EXTRACTING BUILDINGS IN THE CITY OF LISBON USING QUICKBIRD IMAGES AND LIDAR DATA

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ABSTRACT:

The methodology is based on semi-automatic extraction of features, using information from a QuickBird image and LIDAR data. The QuickBird image is suitable to delineate the different elements on the surface based on their spectral characteristics. However, this task is much more successful and richer when altimetric information is also used in the extraction process. Thus, with the introduction of LIDAR data, we intend to study the effect of the contribution of information on the height of urban elements, when classifying orbital data. The thematic information under analysis is the land cover class Buildings.
Two maps are produced and compared. One map is obtained by a classification based only on spectral data while the other map is obtained using spectral and altimetric data. The same methodology is applied in both scenarios, using the same training features. To evaluate the quality of the two maps, a comparison with a cartographic layer is carried out. This reference layer is obtained by visual analysis of the QuickBird image and is used to calculate the Overall Accuracy of the maps obtained with the different data sets.

1. INTRODUCTION

Remote Sensing is a science, a technique and a technology at the service of Earth observation and, in particular, cities. The cities represented in satellite images are objects in the physical sense of the term, characterized by a wide range of spectral responses. These spectral responses only make sense when coupled with thematic content, interpreted based on the shape and morphology of the different elements that are include in the urban environment.

The high rate of changes in cities requires the existence of matching geographic information in order to allow a proper land monitoring and planning. The project GEOSAT explores the potential of high spatial resolution satellite images for extracting spatial information and update existing cartography. The goal is to provide updated spatial data to support the different land-related activities of municipalities. In this context, methods for extracting urban elements relevant to the municipal planning process are tested in the city of Lisbon, Portugal.

The city is characterized by a variety of complex objects (surfaces) which are associated with a wide spectral range. Furthermore, the city is also characterized by volume. Consequently, the shadow projected by the buildings multiply the radiometric effects and complicates the detection of elements. One can conclude that, in the urban realm, the spectral recognition of isolated features is not enough. On one hand, other types of data such as LiDAR (Light Detection and Ranging) must be included to separate impervious surfaces having very high reflectance (like harvested urban agriculture areas, for example) from tall buildings that have similar levels of reflectance. One the other hand, urban remote sensing must ally the spectral recognition of features with the spatial recognition (spatial organization of spectral signatures) (Bähr, 2001). These approaches have been grouped under the term Geographic Object-Based Image Analysis (Hay and Castilla, 2008).

The work presented takes place in the context of project GEOSAT, for which there exist already several publications. Freire et al. (2008) tested the extraction of geographic objects in two study areas located in Lisbon, using a QuickBird image. The authors concluded that the different land cover classes and urban morphology influence the replicability of the mapping processes in distinct urban contexts. Santos et al. (2009) studied the quality of extraction of red tile roofs. The methodology began with the building extraction, followed by geometric generalization and subsequent accuracy assessment. Metrics that enabled comparison of vector data sets were tested in order to assess the compliance of a spatial data set obtained by semi-automated methods, with another set obtained by visual analysis, regarding the thematic and geometric quality. Freire at al. (2009) employed different GEOBIA approaches to extract agricultural use from a pan-sharpened QuickBird image, and results were compared. The study illustrated the potential and limitations of using VHR imagery and feature extraction methods to detect and monitor informal agriculture within a very heterogeneous urban fabric.

2. DATASET AND STUDY AREA

The dataset explored in this paper includes spectral data, acquired by satellite, and altimetric data. The spectral data is a

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QuickBird image acquired in April 14, 2005. The image has a spatial resolution of 2.4 m in the multi-spectral mode (visible and near-infrared bands), a pixel size of 0.6 m in the panchromatic mode, and a radiometric resolution of 11 bits. The image used in this study has an off-Nadir angle of 12.2º.

The altimetric data is composed by two sets. One set is derived from a LiDAR point cloud (Light Detection And Ranging), and the other is derived from cartography. From a LiDAR flight done in 2006, a surface image was produced based on the second return, with 1 m resolution. From 1:1000 scale cartography of 1998, a set of elevation mass points and contours were retrieved.

The study area is located in the oriental part of the city of Lisbon and occupies 64 ha (800 m X 800 m) (Figure 1). The area is characterized by a diverse land cover that includes herbaceous vegetation, lawns, trees and agricultural plots, bare soil, single and multi-family housing, a school, industrial properties, and roads and rail networks.

Figure 1. Study area in the city of Lisbon

3. METHODOLOGY

The cartographic workflow based on spectral and altimetric remote sensing data, begins with the pre-processing stage where the images are orthorectified and registered to the altimetric data. Afterwards, the digital processing of all datasets takes place to produce a map with the location of the desired urban features. In this paper, one wants to evaluate if the introduction of altimetric data together with the spectral data results in a map with higher quality than the map obtained using the satellite image alone. For this purpose, the same methodology is applied, to extractly the same land cover/ land use classes, using two distinct datasets: a spectral dataset and a spectral and altimetric dataset.

3.1 Pre-processing

In this stage, several tasks are applied to geometrically correct the data sets and to attribute a common coordinate system. The altimetric information is also processed in this stage, in order to produce a normalized Digital Surface Model (nDSM).
The QuickBird imagery was orthorectified in order to reduce the geometric distortions introduced by the relief and to attribute a national coordinate system (ETRS89). Previously, a pansharp image of the visible and panchromatic bands was produced for visual benefit, using the method available at PCI Geomatica. The orthorectification of the multispectral and pansharp images was performed based on the Rational Polynomial Coefficients (RPCs) available with the image, and a set of 36 ground control points retrieved from the 1:1000 planimetric and altimetric cartography of 1998. The Root Mean Square Error (RMSE) of the transformation was less than one pixel. Afterwards, a Normalized Difference Vegetation Index image (NDVI) was produced to integrate the dataset for feature extraction.

Regarding the altimetric data, a Digital Terrain Model (DTM) was generated using the elevation mass points and contours obtained from the 1:1000 cartography of 1998. A Triangulated Irregular Network (TIN) was first generated and then converted to a grid with 0.5 m of resolution. The nDSM was produced by subtracting the DTM to the LiDAR image. This raster file has the elevation of all elements above and below terrain.

3.2 Feature extraction

Current and future very high spatial resolution (VHR) satellite imagery provides an advantageous alternative to detect and map urban features. However, their effective use requires the development of novel approaches that enable a timely and consistent discrimination, classification and delineation of these specific land uses with quality indices that match the corresponding map scale. In this context, GEOBIA based approaches are the recent response to this emerged sophisticated user needs and expectations on geographic information products (Hay and Castilla, 2008).

All feature extraction was performed in Feature Analyst 4.2 (by VLS) for ArcGIS (ESRI). The classification is based on a supervised approach. The first step is the manual digitizing of training areas for each class, followed by the definition of parameters like the number of bands to be classified, the type of input representation, and aggregation. The classifier uses feature characteristics such as color, size, shape, texture, pattern, shadow, and spatial association, for feature classification. The use of spatial or spectral or masks during the process, is allowed. After an initial classification, there is the possibility to remove clutter or add missing areas. This hierarchical learning adaptive process allows to iteratively improve the image classification. The classified map can then be post-processed to aggregate and geometrically generalize the features.

The extraction stage was done with the initial objective of correctly identify and classify the geographical elements of municipal interest, but also to evaluate the impact of introducing altimetric data on the map quality. Therefore two mapping approaches are tested: a map produced using only the QuickBird imagery (multispectral, pansharp and NDVI bands), and another map produced with the QuickBird and the nDSM data sets.

The level 1 nomenclature includes the classes “Buildings”, “Pavements”, “Agriculture” and “Trees”, defined according to municipal interest. On the 2nd level, 9 classes are identified: “Buildings with orange tile”, “Buildings with bright roofs” and, “Buildings with other roofs”, “Roads”, “Railway” and “Other impermeable surfaces”, “Trees”, “Agriculture fields” and “Bare soil”.

The first step in the feature extraction process was the selection of training areas for each class. The software allows extracting several classes in one step, or extracting each class independently. The approach selected in this work used, in a first stage, the possibility of classifying the study area in two major classes - “Vegetation”, “No-vegetation” – and in the subsequent stages, each individual class of the nomenclature was extracted independently. The used parameters that produced the best extraction results for each element type are presented in Table 1.

Class (Level 2)	Method & Window (pixels)	Aggregation (pixels)	Mask
Vegetation-No-Veg.	Manhattan 5	10	-
Build. with orange tile	Manhattan 5	10	Vegetation
Build. with bright roof	Manhattan 5	10	Vegetation
Railway	Bull's Eye 2, 9	400	Vegetation
Roads	Bull's Eye 2, 7	50	Vegetation Railway
Other imp. surfaces	Bull's Eye 2, 31	50	Vegetation Railway Roads
Build. with other roofs	Manhattan 5	100	All precedent
Trees	Bull's Eye 3, 11	15	No-Veg.
Bare soil	Manhattan 5	50	Trees
Agriculture fields	Manhattan 7	15	No-Veg. Trees, Bare soil

Table 1. Parameters used for feature extraction in the study area.

The feature extraction stage was difficult due to the complex morphology and to the spatial heterogeneity of the study area. The results that were apparently more interesting (based on visual inspection) were those obtained for the “buildings” classes.

4. RESULTS

After feature extraction, accuracy assessment is carried out to quantify the quality of 1) the two land cover maps and, 2) the contribution of integrating altimetric data in a cartographic framework based on remote sensing data.

The quality assessment for the extracted elements is obtained through conformity analysis. The data used in this process includes the two maps produced by the semi-automatic classifier, and a reference map with the spatial distribution of the land cover classes in the study area, produced by visual analysis and manual digitizing over the pansharp image. Generally, map comparison studies rely on raster data sets (Dungan, 2006), where the comparison is made on a pixel basis (e.g., Bach et al., 2006; Lannon et al., 2007). This approach is oriented by an analytical vision rather than by a large scale cartographic framework. Our work is based on feature comparison in a vector structure, where each extracted feature is treated as a unique entity and corresponds to a second feature in a reference map. Therefore, the conformity is evaluated using a set of metrics that aim to describe the thematic quality between the classified and the reference maps.

4.1 Reference map

To assess the quality of information extracted from images, based on the concept of reference value, it is necessary to assess levels of compliance with information from an independent source. This reference data can be obtained from a field survey (e.g. GPS collection), from an existing map having higher detail or, as in this case, from a map obtained by visual analysis and manual digitizing. To evaluate the quality of the extracted features, a reference map was created by an interpreter, who digitized the land cover classes without taking into account the semi-automatic classification. In this process other data sources were used to support and validate the visual analysis, such as aerial oblique photographs available at maps.live.com.

4.2 Implementation and results

The thematic quality of the classification was evaluated based on the area of overlap with the reference map. The area common to the two sets represents the thematic agreement and indicates the classification’s Overall Accuracy. The area of reference polygons which have no correspondence in the classification stands for the Omission Error, while the area of polygons classified without representation in the reference stands for the Commission Error.

Regarding the map produced using only the spectral dataset, the analysis indicated an Overall Accuracy of 35-39% for the vegetation classes (“Agriculture” and “Trees”), and 52-60% for the urban classes (“Pavement” and “Buildings”) (Table 2). In the map produced with the spectral and the altimetric data, the Overall Accuracy was higher for all classes (Table 3). For the vegetation classes, the values rated 40-48% and for the urban classes the values were 65-72%. In this analysis, we can conclude that the urban classes improved mainly due to the reduction of the Omission Errors, while the vegetation classes beneficiate from the reduction of the Commission Errors.

Class (Level 1)	Spectral dataset		
	Omission Error (%)	Commission Error (%)	Overall Accuracy (%)
Pavement	46	8	52
Buildings	36	9	60
Agriculture	39	48	39
Trees	56	22	35

Table 2. Results of the thematic accuracy of the map produced with the spectral dataset.

Class (Level 1)	Spectral and altimetric dataset		
	Omission Error (%)	Commission Error (%)	Overall Accuracy (%)
Pavement	29	12	65
Buildings	25	5	72
Agriculture	33	37	48
Trees	55	14	40

Table 3. Results of the thematic accuracy of the map produced with the spectral and altimetric dataset.

Nevertheless, low accuracies were obtained for the vegetation classes in both maps. The class “Agriculture fields”, even after several iterations of removing clutter and adding missing data, remained spectrally confused with natural vegetation and grassland. On the other hand, this is a very dynamic class that requires multi-temporal imagery for correct classification. Semi-automated extraction of urban agriculture is therefore complicated by the fact that the class is very heterogeneous, comprised of a mosaic of small parcels having: i) the same crops in different stages, ii) different crops, and iii) fallow or recently farmed parcels.

For the class "Trees", only areas with dense canopies were relatively well identified, failing the identification of isolated trees. The usage of a 2nd return LiDAR image could contribute to the misclassification of this class. In fact, trees are "penetrable" land cover, therefore better captured with inclusion of 1st return LiDAR data. Figure 2 shows the best extraction for the class "Vegetation".

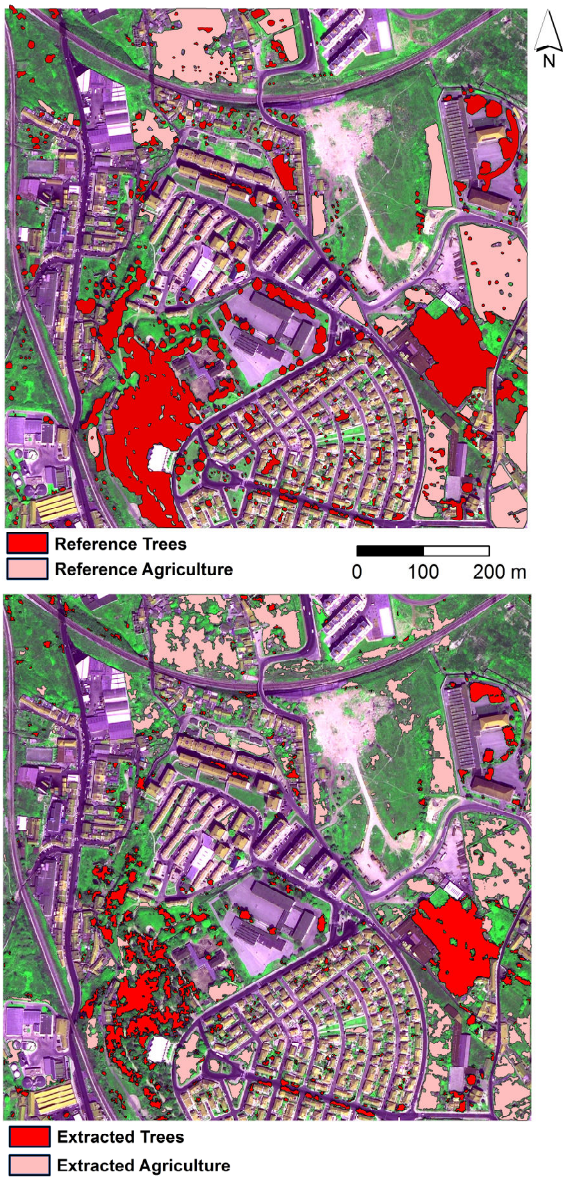

Figure 2. Result of the best extraction for the class "Vegetation" using QuickBird imagery and LiDAR data

The class "Pavement" was difficult to classify. This situation was mainly due to heterogeneity of the materials that constitute roads, variable road age and widths, and existence of parking lots and industrial access roads in the study area (Figure 3).

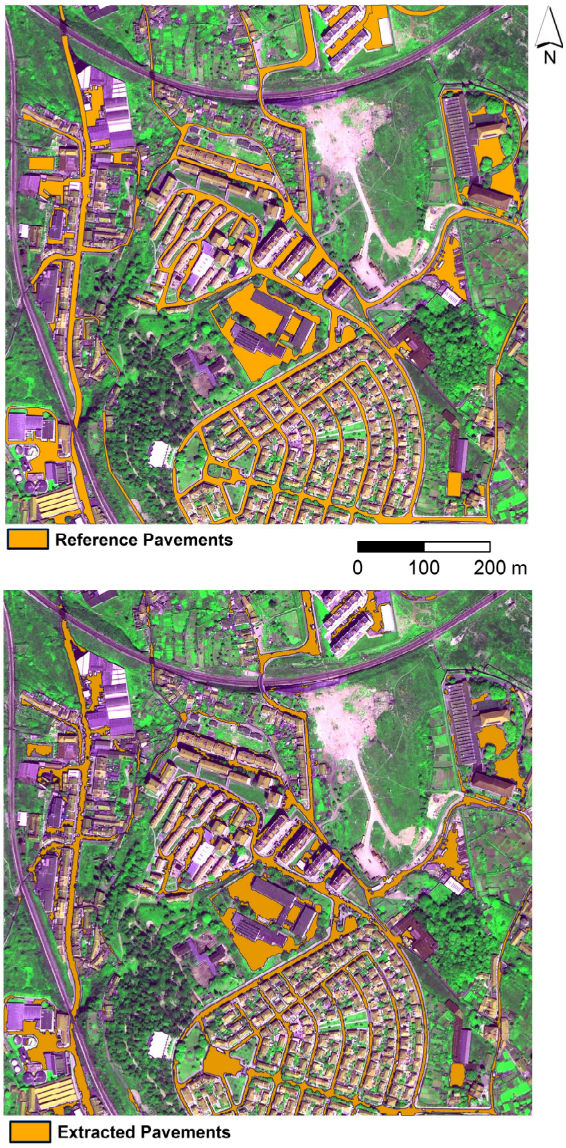

Figure 3. Result of the best extraction for the class "Pavements" using QuickBird imagery and LiDAR data

Nevertheless, the use of altimetric data allowed a better discrimination of this class, increasing its Overall Accuracy by 13%, improving from 52% when using only spectral data, up to 65% with the inclusion of altimetric information.

The best extraction results were obtained for the feature class "Buildings", mainly due to the inclusion of altimetric data (Figure 4). The gain in quality was 12%, from 60 to 72%.

However, features like building annexes or multi-family buildings with varying roof covers or elevator shaft in the same building, as well as the presence of different residential typologies, made the feature extraction more difficult and complex.

The fact that the image has an off-Nadir angle of 12.2º, and the LiDAR data has an orthogonal acquisition, made the referencing for higher buildings less accurate than for singlefamily houses. This situation also contributes to the Omission Error of 25%.

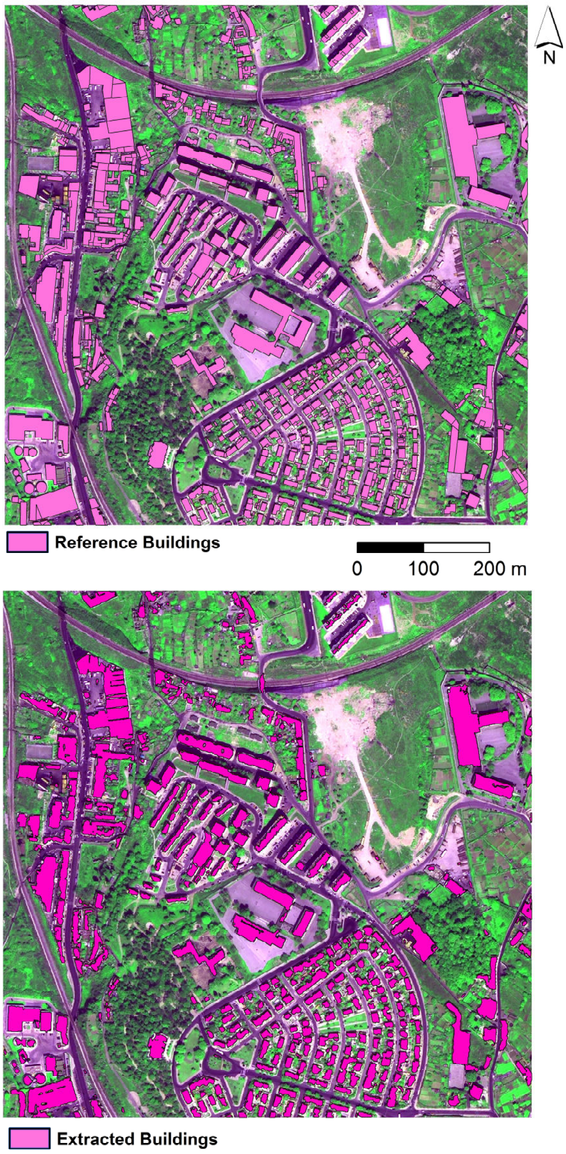

Figure 4. Result of the best extraction for the class “Buildings” using QuickBird imagery and LiDAR data

5. CONCLUSIONS

The present work is integrated in GEOSAT project’s goal of evaluating the potential use of VHR images for extracting features for municipal planning activities. The contribution of altimetric data along with spectral data for mapping quality improvement was analyzed. The extraction results were only good for the “Building” class. Nevertheless, the introduction of LiDAR data revealed to be a good decision since the quality of the extraction was higher for every land cover class.

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