COMPARATIVE METHODS FOR THE EXTRACTION OF COASTAL AREAS FROM VHR IMAGES

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ABSTRACT

This contribution presents the results of a study conducted by the Università degli Studi di L'Aquila, Dipartimento di Architettura ed Urbanistica, and the Università degli studi La Sapienza, Dipartimento Idraulica Trasporti e Strade, dealing with comparative semi-automatic methods for extracting information about coastal lines from very high resolution (VHR) optical satellite images. Two recent standard Quickbird images of the coastal area of Pescara have been utilized for the analysis.

When dealing with very high resolution satellite images, object-oriented classification methods are often used to extract information. This classification method represents a conceptual evolution with respect to the traditional pixel oriented method, implying a preventive subdivision of the image in homogeneous objects through a procedure called segmentation. One of the greatest advantages of the object-oriented approach relies on the classification consistency.

The rigorous orthorectification of satellite images is considered of fundamental importance for this application, since it implies the comparative analysis of the regional coast lines.

The correct selection of the segmentation parameters, strongly related to the objective of the study, is the key for a satisfying classification result. Scale, colour and shape parameters have been carefully selected to avoid over or under-segmentation. Further on, mathematic and logical operators have been developed and compared to extract elements characterized by elongated shape, characteristic of the coastal areas.

INTRODUCTION

This work is part of a wider project called SICORA (Supporto Informativo per la gestione Costiera della Regione Abruzzo), sponsored by the Abruzzo Region, and aiming to help small municipalities monitoring and protecting their coastal areas. The project also involves the University of L'Aquila.

The coastal monitoring activity is of fundamental importance for preserving the natural characteristics of coastal regions. The traditional monitoring techniques such as standard and/or GPS based surveys, or aerial photogrammetry, are costly and time consuming, considering the frequency of the operations needed to monitor large coastal regions.

The availability of commercial satellites with high resolution sensors such as EROS A (2m/pixel), IKONOS (1m/pixel) or QuickBird (0.60m/pixel), offers great opportunities and interesting research perspectives related to the large and middle scale environmental monitoring. The use of satellite images has conspicuous advantages with respect to photogrammetric survey, in terms of scene extension and frequency of acquisition

The objective of this work is the definition of a time and cost effective methodology to extract the coastal line from VHR images.

Since the images are characterized by different levels of geometric correction, rigorous orthorectification is necessary in any case (also for georeferenced images with Circular Error association), to avoid equivoques and errors. The definition of a rigorous procedure to orthorectify the satellite images is considered of fundamental importance for this application, since the multitemporal comparative analysis of the regional coast lines is performed after the extraction. Further on, object-oriented techniques for the semi automatic extraction of the coastal line are explored and applied to the orthorectified the Quickbird images.

The final goal of this project is to built up a standardized and functional methodology that can be used to process satellite imagery to produce coastline vector products. This operation implies Planning and execution of a complex data acquisition exercise, where satellite image acquisitions are required to coincide with low and high tidal states. At the state of the art, a group of experts appointed by the Abruzzo Region is still evaluating “coastal line” definitions, and we are not yet supplied images collected according to a pre-established Data Acquisition Plan. Thus, the results presented in this paper are to be intended only in terms of generic methodological approach for the extraction of a coast line.

DATA AND METHODOLOGY

In this project multitemporal Quickbird images are elaborated using the software PCI Orthoengine for orthorectification procedures, and Definiens Professional 5.0 for the extraction of the coast lines. The principal phases of the work are:

- Orthorectification of pancromatic and multispectral images of the same area acquired in different years;
- Multiresolution segmentation of the multispectral images;
- Object oriented classification;
- Shore lines extraction;
- Diachronic analysis of the coastal areas.

The Standard Quickbird images utilized in this study have 0.61 m panchromatic and 2.44 multispectral resolution. The Abruzzo Region has decided the annual acquisition of these images to evaluate the variations of the coast line.

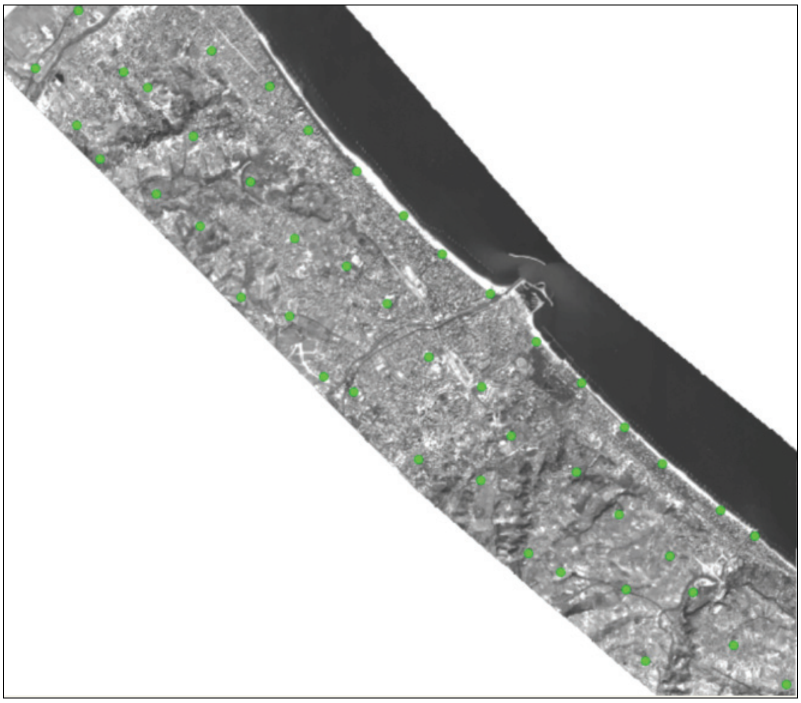

Figure 1: The study area and the GCP. The central part is occupied by the Pescara Harbour.

Actually, only two images are available: one dating August 2004, the other, September 2006. The Standard Quickbird images are already orthorectified by the producer, using orbital data. Altimetry corrections are based on an approximate DEM (GTOPO30).

GCPs are needed to improve the positional accuracy of such a product (Baiocchi et al. 2004, Baiocchi et al. 2006). A rigorous photogrametric model is used to orthorectify the panchromatic images (Toutin's model, developed within the PCI), resulting in an overall accuracy level contained within the 3-4 meters. The GCPs are collected by means of a differential GPS, and collimated over the panchromatic images (see Fig. 1). The choice to collimate the GCPs over the panchromatic image, is made in order to better exploit the high resolution characteristics. The passage from the panchromatic image space to the multispectral image space is performed through a simple scale variation: the panchromatic image coordinates are re-calculated for the multispectral images by dividing them with the scale factor 4, which is the resolution difference (panchromatic resolution 0.61 m; multispectral resolution 2.44 m). The accuracy control over GCP residuals and Check Points, showed a correct calculation of the coordinates.

Procedures for image segmentation have been a main research focus in the area of object-oriented image analysis for many years. Although the object-oriented classification of remotely sensed images is a relatively new approach, there is a variety of fully automated or semi-automatic methods for generating image objects, which cannot be summarized here (Baatz, M. & A. Shape, 2000, Carleer et al., 2005, Curlander and Kober, 1992). The ideal characteristics of a segmentation operation are: generation of homogeneous regions, guaranteeing an adequate class distinction; generation of objects whose dimensions are adequate with respect to the scale of work; universality and applicability of the procedure in other circumstances; time and cost effectiveness.

The coastline detection procedure applied here includes the following sequence of operations:

1. **Initialisation**: segmentation parameters are defined based on the characteristics of the coastline: the study area presents a smooth sandy coast.
2. **Coastline detection**: the input parameters are defined on the basis of the previous segmentation stage. The procedure is tested throughout two different approaches:
   - sea/land detection obtained by performing a multiresolution image classification;
   - direct selection of the objects obtained by establishing shape descriptive criteria.
3. **Extraction of the coastline**: in this stage definitive cleaning and selection of the coastline objects is performed and the results are exported in vector layer.

For our study area different segmentation levels are created to evaluate the optimal solution. The sea/land transition area is characterized by parallel elongated objects. A middle ground *scale parameter* of 30 is found appropriate through trial and error procedure, with the sea/land transition area used as the "acid test" (see Figure 2).

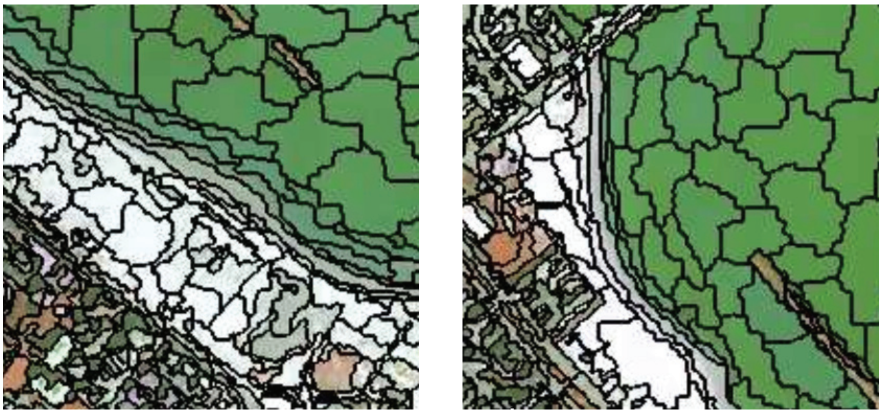

Figure 2: Segmentation patterns.

Once the segmentation parameters are defined, avoiding under or over segmentation, the Coastline detection procedure is tested by comparing two different methods, as described further on in this section. A good image classification is performed when classes are unequivocally defined and separated from each other with the minimal error. A class can be described intrinsically (for example: objects falling within a certain range of spectral values or length/width values), logically (for example: the class "beach" defined as the ensemble of objects adjacent to the class "see"), or by combining the two definitions. It has to be stressed out the fact that a highly circumstantiated class definition may cause the method to loose its validity. For this reason, we preferred to leave a part logical relationships in order to guarantee a generalized extraction process.

A quick analysis of the segmentation result suggested a classification method based on shape characteristics. The principle behind the proposed algorithm is simple: the identification of candidate elements for representing the coast line is based on the value length/width of each element. Different value ranges are defined creating sub-classes that sequentially participate in the selection process. First, objects having a value L/W > 4,5 are selected, then, from this class, objects having a value L/W > 6,5 are retrieved, and further on, those having a value L/W > 8,5. This process flow causes the progressive diminishing of the candidate objects, excluding large part of overestimation errors, but causing visible omission errors. The next step allows the correction of omission errors by means of conditional functions (conditional *if*), that promote objects belonging to a higher hierarchical level. The described work-flow is easily implemented within Definiens Professional. From a first visual confrontation with the Quickbird image, the coast line defined using this method seems rather accurate. The principal problem is related to the fact that elongated objects are not only describing the coast line, but also other features such as streets, etc. Although further investigation is needed to obtain a better performing algorithm, it is evident that these elements not easy to exclude from the classification result.

The image classification method based on spectral characteristics seems to be the most effective and easy solution. This is a standard procedure in Definiens. Although the coastline is the only feature we are interested in, a supervised classification is performed over the entire image, after a careful selection of the training sets and the determination of the feature space characteristics. A standard Nearest Neighborhood algorithm returns a classification product containing the following classes: **clear water; shallow water; coast line; sand; built up area; green area; bare soil**. An overall ground truth based classification accuracy was not performed, although the visual comparison with the Quickbird image, shows a precisely defined coast line.

It is possible at this point to extract the detected coast line by merging and polygonizing the classified objects and, further on, by creating a polyline through the application of a skeleton function (the skeleton function is implemented in Definiens by performing a Delaunay triangulation of the objects' shape polygons). All available orthorectified images for the subject area, along with the generated polyline of the coast line, and with a vector base map of the region, were then loaded into a GIS package (see Fig. 3). The next step is to classify each vector to indicate the type of coastline feature represented. In our case, coastal natural features and coastal anthropogenic features can be distinguished. Within the coastal natural features, only flat sandy shores are distinguishable in the study area.

Accuracy requirements are set with reference to the individual orthorectified satellite images generated using the PCI Orthoengine software and the GCPs, as well as to the coastline vector restitution products generated using the Definiens Professional software.

The mean absolute geometry accuracy for the orthorectified Quickbird optical images shall be 2 meters. On the assumption of a normal distribution of the geometric accuracy, mean distance between check points and pixel geometry is to be less than 2.44 meters.

The Semantic Precision of the classification for the digitised coastline features, defines the required ratios for the percentage of objects digitised, recognised and identified. These terms are defined as follows:

- **detected**: coastline elementary object that is visually discernible on the satellite image by photo interpretation;
- **digitised:** coastline elementary object that has been discriminated as a coastal feature;

- **recognised**: coastline elementary object that has been digitised and characterised at a first thematic level, (coastal natural feature, coastal anthropogenic feature, shallow water, etc.);
- **identified**: coastline elementary object that has been digitised, recognised and characterised at a second thematic level, (for coastal natural features: cliffs, sand hills, reefs, etc.).

Table 1 – Semantic Precision Requirements

Required ratio	Coastline restitution
Recognised objects vs. detected objects	97%
Identified objects vs. detected objects	80%

It should be noted at this point that even with a precise orthorectification of the Quickbird satellite images, there is still some ambiguity in the exact position of the coastline. As already pointed out, the time of observations with respect to high tide is another source of error in the precision of the shoreline location.

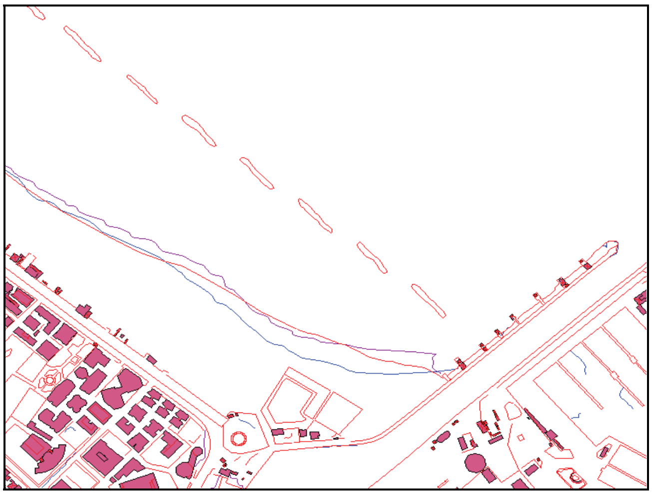

Figure 3: Coastal lines comparison (part): in red, 1:5000 regional cartography (2001); in blu, the line extracted from the 2006 image; in violet the line extracted from the 2004 image

RESULTS

The results obtained are to be considered intermediate, since the satellite images are not acquired following a preliminary Data Acquisition Plan, the high tide effect is not considered and the digital cartography depicts the shoreline as it is at the acquisition date. Nevertheless, it is possible to illustrate the transformations by showing the different coast line paths.

The tentative to quantify the transformations by describing the reciprocal positions of the three coast lines: 2001, 2004, 2006, showed contrasting results, due to the fact that satellite images are taken in different periods of the year. By comparing the 2004 and 2006 Quickbird images over a coastal area of 15.5 km, the Minimum and Maximum values of coastal line differences are respectively -19.8 m and 21.5 m (positive values indicate Progradation).

CONCLUSIONS

The orthorectification of multispectral images can be accurately done through the procedure of collimation of GCPs on the correspondent panchromatic images.

Very high resolution (VHR) optical imagery such as Quickbird is excellently suited to mapping of coastlines, also in key areas, such as ports and river approaches, with high level of accuracy.

The object-oriented approach helps to easily and quickly retrieve the coast line in sandy coastal areas. The classification based on spectral values shows better results in terms of cost-effectiveness, compared to the classification based on the shape of elements, although further investigation is needed to definitively establish the extraction routine.

The results obtained can not be evaluated, unless the available data is collected according a pre-established Data Acquisition Plan. Ancillary climatic and bathymetric data is needed to evaluate high tide effects and further develop the extraction model.

The task of mapping coastlines from satellite imagery in general lends itself excellently to a work-flow-driven production environment, which could well be implemented operationally after the necessary development operations are carried out.

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