSFinder) to implement RLPAF for engineering application purposes. This paper introduces the extended technical framework, a comprehensively designed feature set, key technology, and software implementation. To our knowledge, RSFinder is the world's first OBIA system based on two types of primitives, namely, regions and lines. It is fundamentally different from other well-known region-only-based OBIA systems, such as eCogntion and ENVI feature extraction module. This paper has important reference values for the development of similarly structured OBIA systems and line-involved extraction algorithms of remote sensing information.

1. Introduction

In object-based image analysis (OBIA), objects generally refer to groups of closely related pixels that constitute pieces of non-overlapping regions obtained by means such as image segmentation. As a result, regions (segments) form the basic units for subsequent feature extraction and analysis, and are called object primitives because of their fundamental roles in OBIA (Baatz and Schäpe, 2000). Theoretically, OBIA has many distinctive advantages over pixel-based image analysis (PBIA). For example, OBIA aids in fully utilizing features, such as the spectral signature, texture, shape, and spatial relationship among objects. OBIA also facilitates the linkage of image processing with other information sources, such as GIS database and expert knowledge. Thus, OBIA has been studied and received much attention in the field of remote sensing applications (Benz et al., 2001, 2004; Walker and Blaschke, 2008; Myint et al., 2010; Blaschke, 2010; Hofmann et al., 2011; Blaschke et al., 2014). After decades of development, OBIA has become the paradigm technique for the analysis of high-spatial resolution (HSR) remote sensing images (Blaschke et al., 2014).

Within the global scope, representative OBIA software systems include Trimble's eCognition and the ENVI feature extraction module. In both systems, region primitives (segments) are obtained by image segmentation with different algorithms. Despite the existence of different implementations, OBIA research and applications based on region primitives are prevalent, which cover image classification (Laliberte et al., 2012; Rasi et al., 2013; Dronova et al., 2014; Du et al., 2015; Robson et al., 2015), thematic information extraction and object recognition (Sebari and He, 2013; Hegarat-Mascle and Ottle, 2013; Cheng and Han, 2016), and change detection (Lu et al., 2011; Hebel et al., 2013; D'Oleireoltmanns et al., 2014; Qin et al., 2015; Yu et al., 2016; Ma et al., 2016). Man-made object (typically urban impervious surface) extraction is a current interest in these applications, which is promoted by the emergence of HSR images and commercial OBIA software (Weng, 2012).

Despite its significant advantages, OBIA still has many problems to be solved, such as the following:

First, accurate HSR image segmentation is still a big issue. Successful OBIAs require accurate object primitives—correct image segmentation—that significantly influence subsequent analysis. In

* Corresponding author at: Key Laboratory of Virtual Geographic Environment (Nanjing Normal University), Ministry of Education, Nanjing, Jiangsu 210023, PR China.

E-mail addresses: sysj0918@126.com (M. Wang), jinjinwxgis@163.com (J. Xing), wangjieyl@sina.com (J. Wang), gnlu@njnu.edu.cn (G. Lv).

http://dx.doi.org/10.1016/j.isprsjprs.2017.06.002

the OBIA field, the multiresolution segmentation (MRS, which originated from a framework called fractal net evolution approach) (Baatz and Schäpe, 1999, 2000), along with the successful business application of eCognition software, has been the most popular segmentation method. Succeeding progress related to MRS includes optimizations of segmentation scale selection (Drăguţ et al., 2010, 2014; Tullis et al., 2010; Tong et al., 2012), resegmentation in classification stage (Tiede et al., 2010, 2011), and novel segmentation schema by combining region and edge information (Chen et al., 2012; Yu et al., 2012; Wang and Li, 2014; Wang et al., 2015, 2017b). However, remote sensing image segmentation, which is an ill-posed problem (Belgiu and Drăguţ, 2014; Drăguţ et al., 2014; Troya-Galvis et al., 2015) and has significant ambiguity and subjectivity (Clinton et al., 2010), still lacks a final solution, especially on method accuracy.

Second, object-based classification/recognition techniques also require significant improvements. The classifiers adopted in OBIA are generally the same as those in PBIA. Commonly utilized classifiers include knowledge rule induction, k-nearest neighbors (k-NN), and decision tree, as well as other more popular types (e.g., random forest, SVM, and deep neural network). Although OBIA has several performance advantages in certain aspects, it has not shown significant accuracy improvements over PBIA for several median resolution remote sensing image classification tasks (i.e., TM and SPOT-5) (Dingle Robertson and King, 2011; Duro et al., 2012). Aside from the improvements on classifiers, sophisticated feature utilization schemes, new types of image features with enhanced object discriminating capability and flexible classification rules with high transferability (Hofmann et al., 2011) can also be crucial to improve the classification accuracy in routine OBIA applications.

Third, OBIA has limitations in the technical framework of "segment and then classify." Vector data types, such as points, lines, and regions, correspond to pixels, edge lines, and regions in images, respectively. PBIA and OBIA have been the paradigms for remote sensing applications, in which pixels and regions are regarded as primitives for low- and high-resolution image analysis, respectively. However, image edge lines, which are commonly defined as collections of local contiguous edges and possess strong semantic meanings, have not obtained the same primitive-level attention as pixels or regions in image analysis. For example, image analysis in eCognition is completely conducted on regions, whereas the edges only function as an auxiliary feature. Image edge lines are composed of highly related pixels similar to regions; thus, they can also be regarded as objects. Furthermore, straight edge lines are important types of edge lines for image interpretation (Burns et al., 1986), which are typically adopted to locate and distinguish man-made objects from remote sensing images. Thus, edge lines, especially straight lines, can be more important in OBIA than they currently are.

Specific roles of straight lines in OBIA include the following aspects:

(1) Straight lines have distinctive features that differ from those of regions. Line features, including length, direction, density, and other statistics, are considerably useful for image classification. For example, straight lines in natural surfaces are often cluttered, whereas those in man-made objects are frequently distributed structurally (see Figs. 7–9 in Section 3 for illustrations). Straight lines can be independent or an auxiliary in classifying man-made and natural objects.

(2) Simply shaped straight lines facilitate line pattern searching and matching, whereas region matching is generally more complex. In objected-based change detection (OBCD), image changes are often distinguished by similarity matching of regions. However, some changes can be easily located by emergence, vanishment, or appearance changes of straight lines before the region-based change recognition is conducted. Thus, region-line association change analysis has great potential in OBCD.

(3) Straight lines can be important in the OBIA shape analysis. Over- and under-segmentation, as well as segment boundary imprecise errors, generally exist in multi-scale image segmentation (e.g., MRS). Segment boundaries can deviate from actual object boundaries in locations and quantities (see Fig. 6 in Section 3 for illustrations of the MRS method). Hence, segment shape measures frequently deviate from actual object appearances. Conversely, straight line detection can be precisely in position. Furthermore, man-made objects generally have distinctive straight line distributions, such as in parallel or perpendicular arrangements. Thus, man-made object shapes can sometimes be inferred by related straight lines in easy but precise ways. Straight lines can also be utilized to refit object shape deficiencies commonly observed in man-made objects.

(4) Straight lines can also be important in OBIA direction and topology analysis. Sometimes, OBIA needs main segment directions or topology relationships. Direction calculation might involve a segment's minimum boundary rectangle or main axis, which might be time consuming and imprecise for complex shapes. However, line direction calculation is easy. Topology relationship analysis, which involves determining whether two objects are neighbors that share common boundaries, might be imprecise because of segmentation errors (see Fig. 6 in Section 3 for illustrations on the "transition belt" error of the MRS method). Sometimes, such judgments need to be relaxed by buffer zones around regions. Conversely, straight lines are simple subjects for buffer or topology analysis, which avoid calculations of complex region relationships.

Clearly, straight lines can be more important in OBIA. However, edges occur only in specific locations rather than cover the entire image. Lines by themselves cannot support full image domain analysis, unlike pixels or regions. Currently, line utilization in image analysis is commonly application driven, i.e., specific algorithm for specific goals (Unsalan and Boyer, 2004; Agüera and Liu, 2009; Hegarat-Mascle and Ottle, 2013). Developing a suite of generic line utilization techniques can avoid technology fragmentation and improve its universality. Furthermore, viewpoints of line primitive and region-line collaborative analysis from current OBIA framework become noticeable and improve its capabilities.

In a previous study (Wang and Wang, 2016), we established a new OBIA technology model that involves both regions and straight lines; this model is called the region-line primitive association framework (RLPAF). In this framework, straight lines are detected aside from regions. Straight line and region-line association features are extracted. In the object classification stage, regions and lines are collaboratively utilized for comprehensive image analysis. We developed several RLPAF-based object extraction algorithms for HSR images and validated that RLPAF performed better in man-made object extraction compared with conventional region-based OBIA technology by involving line primitive and region-line association features (Wang et al., 2015, 2017b; Wang and Wang, 2016).

In this study, we develop the first OBIA system based on region-line association from the previous work. This paper focuses on new technical contents, including system design and implementation. Although utilization of regions and lines is not a new topic in image analysis, the highly integrated techniques of region-line association and software system for OBIA are the distinctive characteristics and original achievements of this study.