ISPRS Journal of Photogrammetry and Remote Sensing 90 (2014) 1–9

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

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

Introducing mapping standards in the quality assessment of buildings extracted from very high resolution satellite imagery

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ARTICLE INFO

Article history:
Received 11 October 2012
Received in revised form 13 December 2013
Accepted 24 December 2013

Keywords:
QuickBird
Feature extraction
Buildings
Urban
Accuracy
Lisbon

ABSTRACT

Many municipal activities require updated large-scale maps that include both topographic and thematic information. For this purpose, the efficient use of very high spatial resolution (VHR) satellite imagery suggests the development of approaches that enable a timely discrimination, counting and delineation of urban elements according to legal technical specifications and quality standards. Therefore, the nature of this data source and expanding range of applications calls for objective methods and quantitative metrics to assess the quality of the extracted information which go beyond traditional thematic accuracy alone. The present work concerns the development and testing of a new approach for using technical mapping standards in the quality assessment of buildings automatically extracted from VHR satellite imagery. Feature extraction software was employed to map buildings present in a pansharpened QuickBird image of Lisbon. Quality assessment was exhaustive and involved comparisons of extracted features against a reference data set, introducing cartographic constraints from scales 1:1000, 1:5000, and 1:10,000. The spatial data quality elements subject to evaluation were: thematic (attribute) accuracy, completeness, and geometric quality assessed based on planimetric deviation from the reference map. Tests were developed and metrics analyzed considering thresholds and standards for the large mapping scales most frequently used by municipalities. Results show that values for completeness varied with mapping scales and were only slightly superior for scale 1:10,000. Concerning the geometric quality, a large percentage of extracted features met the strict topographic standards of planimetric deviation for scale 1:10,000, while no buildings were compliant with the specification for scale 1:1000.

1. Introduction

A spatial component is associated with the majority of municipal activities, namely in urban planning and management. At this level, decision-making is supported by large-scale spatial data that include both topographic and thematic information, but which rapidly become outdated due to the strong dynamics of the urban environment. These frequent changes require faster updating of municipal spatial databases. The combination of widely-available, wide-coverage, cost-effective very high spatial resolution (VHR) satellite imagery and Geographic Object-Based Image Analysis (GEOBIA) hold promise for this purpose, despite the spectral limitations of the former (Herold et al., 2003) and the shortcomings of the latter (Lang, 2008). In a detailed evaluation of classification performance, Herold et al. (2003) identified spectral limitations of IKONOS imagery for pixel-based classification of urban land cover, indicating that 4-band VHR satellite imagery are not well suited to capture in detail the unique spectral characteristics of the urban environment (Herold et al., 2003). However, those authors admit the possibility that other classification approaches such as GEOBIA may be more appropriate for urban mapping, potentially enabling increases in map accuracy. Among the weaknesses attributed to GEOBIA methods are the difficulties in processing very large data sets (and VHR satellite scenes can be enormous), the fact that segmentation does not have a unique solution, and the insufficient understanding of scale and hierarchical relations among objects derived at multiple resolutions (Hay and Castilla, 2008).

Despite these challenges, there is great potential for expanding the use of VHR satellite imagery for urban management at the municipal level. In a recent survey (Santos, 2011) of the Portuguese municipalities carried out by the authors, the majority of those

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http://dx.doi.org/10.1016/j.isprsjprs.2013.12.009

institutions indicated needing spatial information with higher temporal detail, generally on a monthly basis. The 23% of municipalities that already use satellite images for land planning and management do it mainly on a daily basis. Of those municipalities that do not use satellite images, 47% have stated that it should be easy to include this data source in their activities. Based on these responses it was concluded that geographic information having higher spatial and temporal detail is required for municipal activities and that VHR satellite imagery could assist in performing those tasks.

Additionally, the nature of this recent data source and target features, the GEOBIA approach, and the expanding range of applications call for additional methods and metrics to assess the quality of the extracted spatial information (Zhan et al., 2005). These methods should advance beyond traditional pixel-based thematic accuracy alone, requiring assessing the quality of discrimination/classification (thematic quality), detection/counting (completeness), and delineation (geometric quality) of features of interest. Object-based accuracy involves both semantic and geometric agreement (Lang, 2008) often of a single class map, since the objective of feature extraction is to distinguish between two classes, object and background (Rutzinger et al., 2009). Also, an efficient operational use of feature extraction from VHR satellite imagery suggests using accessible commercial-off-the-shelf software for mapping of urban features. However, large-scale topographic mapping usually has to conform to legal technical specifications and quality standards. These concerns contribute to making accuracy assessment a 'hot' research topic in GEOBIA (Blaschke, 2010).

Buildings are a major urban element and one of the main feature classes of interest for a municipality, whose 'correct' automatic extraction from imagery remains a challenging task, even with the advent of high spatial resolution. Difficulties include scene complexity, building occlusions (trees, shadows), and heterogeneity of feature class, and these challenges increase with refinement of image resolution (Awrangjeb et al., 2010). To obtain a cartographic product from VHR imagery using feature extraction, most of the challenge results from the interplay of several factors, namely: (a) the object and its context, (b) the nature of imagery, and (c) the mapping requirements and constraints. Despite the many methodologies proposed for feature extraction, none has proved to be effective in all conditions and for all types of data (Salah et al., 2009). For the image analyst/map producer the challenge may be limited to handling the necessary stages of image pre-processing, image segmentation, and generalization of features to produce a map. At present, the quality assessment of extracted buildings is a complex endeavor for which there is no optimum, consensual, or standard approach (Rutzinger et al., 2009). In this context, for a given classified map, quality assessment results will depend and vary with reference data used and accuracy assessment method employed, preventing their comparison.

Van Coillie et al. (2008) presented a methodology for a supervised, objective evaluation of segmentation quality based on quantitative similarity measures. The methods were tested on a single house, and its manual digitizing was used as reference. Eight quality measures were tested to compare different segmentation layers with the reference one. The discrepancy quality measures included the number of segments that have their centroid in the reference polygon, difference in total area and perimeter, difference in shape complexity, average distance between edge pixels and cumulative distance from the reference.

Regarding polygon generalization, despite being the subject of significant research, there is still a need for comprehensive investigation (Podolskaya et al., 2007). Khoshelham et al. (2009) have conducted a detailed comparative analysis of five automated methods for building detection, but used pixel-based metrics for accuracy assessment.

Accuracy assessment of thematic maps, based on map comparison, has often neglected cartometric quantities (Dungan, 2006). In the case of buildings, topographic maps represent the building footprint according to scale-dependent constraints. Vu et al. (2009) propose a multi-scale solution based on mathematical morphology for building extraction using LiDAR and image data. This approach allows extraction of complex buildings as scale-dependent multi-part objects and capture building footprint.

Very few studies have introduced mapping specifications in quality assessment of features extracted from satellite imagery. Holland and Marshall (2004) and Holland et al. (2006) conducted a qualitative evaluation of the potential of QuickBird imagery for updating topographic maps in Great Britain, concluding that the imagery can be used as source of some feature types at scales up to 1:6000 and should be used in a supplementary way to conventional data sources. Gianinetto (2008) tested roads and buildings extracted from pansharpened QuickBird imagery for updating large-scale topographic databases of urban areas, considering mapping specifications of the Lombardia Region. Results showed that updating of scale 1:10,000 was always compliant with standards, while updating of scale 1:5000 was only possible in certain situations. However, the features used for testing were visually interpreted and manually digitized from the imagery.

The GeoSat research project, which involves the Lisbon City Hall, aims at developing methods to expedite the production of geographic information for municipal planning and land monitoring, and investigates the potential of VHR satellite imagery and GEOBIA for detection and mapping of urban features and their integration into operational urban planning and management activities. Previous work (Santos et al., 2009) has explored and proposed detailed vector-based metrics for accuracy assessment of QuickBird-derived buildings, but without taking map standards into account.

The main goal of the present research is to present an approach that incorporates existing scale-based mapping constraints from official specifications in the process of quality assessment of building polygons extracted semi-automatically from VHR imagery. The approach was first developed and presented by Freire et al. (2010a). The motivation is to evaluate the feasibility of features extracted from VHR imagery by semi-automatic methods to be able to integrate a municipal GIS database with minimum additional editing. First, buildings were extracted from the image using feature extraction software and ancillary data. The second part included the development and testing of quality assessment procedures considering thresholds and standards for the different mapping scales used by municipalities, analysis of metrics, and discussion of results.

2. Study area and data

2.1. Study area

For this study, an area located to the northeast of the downtown of the city of Lisbon, Portugal, was selected (Fig. 1). This area occupies 64 ha (800 m × 800 m), and has a diverse land use/land cover (LULC) that varies from urban to open field with and without vegetation. It includes trees, lawns, herbaceous vegetation and agricultural plots, bare soil, a school, industrial properties, roads and rail networks, and residential housing. This latter use includes a mixture of single homes and multi-story apartment buildings. Due to its diversity, this area provided a good testing ground representative of the challenges for feature extraction existing in the city of Lisbon.

In the study area 627 building blocks were identified, having a wide variety of roof types. Building blocks are typical of dense