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USE OF MULTISPECTRAL SENSORS WITH HIGH SPATIAL RESOLUTION FOR TERRITORIAL AND ENVIRONMENTAL ANALYSIS

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ABSTRACT:
The variations to which the land is subject caused by human activities that increasingly involve the natural environment make territorial planning necessary to ensure a sustainable organization of space that is beneficial to the community. The most changes concern both urban and natural areas. Having updated information on these changes is important if one wishes to analyze the relationships between human activities and the natural environment. Such information may be obtained by means of aerial and/or satellite images in GIS systems, into which different types of data are integrated for performing spatial analysis. The new satellites for remote sensing allow the acquiring of high-resolution images in several spectral bands which, combined together, provide information on land cover, such as vegetation or the presence of water. The applications are numerous: for example, it is possible to analyze the state of the vegetation in rural areas, or assess changes in the land using images from different time periods. This paper reports two territorial applications: the first concerning changes in land use in an urban area using high-spatial-resolution satellite and aerial imagery from different periods; the other regarding a coastal area in which the instantaneous shoreline has been detected. Algorithms for automatic detection of vegetation and water and automatic multispectral classification have been applied to these images.

Key-words: *Environmental analysis, Land surveying, Remote sensing, GIS, satellite image*.

1. INTRODUCTION

Over the past few decades, the land has undergone significant changes due both to human activities through the construction of buildings, roads, infrastructures, quarrying, etc., and to natural or anthropogenic causes, such as coastal erosion, landslides, earthquakes, and so on. The most visible changes are seen above all in built-up environments, but rural areas have also been profoundly transformed, for example through the intensification of agriculture or the rectification of river beds.

Knowledge of the dynamics of land use and land cover is a strategic element in land planning, because through the analysis of the current state of the land, understood as the result of a series of past events, it is possible to monitor and predict future events.

In order to study these types of problems it is necessary to have an entire series of specific information on different spatial and temporal scales. To this end, GIS technologies currently represent a real tool for the analysis and understanding of phenomena regarding the land, linking data very different from each other and acquired at different time periods, thus allowing for the temporal dimension, i.e. the fourth dimension, beyond the spatial dimension. Systems of this type are of enormous importance in projects where, for example, it is desired to link human activities with the natural environment, or when one wants to study the evolution of a particular phenomenon in the natural landscape over time, such as changing of the coastline.

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A wide variety of data can be used in GIS systems: raster data (orthophotos, Digital Terrain Models, Digital Surface Models, land use maps, historical maps, ...), vector data (cartographic techniques, land cover, roof maps), planimetric data and elevation information, also at different resolutions. To ensure that new information can be obtained from the material stored in the form of databases, using typical GIS integration and combination tools (Malczewski**,** 2007), it is necessary that all the material be georeferenced in a common reference system (Datum).

Currently, due to the presence of new sensors and specially developed processing algorithms, remote sensing, along with traditional aerial photogrammetry, is one of the most commonly used land surveying techniques, constituting a valuable source of data and information for analyses on land cover and its changes over time, important for territorial planning and monitoring.

2. REMOTE SENSING FOR LAND SURVEYING

2.1 Multispectral images and processing techniques

The term remote sensing refers to the set of theories, tools, techniques and means of interpretation that make it possible to acquire, process and interpret at a distance data on the land and the environment. Acquisition is done using passive sensors placed on satellites for remote sensing or on aircraft for aerial photogrammetry surveys, which use the part of the solar radiation reflected from various surfaces present in the study area to form images. These surfaces are very different from one another; for example, vegetation, bare ground, paved areas, the roofs of buildings, water – all surfaces that reflect solar radiation in very different ways (**Fig. 1**).

Thanks to this different behavior, which generates the spectral signature typical of each surface, it is possible to distinguish different land covers by analyses that take into account the response in several spectral bands.

In recent years, as part of the observation of the area by aerial or satellite platforms, sensors have been developed that can acquire images with high spatial resolution and in different bands of the electromagnetic spectrum (visible and invisible). With satellite images, there is also the advantage of acquire information of very large areas in a single scene, and currently there are numerous algorithms for geometrically correcting them, i.e. to eliminate the distortions in them (Dermanis & Biagi, 2007a), and for georeferencing them for use in territorial and environmental analysis. Indeed, the new sensors, having a spatial resolution of 50 cm (WorldView2, GeoEye, QuickBird,) have an accuracy compatible with that of medium-scale mapping, so they can certainly be used for the creation of new medium-scale topographic maps or for updating existing maps.

Having digital images available also makes it possible to apply automatic algorithms to them to facilitate visual interpretation or improve the results of subsequent processing (automatic filtering, radiometric corrections, emphasis), (Dermanis & Biagi, 2007b), without altering the metrical characteristics. The ability of the new sensors to capture images in several spectral bands, typically the four Red, Green, Blue and Near Infrared (R, G, B, NIR) bands, allows the highlighting of certain features of the area, such as vegetation or the presence of water, according to their spectral signature.

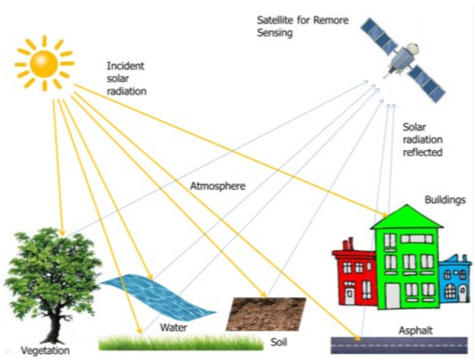


Fig. 1 Solar radiation reflected from different surfaces.

Fig. 2 Left, a satellite image; right, the NDVI.

For example, by using particular combinations of the images in the red and infrared bands, it is possible to calculate, completely automatically for each pixel, the indices that allow one to obtain information about the state of health, the productivity, the density and the vegetation cover in the scene. In the literature there are different expressions for evaluating the vegetation index, depending on the amount of plant biomass, the LAI (leaf area index) and the concentration of chlorophyll, based mainly on the red and near infrared wavelengths (Chen & Cihlar, 1996) The most widely used of these indices is the NDVI (Normalized Difference Vegetation Index), which takes on values between -1 and + 1 normally represented in gray-scale images (**Fig. 2**): low values are represented by dark colors and indicate the pixels corresponding to areas not covered by vegetation; the values greater than 0.2-0.3, represented by light colors, instead indicate areas covered by vegetation; water instead is represented by values less than 0.

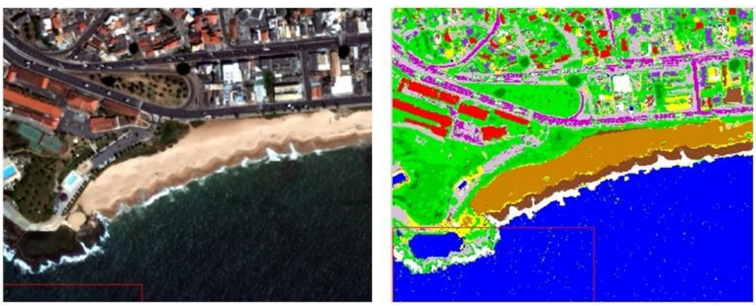


Fig. 3 Left, the satellite image; right the classified image.

In addition, the combination of bands also allows a multispectral classification of the images (Lu & Weng, 2007), such as to create maps of land cover. This operation allows the “cataloging” of the image pixels by assigning them to certain defined classes either by the user (supervised classification) or automatically by the algorithm (unsupervised classification).

Typical examples of land cover classes identified on multispectral images are: buildings, roads, vegetation, water, fields, etc. (**Fig. 3**), and there are different classification algorithms, among which the one most commonly used is that of maximum likelihood. With this algorithm, the assignment of a pixel to a specific land cover class is according to the criterion of maximum probability of belonging. The greater the number of bands used to create the image, the better is the result of the classification.

In the literature there are various studies that summarize the many applications of multispectral image processing in various fields (earth observation, maritime areas, air quality, climate, emergencies, etc.), (Nereus).

In this regard, very interesting applications are made with the sensor mounted on the WorldView 2 satellite, which acquires images in 8 spectral bands, 4 more than the typical four Red, Green, Blue, Near Infrared bands, each of which, in combination with the others, makes it possible to highlight a particular feature (Coastal, Red Edge, Near Infrared 2, Yellow), (Digitalglobe; Baiocchi et al., 2012).

The same processing can be done on multi-temporal images, i.e. the taking of images at different times and then, by comparing them in a GIS environment, it is possible to evaluate automatically/semi-automatically the variations in the time period considered.

3. DETECTION OF CHANGES IN THE TERRITORY

3.1 Study area and materials used

In this work the authors wish to seek a semiautomatic method for the comparison of photogrammetric and cartographic material in order to detect the changes in the territory that have occurred over a given period of time in an area of the municipality of Foligno (Perugia), in order to upgrade the existing maps.

The material used consists of: an aerial orthophoto from 2005 in 4 spectral bands having a geometric resolution of 0.50 meters supplied by the Region of Umbria; an orthophoto obtained from the QuickBird satellite image from 2003, also in 4 bands with a geometric resolution of 0.70 meters obtained from a previous experiment; and the vectorial Regional Technical Map (RTM) in 1:10,000 scale (2000).

Although not very wide, the time interval considered is appropriate for the type of analysis, because the most significant changes occurred within the study area precisely within this period. There is also updated photogrammetric data available that will be used to validate the results of experimentation.

The experiment was performed on two cutouts (**Fig. 4**): the first is of an area of about 6 km2 regarding an industrial zone that has undergone significant expansion in recent years; the second instead is of a smaller, less built-up area, but with a variety of vegetation and a morphology representative of the entire study area.

Fig. 4 Cutout 1 aerial orthophoto from 2005 – industrial area (a) and Cutout 2 aerial orthophoto from 2005 – rural area (b).

3.2 Vegetation index

On various images, the vegetation index NDVI was evaluated in a fully automatic manner, dividing the pixels into 4 vegetation classes: no vegetation, sparse vegetation, moderate vegetation and dense vegetation. **Fig. 5** and **6** shows as an example the NDVI evaluated for the 2003 orthophotos.

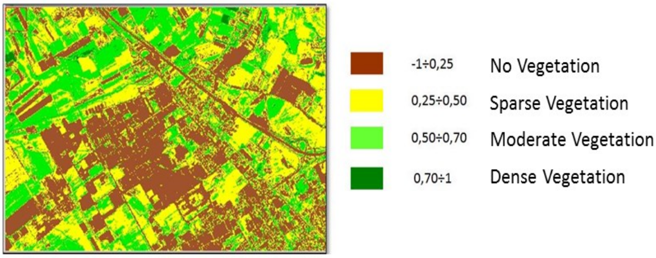


Fig. 5 NDVI Cutout 1_2003.

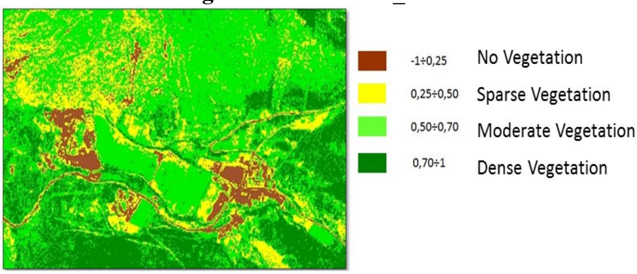
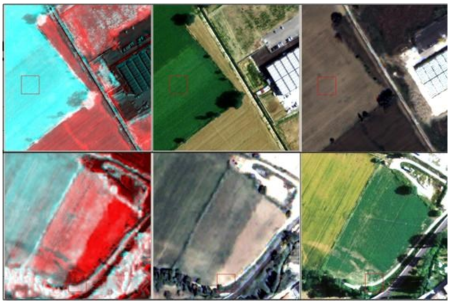


Fig. 6 NDVI Cutout 2_2003.

At this point a comparison was made, by means of subtraction pixel by pixel, between the vegetation indices evaluated for the two periods considered, obtaining the color maps in which the strongest tone (red and cyan in **Fig. 7a**) represent the areas in which there were the most evident changes.

Analyzing only the vegetation index, the changes detected depend exclusively on the different state of the vegetation, thus also on seasonal variations and not just on changes in land cover. Indeed, the changes to the areas not covered by vegetation (built-up areas, paved areas, fields, etc.) taking place during the period considered were not detected, even though they were macroscopic (construction of new buildings). An example is shown by the area circled in red in **Fig. 7b**.



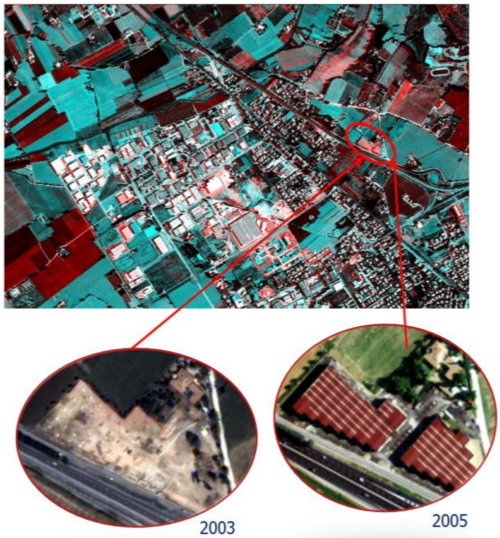
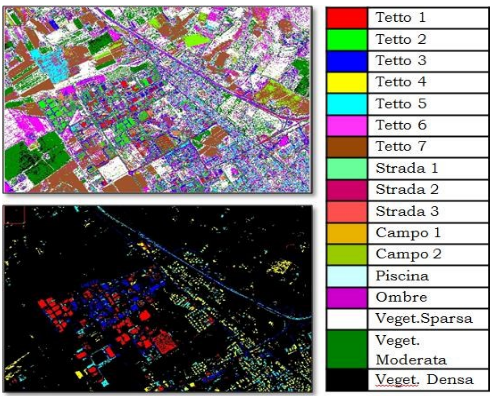


Fig. 7 Comparison between vegetation indices - Cutout 2 (a) and Comparison between vegetation indices does not show changes in built-up areas (b).

3.3 Multispectral classification

In order to investigate better the built-up areas, the same images were subjected to a multispectral classification using the maximum likelihood algorithm, defining different classes of land cover (through photointerpretation) including buildings, roads, shadows, fields, etc. and vegetation detected automatically as seen in the previous section. **Fig. 8** shows as an example of the classification output the image obtained for cutout 1 from 2005. The same operation was also carried out on the 2003 image.



Tetto=Roof;
Strada=Road;
Campo=Field;
Piscina=Swimming pool;
Ombre=Shadows;
Veget.Sparsa=Sparse Vegetation ;
Veget. Moderata=Moderate Vegetation.;
Veget.Densa= Dense Vegetation.;

Fig. 8 Above, classified image (2005); below, building class – cutout 1.

The image pixels were correctly classified with the exception of those with a color similar to other cover classes (e.g. roofs of the same color as the fields or roads). The errors can be reduced by entering the elevation information, which clearly distinguishes a roof from a field or a road that lie at different elevations (Brigante, 2010).

The comparison between the classified images for the two periods, done by a process of subtraction pixel by pixel, made it possible to highlight the changes that have occurred, especially in the industrial area, which has undergone some expansion within the time span considered. In **Fig. 9** some buildings can be seen (cyan color), detected automatically by the algorithm, that are in the 2005 cutout and are not in the 2003 cutout, and therefore are newly built.

Fig. 9 Classification difference 2003 and 2005 - Cutout 1.

As it was desired to update the existing maps, a further comparison was performed automatically in a GIS environment among the buildings detected in the 2005 orthophoto and those on the RTM in 1:10 000 scale, which succeeded in highlighting the changes and thus the elements to be updated. In **Fig. 10** it is possible to see in cyan the buildings that are not on the RTM, as they were built after the date when the RTM was prepared.

Fig. 10 RTM superimposed over the classified image and over the orthophoto – cutout 1.

4. COASTLINE DETECTION

There are interesting applications of the processing of multispectral images in the coastal environment. This paper gives an example aimed at detecting the coastline, or instantaneous shoreline, using satellite pansharpened images taken by the WorldView 2 satellite, with 8 spectral bands and a geometric resolution of 0.5 m.

The coastal environment is the transition zone between the land and the sea and is a highly dynamic system where erosion, and thus the retreat or advance of the coastline, are controlled by many meteorological-climatic, geological, biological and human factors (Basile et al., 2011). A key element in monitoring changes in the coastal environment appears to be the determination of the instantaneous shoreline. The position of the coastline and its historical change can provide important information for the planning of coastal protection works, plans for coastal development, and the calibration and testing of numerical models (Klein & Lichter, 2006). Added to the continued growth of interest in the coastal area is the concern of the risk and consequences of increasing anthropogenic pressure. Hence the need to support coastal planning with the monitoring of the shoreline with surveys at short time intervals in order to correct for seasonal variabilities or the effects due to storms. Effective monitoring requires the development of technologies that are able to provide knowledge with a view to protection, prevention, action and management. There is no single method for coastline modeling that has been widely accepted by the coastal communities, although in the last decade there has been great progress in mapping technology, which goes from the development of new and more accurate GPS (Global Positioning System) equipment, to the putting into orbit of high- and very-high-resolution satellites, and the development of devices that are especially efficient for the assessment of coastal topography, such as LIDAR (Light Detection And Ranging). The methods used for monitoring include: traditional topographic surveys, GNSS surveys, processing of aerial images, video systems and satellite remote sensing.

4.1 Study area and materials used

The image used in the experiment was taken from the WorldView-2 satellite and represents a portion of the Adriatic coast (**Fig. 11**) at the town of Ortona (Chieti).

Fig. 11 Study area – Ortona.

This image is to be used to test the possibility of extracting the instantaneous shoreline by means of an automatic or semiautomatic analysis algorithm. All processing was done using commercial ENVI 4.7 software by Exelis Visual Information Solutions, specifically designed for the visualization, analysis and classification of different types of digital images.

4.2 Multispectral classification

A supervised multispectral classification was initially carried out on the study area using the maximum likelihood algorithm, which allowed the detection of several classes of land cover, including 4 different types of buildings, streets, pools, sidewalks, shadows, sea, vegetation (automatically detected), and it was also possible to distinguish dry sand from wet sand (**Fig. 12**).

Fig. 12 Classified image.

However, this separation is made evident only by exploiting the radiometry of the image. Furthermore, the classification process, especially if supervised, is not completely automatic, but instead requires operator intervention at different stages (identification of cover classes, validation of results, editing,).

4.3 Automatic processing algorithms

Several algorithms for processing multispectral images were tested, with the aim of obtaining a coastline in an automatic manner. Very significant results were obtained by calculating the vegetation index that, besides showing the presence of vegetated areas, makes it possible to identify the areas covered by the water, as it assumes a negative value for them.

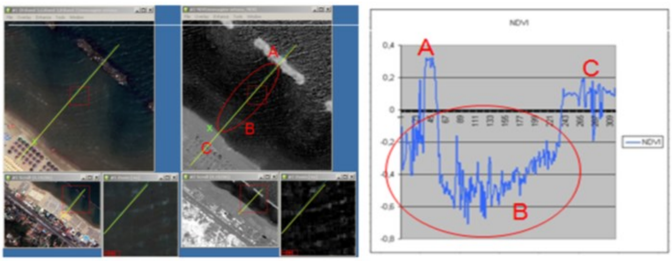


Fig. 13 Left, RGB image; center, NDVI; right, cross-section

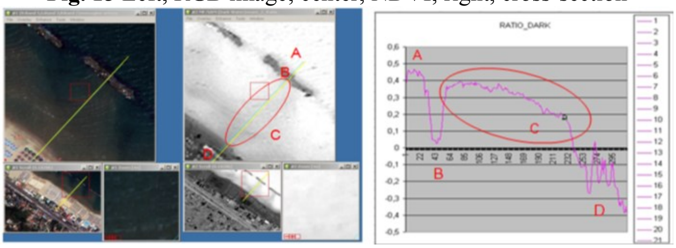


Fig. 14 Left, RGB image; center, MF/SAM; right, cross-section.

Performing a cross-section to the coastline on the image obtained by the NDVI algorithm, a sharp change can be seen in the slope of the curve at the sand/sea passage points (**Fig.13**). By means of a similar procedure, the presence of water covered areas was studied using the information contained in the green, blue, red and infrared bands, using the MF (Matched Filtering), SAM (Spectral Angle Mapper) algorithms and the relationship between the two, which better highlights the separation between dry and wet sand. A cross-section done on these images shows the sharp changes in the slope of the curve at the transition between dry sand/wet sand and wet sand/water, (**Fig.14**).

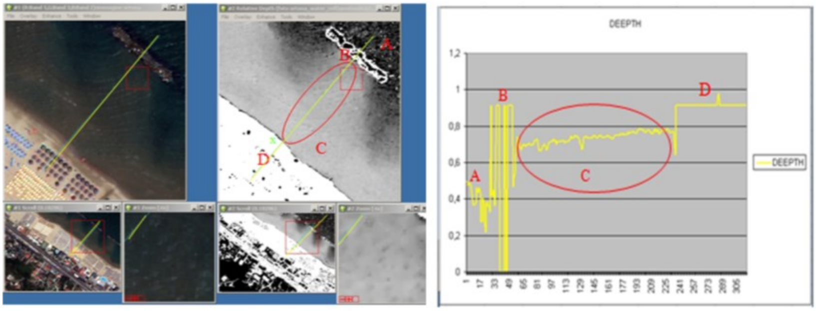


Fig. 15 Left, RGB image; center, Relative Depth; right, cross-section.

Another algorithm that made it possible to show a clear separation between the sand and the sea is that which evaluates the Relative Depth. This tool uses a bathymetry algorithm developed by Stumpf and Holderied (2003), which relates the different bands present in the multispectral image, in particular the coastal band and the blue band. Although they do not represent the absolute depth of the water in the study area (values ranging from zero to one), the Relative Depth results provide a useful analysis of the seabed down to depths of 14 m (**Fig. 15**).

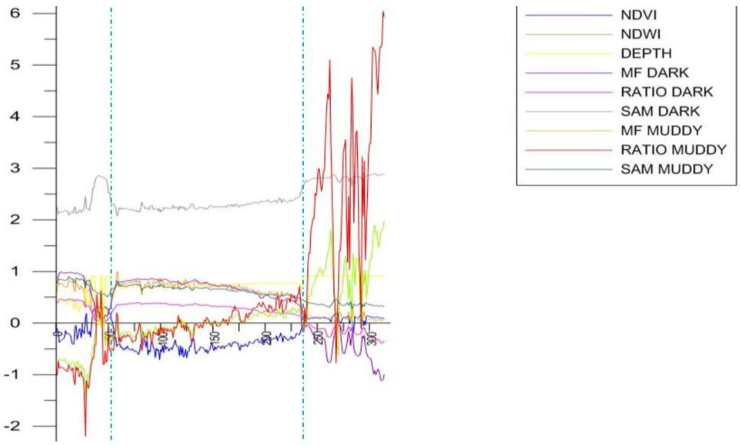


Fig. 16 NDVI, NDWI, SAM, FM, FM/SAM, Relative Depth Trend.

In **Fig. 16** all the curves obtained at the same section representing the NDVI, NDWI, MF, SAM, MF/SAM and Relative Depth indices have been superimposed. All the curves have a similar trend, especially at the passages between dry sand/wet sand and wet sand/water, where a sharp change of slope (dashed lines) can be seen.

Extending the analysis carried out along a section to the entire image, one can obtain the shoreline, understood as the separation between the dry sand/wet sand classes, which can subsequently be vectorized, for example to compare it with the one shown on an existing map, in order to update the existing map if it was not recently drawn up (**Fig. 17**).

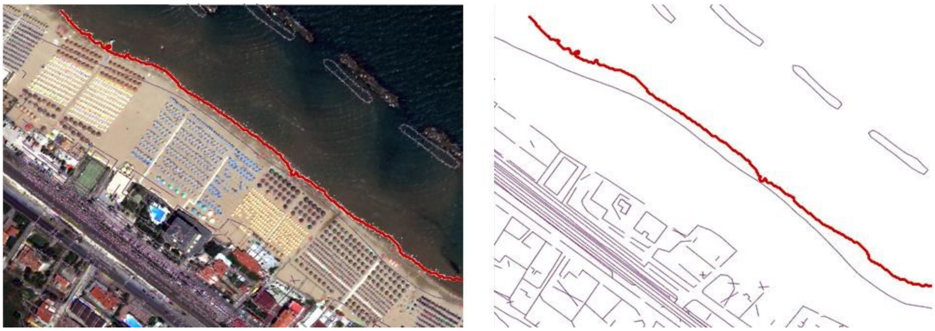


Fig. 17 Coastline superimposed over the Abruzzo regional technical map.

5. CONCLUSIONS

Thanks to the evolution and development of new sensors for remote sensing, there are more and more possible applications for using this surveying technique. This work gives two examples of application, the first in urban and rural areas (Foligno), and the second in a coastal environment (Ortona), both aimed at finding an automatic/semiautomatic method for the creating or upgrading of maps.

As regards the experiment on Foligno through the comparison of photogrammetrical data from different periods, it was possible to detect the main changes that had occurred over a given period of time, especially the construction of new buildings in an industrial area. During the experiment some problems were encountered due to the heterogeneity of the material available for processing. These problems could be overcome by using homogeneous data from a single source, such as using images taken from a single satellite (preferably the latest generation with high spectral and geometric resolution, made in the same period of the year especially for studies on vegetation whose seasonal variations are detected as changes in the area. Having homogeneous images available, classification processes could also be more standardized, with the possibility of application of the method to study areas with different characteristics.

The analyses carried out on the Ortona image instead made it possible to extract the instantaneous shoreline using automatic algorithms.

In order to test the accuracy and reliability of the procedures tested, a comparison will have to be made between the shoreline extracted from satellite images and those obtained using GPS or conventional ground measurements conducted at the same time or within a few hours from the acquisition of the image for a more detailed check. For a better validation of the experiment, one may also consider integrating the results obtained from the WorldView images with elevation information obtained by the intersection of a digital surface model (obtained from stereo images or maps) with a properly calibrated geoid model of the same area. The results obtained are certainly an important starting point for the use of this method for the possible updating of regional technical maps and especially for the updating of coastlines. Indeed, the checking techniques usually used (classical relief, GPS and aerial photogrammetry), valid as far as accuracy is concerned, may not be particularly practical or economical for continuous monitoring of the coastal zone.

Remote sensing also offers the advantage of being able to acquire images of large scenes (several km2) at given time intervals, making it possible to continuously monitor the study area. As regards the automatic classification process, it must be emphasized that in addition to the pixel-based approach used here, which for information uses exclusively the radiometry of the object detected, one may use the so-called object-oriented techniques that along with color utilize other features such as the shape and size of the objects to be detected.

It is also important to point out the gradual reduction of the costs of satellite imagery and the availability of software for processing it, which is leading to the spreading of this survey technique, together with the presence of the archive material available and obtainable at low cost.

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