Coastline Detection Using High Resolution Multispectral Satellite Images

Valerio BAIOCCHI, Raffaella BRIGANTE, Donatella DOMINICI, Fabio RADICIONI, Italy

Key words: WorldView-2, Abruzzo, multispectral classification, coastline

SUMMARY

In the last 50 years the inhabitants of the 19 municipalities along the Abruzzo coast have doubled, and a stronger impact of the activities connected with the tourism has been experienced. The area, naturally exposed to the effects of changes of the sea level, has been interested by a dramatic increase of erosion, due to the reduction of the solid transport from rivers to the sea, as a consequence of extensive works carried out on the watersheds to mitigate extreme rainfall and consequent flooding.

The availability of data acquired by different sensors on the last few decades might be useful to assess overall accretion/erosion trend of coastline, whereas combination of different observations taken in a restricted timeframe may provide interesting inputs for detailed studies (e.g. about the local impact of coastline protection works).

In the present paper is proposed a methodology for the coastline identification from WorldView-2 images, available in 8 spectral bands, with 0.5 m of spatial resolution for panchromatic images and 1.8 m for the multispectral channels. In particular, a pixel based multispectral classification was used to identify various types of land cover. The 8 bands allow to get good results both in the classification process and with NDVI, NDWI, SAM, FM algorithms, for the identification of various land cover and in particular to separate dry sand from wet sand. Interesting results were obtained testing an algorithm that evaluates the relative depth of the water using the "coastal blue" band. Better results can surely be obtained by using elevation data (geoid models and digital terrain models) integrated with radiometric information. Very interesting is the comparison of the estimated coastline with such methodology and a topographic map of same area. This comparison highlights the changes in the study area. The possible applications of the proposed techniques are many, such as map updates, but also coastal change monitoring.

RIASSUNTO

Negli ultimi 50 anni i 19 comuni situati lungo le coste abruzzesi hanno visto un notevole incremento sia del numero degli abitanti che delle attività turistiche. In tali zone, naturalmente esposte agli effetti dell'aumento del livello del mare, si è avuto un incremento dell'erosione a causa della riduzione del trasporto solido dai fiumi al mare, conseguenza di interventi effettuati sui bacini per mitigare le abbondanti precipitazioni e le conseguenti inondazioni. In particolare, la possibilità di avere serie storiche di dati acquisiti da diversi sensori (disponibili da qualche decennio), potrebbe rivelarsi utile per valutare la tendenza all'accrescimento/erosione della linea di costa, mentre la combinazione di diverse

osservazioni effettuate in un breve intervallo di tempo possono fornire un contributo interessante per studi di dettaglio (ad esempio l'impatto locale delle opere di protezione).
La sperimentazione in oggetto è volta alla definizione di una metodologia di individuazione della linea di costa, o linea istantanea di riva, tramite delle immagini riprese dal satellite WorldView 2, con 8 bande spettrali, aventi risoluzione geometrica pari a 0.5 m per l'immagine pancromatica e 1.8 m per quella multispettrale. In particolare viene utilizzata una metodologia di classificazione multispettrale "pixel based" con la quale si identificano i vari tipi di copertura del suolo. Le 8 bande in cui è ripresa l'immagine consentono di ottenere buoni risultati sia nel processo classificativo sia nella combinazione tra bande, tramite gli algoritmi NDVI, NDWI, SAM, FM, riguardo alla identificazione delle varie coperture del suolo e in particolare della linea di separazione sabbia asciutta-sabbia bagnata. Sicuramente risultati migliori possono essere ottenuti utilizzando dati altimetrici (modelli di geoide e modelli digitali del terreno) unitamente a quelli radiometrici presenti sulle immagini. Molto interessante è il confronto tra la linea di costa estratta con tale metodologia ed una carta topografica della stessa area, che evidenzierebbe i cambiamenti avvenuti nell'area di studio. Le possibili applicazioni di tale tecnica sono diverse, ad esempio l'aggiornamento di cartografia esistente o monitoraggio dell'ambiente costiero.

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1. CHANGE DETECTION IN COASTAL ENVIRONMENT

1.1 Introduction

The coastal environment represents the transition area between land and sea. It is a natural and economic resource of extraordinary value, but is subjected to a continuous and constant transformation. The coastal environment is in fact a highly dynamic system where the erosion (coastline advance or recession) is influenced by several factors, meteorological, geological, biological and anthropogenic, for example the growing urbanization of the coastal territory since World War II, linked to a social and economic developing, with the continuous evolution of industrial, commercial and touristic-recreational activities.
The coastline detection is a complex issue, starting from the uncertainty to identify a clear and universally accepted definition of the coastline itself, and then to define appropriate methods of coastal monitoring and its changes. Currently, remote sensing is becoming one of the most relevant methods for this kind of study, thanks to the many advantages of this technique (ability to capture large areas in one image, high geometric resolution of the satellites sensors, ability to acquire the scene in multiple spectral bands, ...).

1.2 Coastline changes

The term "dynamic coast" indicates the complex phenomena that govern the coastline evolution over time. The description of the coastline evolution requires an analysis of river and marine dynamics; in fact coasts receive most of the sediments that nourish the beaches from land by rivers. The sea, through the action of waves and currents, contributes significantly to model the coastal shape, performing a triple action of erosion, transport and accumulation of coastal sediments. Such modeling work of the sea can determine the coastline recession when the erosive effects prevail, or a progress if the accumulation processes prevail. Often both phenomena act simultaneously in adjacent coastal areas.
In Italy two main morphological types of natural coasts are found alternating:

- high and rocky coasts (morphologically rough coast, with very steep walls, often sub-vertical, parallel to the shoreline), about 34% of the total;
- low and sandy shores (more or less extensive beach in very weak slope, with the possible presence of dune systems) for approximately 58%.

The coastline amplitude can be influenced from the subsidence and *eustasy effects*. Subsidence is a long-term process of slow subsidence of the ground linked to natural constipation of fine sediments in floodplains, often exacerbated by the extraction of water and hydrocarbons from subsoil. The term eustasy indicate changes in the long term, positive or negative, of sea level, connected to climatic factors. (Antonioli, Silenzi, 2007).
Furthermore, sudden coastline variations can be induced by tectonic movements, mostly

associated with strong magnitude earthquakes. An important morphological parameter comes from the study of the historic changes of the shoreline, which allow to perform various analysis to define the natural tendencies of coastline evolution. Thus, it is possible to identify areas subject to local erosion or enhancement due to construction of coastal works, to calibrate numerical models of shoreline's evolution, to estimate the solid balance sheet of the coastline, and so on.

1.3 Coastline detection

The coastline is a portion of land that contains the emerged and submerged areas (Figure 1) and is subject to continental and marine geomorphologic processes. The shoreline determination and its restitution is a key element in the coastal environment's monitoring for emerged and submarine zone.

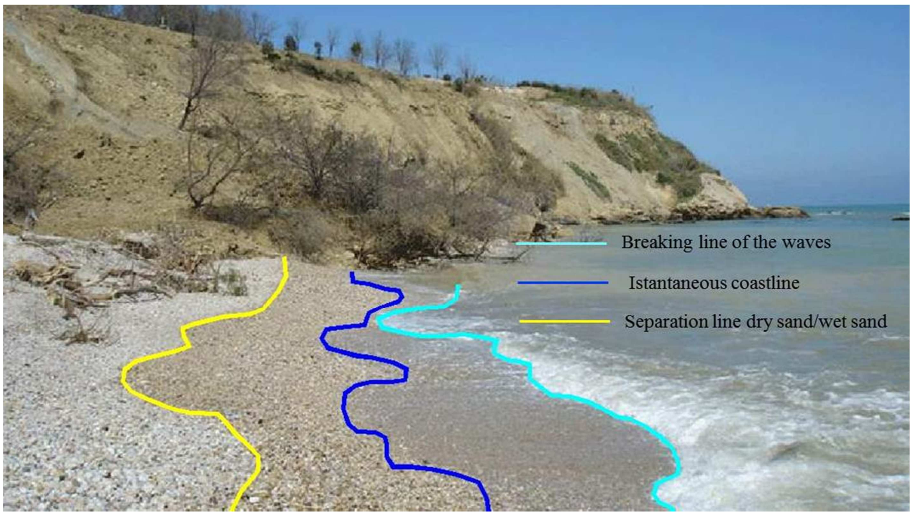

Figure 1 – Limits identified in coastal environment

The coastline is the clearest expression of how this sector is particularly dynamic, requesting to record the changes more or less immediately (Cervino et al, 2010). The evaluation of the coastline's position and changes is an important consideration for scientists, engineers, and other operators involved in coastal management. The position of the coastline and its historical change can provide important information for the design of coastal protection works, coastal development plans, and the calibration and verification of numerical models (Klein et al, 2006). As well as the continued interest for the coastal areas, the risk and consequences of the development of anthrophic structures are very important (on the coast are concentrated over two-thirds of world population).

So, the coastline's planning has to be supported by the monitoring of the shoreline by means of repeated surveys often to correct the seasonal variability of the singularities induced by intense storm and to identify more efficient methods for its extrapolation, reaching a good compromise between accuracy, cost and time. An effective monitoring requires the development of technologies capable of providing useful contributes to the protection, prevention, intervention and management.

There is no single method for the modeling of coastline, which would be commonly accepted by coastal communities, although in the last decade a great progress in mapping technology has been reached. For example, the development of new and more accurate GPS equipment, new high and very high resolution satellites, and the availability of very efficient devices for the assessment of coastal topography such as LIDAR (Light Detection and Ranging) (Tarig, 2003).

1.4 Current techniques for coastline mapping

In this paper the acquisition methods of submerged beach are not considered, but we will focus on techniques of emerged beach survey. Currently the most common methods in use are (Ivaldi, Surace, 2010), (Baiocchi et al, 2010):

- *Geodetic survey and GPS* (RTK), allowing high accuracy (millimeter with geometric leveling, centimeter with total stations and GPS positioning systems), but provide a survey for single points only;
- *Aerial photography*, which need to be orthorectified (through the knowledge of a DSM), but provide a continuous survey, representing the entire study area at the time of the acquisition; the accuracies obtainable are at centimeter or subdecimeter level, but the costs are high;
- *Airborne videography*, based on a similar approach to aerial photography, where the camera is replaced by a video-camera. This technique is promising, but its application may focus more on qualitative recognition of changes rather than on quantification of changes, due to a general lower resolution of the data;
- *Video systems* that allow continuous (typically every hour) collection of image data with a resolution from centimeters to meters. Typically they are composed by four to five video cameras, spanning a 180º view, and allowing full coverage of about four to six kilometers of beach. The scanned image is oblique and must be orthorectified and geo-referenced (Kroon et al, 2007).
- *Remote sensing*; it is a technique increasingly competitive compared to the other above-mentioned, especially with reference to high resolution satellites of last generation. Compared to photogrammetry it allows a very speed data acquisition and processing with accuracies comparable due to the high spatial resolution. The ability to record the scene in multiple spectral bands is also important: it allows for much more information than the visible bands and can create thematic maps of the area using multispectral classification. The short revisiting time (a few days) also allow to carry out monitoring studies of the area under examination, by means of images acquired at different times.

1.5 WorldView-2 imagery

WorldView-2 was launched on October 8, 2009. It is the first high resolution commercial satellite with 8 multispectral bands; in fact WorldView-2 includes 4 new bands at 1.8 meter of spatial resolution in addition to the standard 4-band (blue, green, red and near infrared): *coastal blue, yellow, near infrared, and rededge-2* (figure 2). It works at an orbital altitude of

770 km and can simultaneously collect panchromatic imagery at 0.46 m and multispectral imagery at 1.84 m of spatial resolution. The high spatial resolution allows discrimination of a lot of details, such as vehicles, the shallow waters and the individual trees, while the high spectral resolution provide detailed information on various areas such as quality of road surface, the sea depth and plant health.

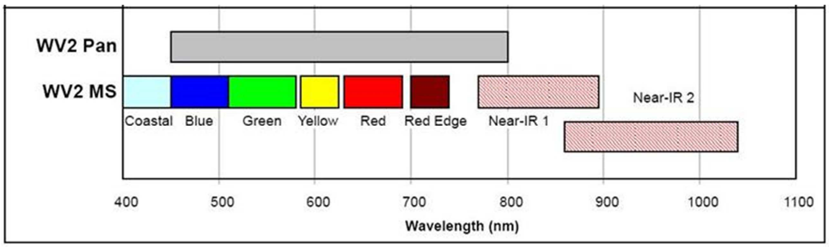

Figure 2 – Spectral bands of the WorldView-2 satellite

These bands offer several advantages to users in the identification of a greater number of ground cover classes (e.g. more variety of vegetation), in the extraction of a greater number of features, in monitoring changes in the use of the soil and any building abuses and violations and in displaying images more realistic, very similar to the natural human vision. Further information on WorldView-2 satellite can be found at **http://www.digitalglobe.com**.

2. EXPERIMENTATION

2.1 Study area and available data

The image used in this experimentation was a WorldView-2 acquisition representing a portion of the coast of Ortona (Chieti, Abruzzo) shown in Figure 3.
Ortona is located on the Adriatic Sea shores and, except for the first part where there is a large sandy beach, present an high rocky coast. The land alternates between flat and hilly areas.

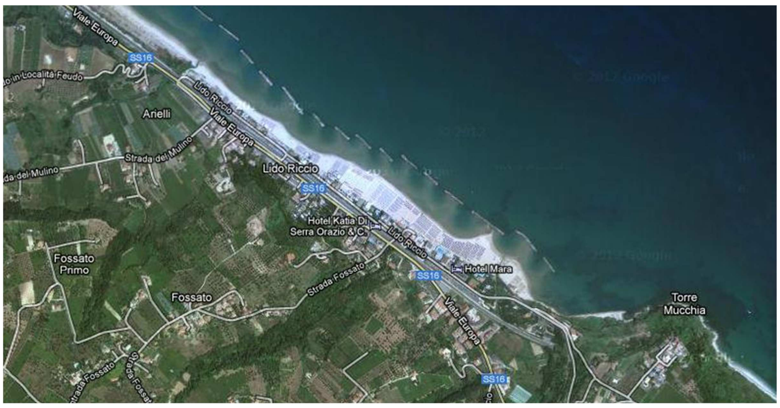

Figure 3 – Study area

In this work we want to test the ability to automatically detect the coastline (or rather the instantaneous coastline) from that image. In particular, our research is directed at an identification of an algorithm that allows the coastline extraction in automatic or semi-automatic mode. All process were performed using the commercial software ENVI 4.7 of Exelis Visual Information Solutions, software for display, analyze and classify different types of digital images.

2.2 Single band analysis and bands combination

The first operation performed in this work was the pansharpened creation of a representative zone of the study area (Figure 4), through the algorithm *Gram-Schmidt* which allows to integrate the geometric detail of the panchromatic image (0.5 m of spatial resolution) with the radiometric information of the eight multispectral bands but with lower spatial resolution (1.8 m) to produce a multispectral image with high resolution (figure 5).

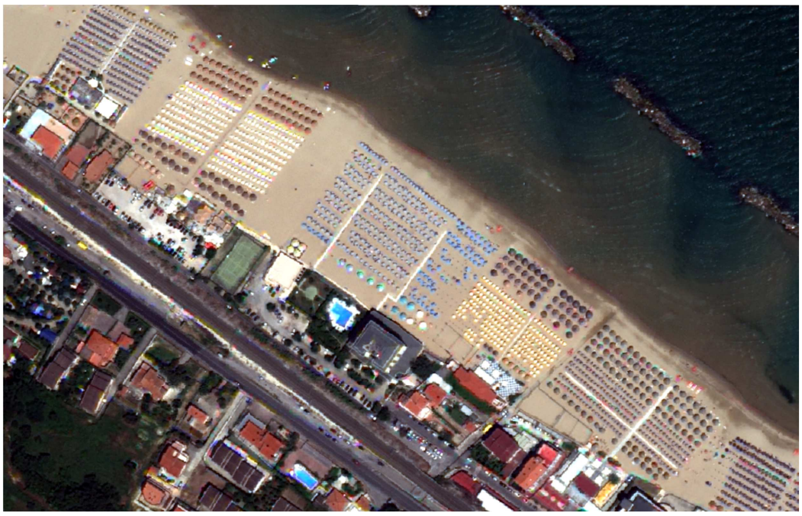

Figure 4 – Pansharpened image

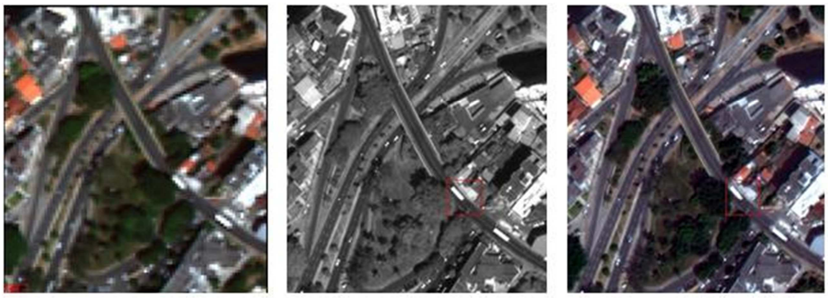

Figure 5 – Multispectral, panchromatic and pansharpened image

Pixel-based classification techniques have been applied on that image and some algorithms useful for the vegetation and water study were used (such as the vegetation index NDVI and the normalized index NDWI) in order to better define the coastline location.

The Normalized Difference Vegetation Index is a simple algorithm to estimate the vegetation density and condition, which exploits the different response of the vegetation to the spectral bands of the visible (red) and near infrared, and provides a dimensionless numerical value between -1 and +1. It is calculated by:

$$NDVI = \frac{NIR - R}{NIR + R}$$

It can be also used to obtain useful information about the coastline, in fact it assumes values between -0.1 and -0.5 at the separation from sand / water.
The Normalized Difference Water Index is used to study the areas covered from water. It is similar to NDVI but using the green band instead of the red one.

$$NDWI = \frac{NIR - G}{NIR + G}$$

With this algorithm water assumes positive values, while terrain and vegetation have negative values; dry sand, due to its high reflectance in green band and in near infrared band, is characterized by positive values but near to zero.

2.3 **Vegetation and water automatic detection**

The Envi software enables a complete analysis about the vegetation in the image, using the information contained in the red and infrared bands by *vegetation delineation* algorithm. This algorithm automatically creates three classes of vegetation (sparse, moderate and dense) that can be used in a multispectral image classification as *Region of Interest* (ROI) (section 2.4). Performing a cross-section to the coast line on the image obtained by the algorithm NDVI, a sharp change of slope of the curve at the points of passage sand-sea can be seen (Figure 6).

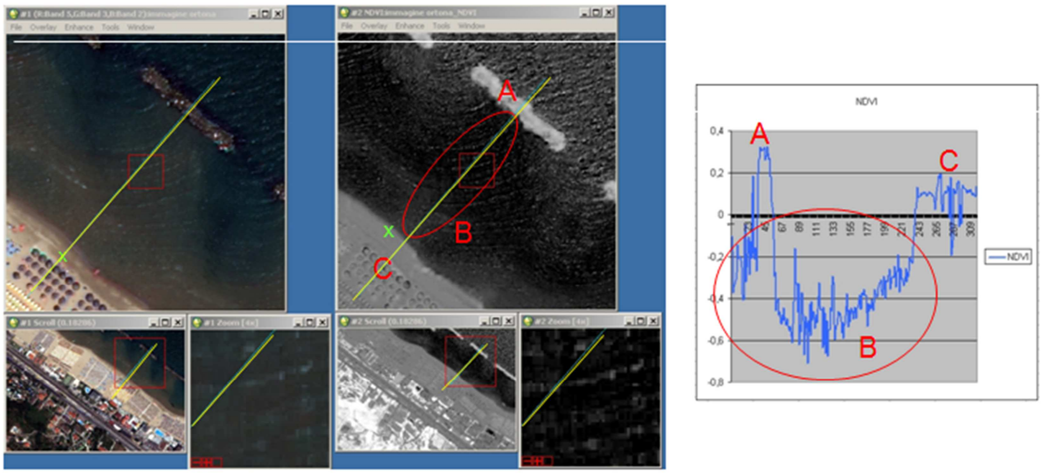

Figure 6 –RGB image, NDVI, cross section

A similar process allows to study the presence of areas covered by water, using the information contained in the green, blue, red and infrared bands, and separating them into Muddy Water and Dark Water, through the algorithms MF (Matched Filtering), SAM (Spectral Angle Mapper) and their ratio that shows the best separation between the dry sand

and the wet sand with a sharp change of the slope of the curve (Figure 7).

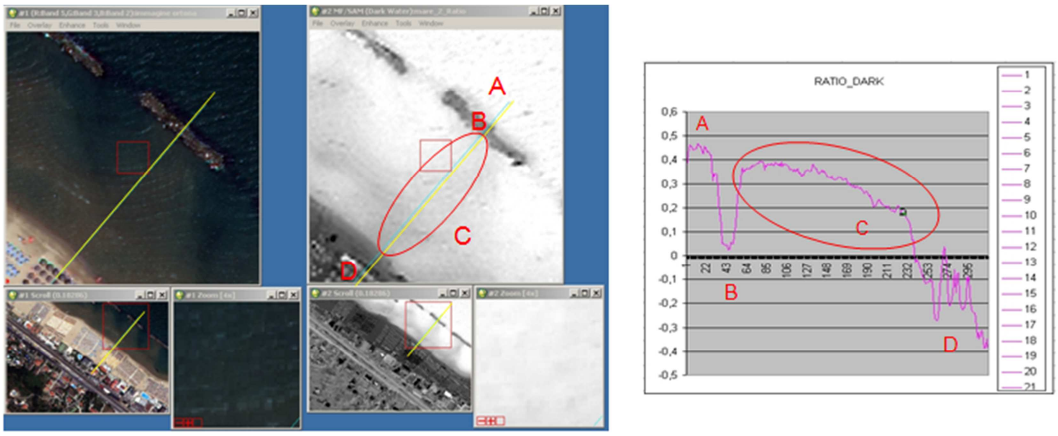

Figure 7 –RGB image, MF/SAM, cross section

Another algorithm used in image processing and showing a clear separation between the sand and the sea is the *Relative Depth*. This tool uses a bathymetry algorithm developed by Stumpf and Holderied (2003), which correlates the various bands in the multispectral image, in particular the coastal and blue bands. The "Relative Depth" function allows an useful analysis of the seabed at depths up to 14 meters (Figure 8) though not representing the absolute depth of the water present in the study area (values range from zero to one).

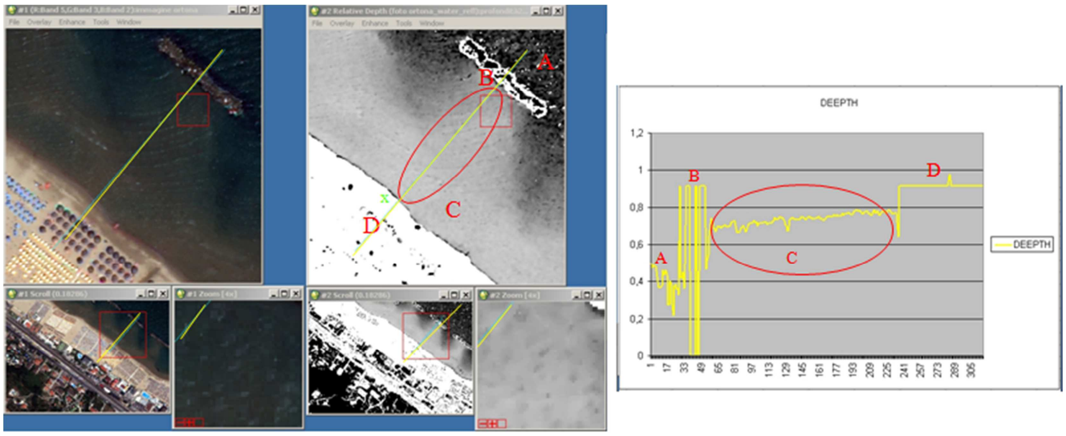

Figure 8 –RGB image, Relative Depth, cross section

In Figure 9, all curves obtained at the same section representing the indices NDVI, NDWI, FM, SAM, FM / SAM and Relative Depth were superimposed. All curves have similar trend, specially in correspondence of the passages between dry sand-wet sand and wet sand-water, in which there is a sharp change of slope (dashed lines).

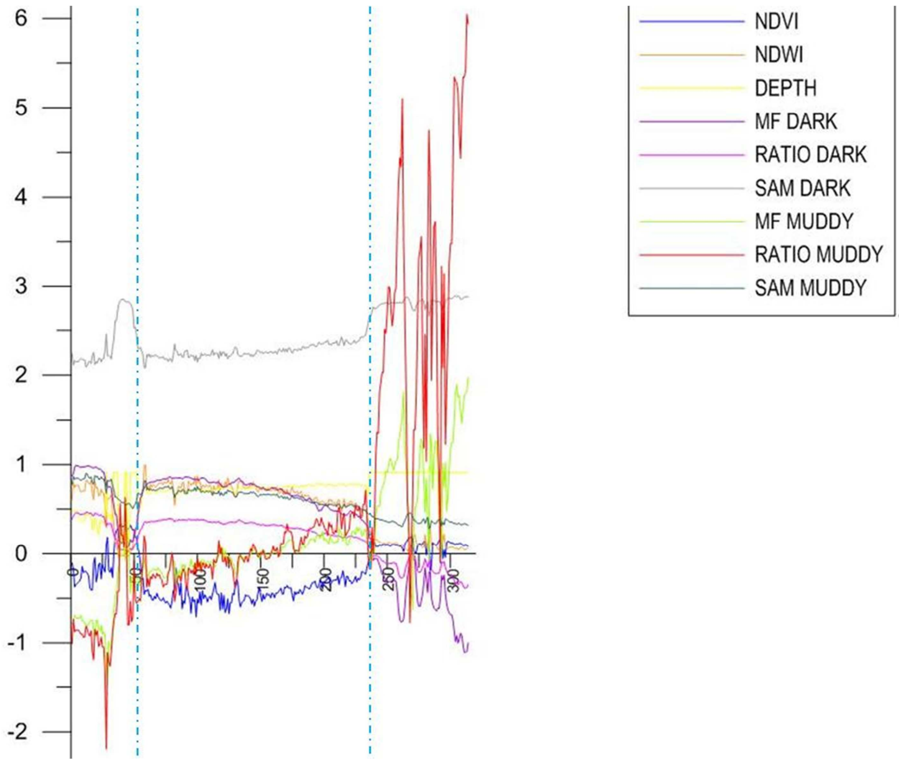

Figure 9 –NDVI, NDWI, SAM, FM, FM/SAM, Relative Depth

2.4 Multispectral classification

Finally, a supervised multispectral classification using Maximum Likelihood algorithm was performed on the study area. Several regions of interest (ROI) have been defined including 4 different types of buildings, dry sand, wet sand, roads, pools, sidewalks, shade, water and three classes of vegetation identified automatically by the tool *vegetation delineation*. As a result, we obtained a new image in which each pixel is associated with a digital number representative of the corresponding class of land cover (Figure 10).

Figure 10 – Classified image

Classification works well with buildings and vegetation, as for the separation of dry sand-sea-wet sand. The separation between these classes can be vectorized obtaining a shapefile used for further analysis. For example you could compare the instantaneous shoreline obtained from satellite imagery with the one shown on existing maps, so an update of it can be obtained (Figure 11). This process may seem inaccurate because it assumes that the instantaneous shoreline and coastline are coincident, however in many technical specifications of regional maps (including the Region of Abruzzo) it has predicted that the coastline must be vectorized as visible on individual frames and then in reality it is the instantaneous shoreline.

Figure 11 – Coastline superimposed on regional map

The comparison shows that the present coastline (red) has not significantly changed compared to 2003, the year of the last update of the regional map of Abruzzo, so we can suppose that there has been a very little erosion meanwhile.

2.5 Relative Depth

The results obtained evaluating the relative depth are very interesting: using the new “Coastal Blue” band useful information for the study of coastal areas can be obtained, due to its penetration of the clear water up to 14 m of depth. Using this band in the calculation of Relative Depth, the sand and the sea cliff assume constant value equal to 0, while the trend in correspondence of the sea shows the shape of the seabed (Figure 11).

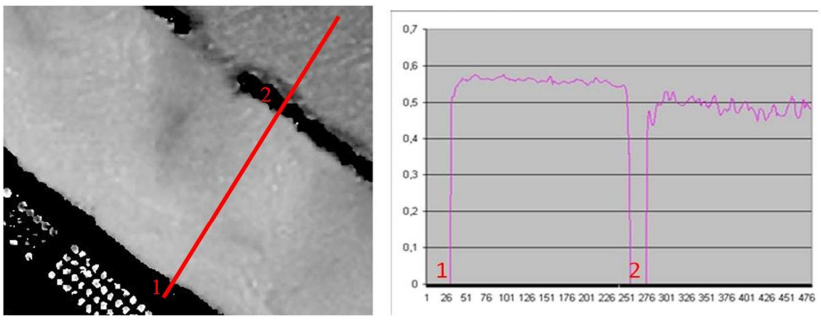

Figure 11 – Relative Depth with Coastal band

If these results are integrated with bathymetric information the absolute depth of the sea could be obtained, "scaling" the values of relative depth on the actual values of the absolute depths, for example found by bathymetric curves mapped on the IGM25 maps and derived from those of the Istituto Idrografico della Marina (Hydrographic Institute of the Navy) that has made using various techniques over the years. In this study we have used absolute depth data detected by IGM maps and the relative depth was scaled by functions "raster math" obtaining the absolute values of depth. The median filter was used to eliminate the "noise" present on the image because the roughness present seemed excessive for this type of seabed. Finally, a section of the coastline was carried out at and the profile shown in Figure 12 was obtained.

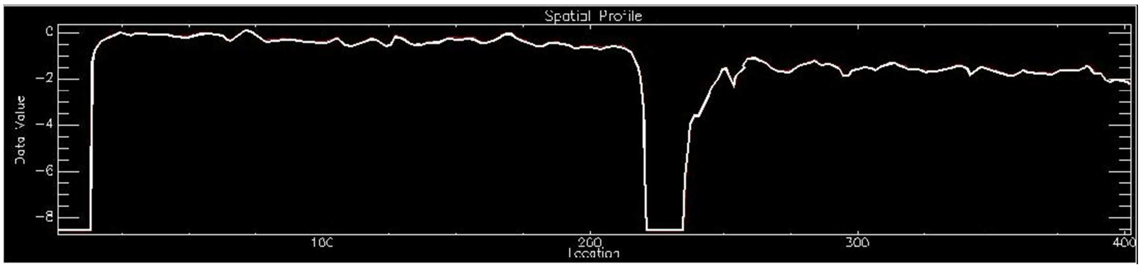

Figure 12 – Absolute Depth

The shape of the seabed obtained is very similar to the expected one, from a depth value equal to 0 on the coastline to a max of -2.20 m in accordance with the bathymetric contours reported on the IGM cartography, although with some peak values probably due to the proximity to the shore and the presence of the breakwater.

This shape can be observed by extracting the contour line of the bottom (Figure 13). The morphologies revealed by circular bathymetric lines, not entirely compatible with the known morphologies of the seabed in that area, could be due to the large degree of detail of information or to the "noise" of the technique not yet been properly modeled.

Figure 13 – Contours of seabed

3. CONCLUSIONS

In order to test the accuracy and reliability of the procedures experimented in this work, a comparison between the shoreline extracted from satellite images and the one obtained by map, or by GPS, or by traditional geodetic survey carried out simultaneously or in a few hours away from image, must be compared. For a better validation of the test, it can also be assessed integrating the results obtained from the WorldView images with altitude information obtained by the intersection between a digital model of the surface (from stereo images or existing maps) and a properly calibrated geoid model of the study area.
As for the absolute depth, a comparison with a bathymetric survey conducted in the same area will be carried out in order to evaluate the deviation of the depth identified by the image and the actual one. The results, which surely need to be integrated and validated, constitute an important input for the use of the proposed methods for a possible update of the regional technical maps, with particular refer to the shorelines updating.
In fact, the control techniques used (topographic, GPS surveys, and aerial photogrammetry), even if valid for their accuracy, still may not be particularly practical and economical for a continuous monitoring of the coastal zone. In particular, the remote sensing offers the possibility to process the same area after a short time, making the use of these products for the continuous monitoring of the coastline faster and more convenient than other surveying techniques.

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BIOGRAPHICAL NOTES

Valerio Baiocchi, graduated with full marks in Geological sciences at “La Sapienza” University of Rome during 1993. In 1999 he obtained his first PhD degrees in Geodesy and Cartography and in 2010 he obtained his second PhD in Infrastructure and Roads at “La Sapienza” University. From 2008 to 1992 he is Researcher Adjointed professor at “La Sapienza” University, Department of Civil, Environmental and Building Engineering. He is the author of more than 150 scientific papers, published on specialized scientific journals and in the proceedings of national and international conferences.

Raffaella Brigante, graduated in Civil Engineering at the University of Perugia in 2001, with a rating of 110 out 110 with laude. In 2010 she obtained her PhD degrees in Civil Engineering at the University of Perugia with PhD Thesis: “Metodologie automatiche nell’elaborazione di immagini satellitari stereoscopiche per applicazioni ingegneristiche”. Post-doc research activity in the research group of University of Perugia supervised by Prof. Fabio Radicioni: Terrestrial and Aerial Photogrammetry, Remote Sensing, Geographic Information System, Cartography, Digital Terrain Model.

Donatella Dominici is an associate professor in Engineering’s Faculty – University of L’Aquila where teachs Surveying, Satellite Geodesy and Remote Sensing. She obtained a Ph.D. in Geodesy and Surveying in 1999 from Bologna University. Her areas of expertise are GPS analysis data and design network. The latter includes design and materialization of GPS permanent network for Abruzzo Regional Council, monitoring with high resolution satellite images Abruzzo’s coastline, research project to investigate historic and archeological sites with geomatics techniques and so create a complete map of cultural heritage with new technologies for an easier spreading of heritage information. She is the coordinator of Laboratory of Geomatics in Faculty of Engineering of L’Aquila, member of editorial board of Applied Geomatics and member of AFCEA’s council.

Fabio Radicioni, graduated in Civil Engineering at the Ancona University in 1980, with a rating of 110 out 110 with laude. In 1988 he obtained his PhD degrees in Geodesy and Cartography. From 1990 to 1992 he has been Researcher at the Bologna University, Institute of Topography, Geodesy and Mining Geophysics. Since 1992 he is Associate Professor for the ICAR 06 area (Surveying and Cartography) at the University of Perugia, Faculty of Engineering. Since 2002 he is Full Professor for the ICAR 06 area (Surveying and Cartography) at the University of Perugia, Faculty of Engineering. He is the author of more than 150 scientific papers, published on specialized scientific journals and in the proceedings of national and international conferences.

CONTACTS

Prof Valerio Baiocchi
"Sapienza" University of Rome- DICEA - Area of Geodesy and Geomatics
Via Eudossiana 18 , I-00184 – Rome - ITALY
Tel. +39 0644585068
Fax +39 0644585515
Email: valerio.baiocchi@uniroma1.it
Web site:w3.uniroma1.it/**valerio**.**baiocchi**/index.htm

Phd. RaffaellaBrigante
University of Perugia, Department of Civil and Environmental Engineering
Via Duranti, 93 – 06125 – Perugia - ITALY
Tel. +39 075 5853792
Fax +39 075 5853756
Email:raffaella.brigante@unipg.it

Prof. Donatella Dominici
University of L'Aquila - Engineering Faculty- Dept. Architecture and Civil Planning
via Gronchi 12, Zona industriale di Pile, 67100 - L'Aquila - ITALY
Tel. +39 0862 434118
Email: donatella.dominici@univaq.it

Prof. Fabio Radicioni
University of Perugia, Department of Civil and Environmental Engineering
Via Duranti, 93 – 06125 – Perugia - ITALY
Tel. +39 075 5853765
Fax +39 075 5853756
Email: topos@unipg.it