SATELLITE DATA FUSION FOR ANALYSIS OF COASTAL ZONE CHANGES

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Abstract- This study focuses on the assessment of coastal zone land cover changes based on the fusion of satellite remote sensing data.The evaluation of coastal zone landscapes is based upon different sub-functions which refer to landscape features such as water, soil, land-use, buildings, groundwater, biotope types. Mixed pixels result when the sensor's instantaneous field-of-view includes more than one land cover class on the ground. Based on different satellite data (Landsat MSS, TM, ETM, ERS, IKONOS, ASTER and MODIS) was performed object recognition for North-Western Black Sea coastal zone. Preliminary results show significant coastline position changes of North Western Black Sea during the period of 1975-2005.

I. INTRODUCTION

Satellite remote sensing provides a means for locating, identifying and mapping certain coastal zone features and assessing spatio-temporal changes.The Romanian coastal zone of the Black Sea is a mosaic of complex, interacting ecosystems, exposed to dramatic changes due to natural and anthropogenic causes (increase in the nutrient and pollutant load of rivers input, industrial and municipal wastewater pollution along the coast, and dumping on the open sea). Nowadays, huge quantities of satellite images are available from many different Earth observation sites. Moreover, thanks to the growing number of satellite sensors, the acquisition frequency of data from the same scene is definitely increasing. Furthermore, the high spatial resolution of the sensors gives access to detailed image structures. The analysis of spatio-temporal structures is a useful aid to the interpretation and understanding of complex evolutions of coastal zones. Change detection, monitoring and validation of physical models by data assimilation constitute the most used means of information extraction. In many fields, there is a real need to transform growing databases into knowledge. The application of information technology has allowed the development of tools and techniques to handle both acquired and derived coastal geospatial data . With differences in scales, datums, projections, formats, and resolution, the data are often difficult to handle and even more difficult to integrate.

II. IMAGE FUSION METHODS

Information fusion is a process of combining evidence from different information sources in order to make a better judgment. It plays an important role in many application domains.
No single source of information can provide the absolute solution when detection and recognition problems become more complex and computationally expensive. However, complementary information can be derived from multiple sources. One of the important issues concerning information fusion is to determine how to integrate (fuse) the information or data. Depending on the stage at which fusion takes place, it is often divided into three categories, namely: pixel level, feature level and decision level, as Fig.1 illustrates [1,2]. In pixel level fusion, the combination mechanism works directly on the pixels obtained at the sensors' outputs. Feature level fusion, on the other hand, works on image features extracted from the source images or the features which are available from different sources of information. Decision level fusion works at an even higher level, and merges the interpretations of different objects obtained from different sources of information. Several data fusion algorithms have been developed and applied, individually and in combination, providing users with various levels of informational detail in photogrammetry and remote sensing [3]. The choice of a suitable fusion level depends on the available information type: when the sensors are alike, one can opt for fusion at the pixel-level to take all data into account. When sensors or information are very different, decision-level fusion is more suitable and is also computationally more efficient. Feature-level fusion is the proper level when the features as found by the processing of the different sensors can

be appropriately associated. The application of the fusion approach shows successes with techniques ranging from expert systems to probabilistic techniques. As there is no simple rule for selecting the proper fusion technique, a wide range of techniques has potential applicability. The process of selecting the optimum algorithm for fusion is complicated by the fact that data analysis seeks to combine incomplete and missing data in a complex environment in real time. “Data fusion is a formal framework in which are expressed means and tools for the alliance of data originating from different sources. It aims at obtaining information of greater quality; the exact definition of ‘greater quality’ will depend upon the application” [4] . In optical remote sensing, with physical and technological constraints, some satellite sensors supply the spectral bands needed to distinguish features spectrally but not spatially, while other satellite sensors supply the spatial resolution for distinguishing features spatially but not spectrally. For many applications, the combination of data from multiple sensors provides more comprehensive information.

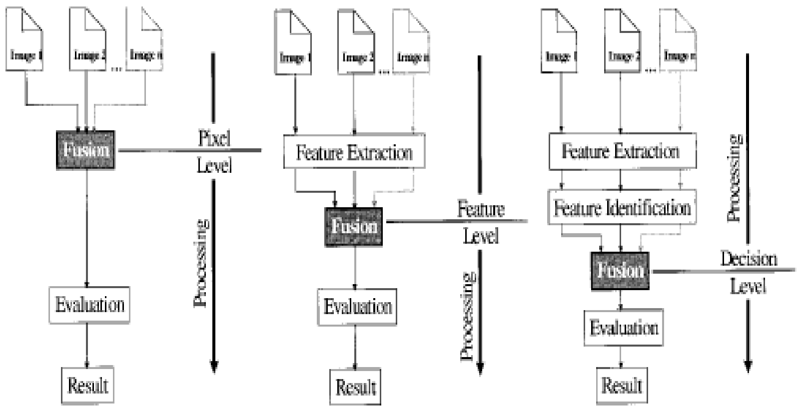

Fig. 1. Processing levels of image fusion.

Developments in the field of remote sensing image understanding over the past four decades have emphasized the requirements of an operational multisource thematic mapping process based on multispectral, hyperspectral and radar images analysis. It has been suggested that the most practical approach is to analyze each data type separately, by techniques optimized to that data’s characteristics, and then to fuse at the label level, as is illustrated in Fig.3. In order to allow the synergy information contents of complementary datasets [5], is very important to derive practical labeling methodologies for effective thematic mapping from mixed data types. Data fusion is an operational method for multisource image analysis. Individual data types may be best analyzed separately, with combination occurring at the label level through some form of symbolic processing. Digital image fusion is very useful for detecting environmental changes at local, regional and global scales.

III. THEMATIC MAPPING

The essential problem in thematic mapping based on satellite images is to specify the data or information that needs to be gathered about a pixel to allow a label to be attached to the pixel consistent with an application of interest. The mapping can be expressed as relations (1):

$$X \in \omega_i \text{ , where } X = X\{x\} \quad (1)$$

in which X is the data description of the pixel, and ω_i is the associated class of interest. X generally consists of a (column) pixel vector x of the measurements. First of all will be found the procedures to extract meaningful information (ω_i) from the data (X) and then move to an understanding of the scene being imaged. So, we need to move along the chain : data >information >understanding
All relevant, coregistered spatial measurements can contribute to the pixel data description and thus be an aid to scene understanding. A more complete data description of a pixel would then described by expression (2):

$$X = X\{x_1, x_2, x_3, ...\} \quad (2)$$

where x_i represent the different data types. Recognition of this more complete pixel descriptor was the forerunner of data fusion methods, and paralleled also the evolution of geographic information systems (GIS). It is not just pixel-specific measurements that tell us something useful about what the pixel represents; its context in relation to other pixels is also significant. That context could be associations among near neighboring pixels (spatial context) or could be represented by the texture of the region in which the pixel resides. So, the data description more generally could be
expressed as relation (3) shows:

$$X = X\{x_1, x_2, x_3, \ldots . | C\rangle\} \quad (3)$$

where C is a representation of context. For some preexisting information available regarding the pixel—from the knowledge of some expert or from the application domain, the pixel description most generally represents a data and information description of the form of relation (4) as :

$$X = X\{x_1, x_2, x_3, \ldots . | C, I\rangle\} \quad (4)$$

where I represents sources of available ancillary information. In the past three to four decades research has focused on devising mapping techniques for labeling pixels based on differing degrees of complexity in the data/information description of (1), and the derived most appropriate pixel, based on spatial, contextual, and prior sources of data or information, represented schematically by Fig. 2. Image fusion is an important tool for topographic mapping and map updating in the provision of up-to-date information. Areas that are not covered by one sensor might be contained in another. In the field of topographic mapping or map updating often combinations of VIR (Visible Infra Red) and SAR (radar) are used [6]. The optical data serves as a reference whilst the radar data that can be acquired at any time provides the most recent situation. In addition the two data sets complement each other in terms of information contained in the imagery.

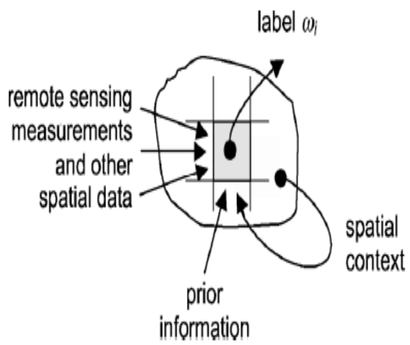

Fig. 2. The most appropriate label for a pixel

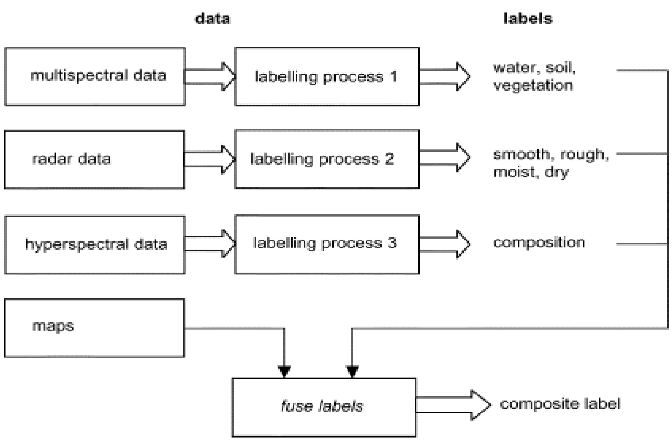

Fig. 3. Fusion of mixed data types at label level.

IV. PRINCIPAL COMPONENT ANALYSIS (PCA)

PCA is very useful technique for image encoding, image data compression, image enhancement, digital change detection, multitemporal dimensionality and image fusion. It is a statistical technique that transforms a multivariate data set of intercorrelated variables into a data set of new un-correlated linear combinations of the original variables. It generates a new set of axes which are orthogonal [7]. The approach for the computation of the principal components (PCs) comprises
the calculation of:

1. Covariance (unstandardised PCA) or correlation (standardised PCA) matrix
2. Eigenvalues, -vectors
3. PCs

An inverse PCA transforms the combined data back to the original image space. The use of the correlation matrix implies a scaling of the axes so that the features receive a unit variance. It prevents certain features from dominating the image because of their large digital numbers. The signal-to-noise ratio (SNR) is significantly improved by applying the standardised PCA . Better results are obtained if the statistics are derived from the whole study area rather than from a subset area. Two types of PCA can be performed: selective or standard. The latter uses all available bands of the input image, e.g., TM 1- 7, the selective PCA uses only a selection of bands which are chosen based on *a priori* knowledge or application purposes [8]. In the case of TM the first three PCs contain 98- 99% of the variance and therefore are sufficient to represent the information. PCA in image fusion has two approaches:

1. PCA of multichannel image replacement of first principal component by dfferent images (*Principal Component Substitution*- PCS) ;
2. PCA of all multi-image data channels.

The first procedure follows the idea of increasing the spatial resolution of a multichannel image by introducing an image with a higher resolution. The channel which will replace PC1 is stretched to the variance and average of PC1. The higher resolution image replaces PC1 since it contains the information which is common to all bands while the spectral information is unique for each band; PC1 accounts for maximum variance which can maximize the effect of the high resolution data in the fused image [9]. The second case integrates the disparate natures of multisensor input data in one image. The image channels of the different sensors are combined into one image file and a PCA is calculated from all the channels. The PCA approach is sensitive to the choice of area to be analyzed. The correlation coefficient reflects the tightness of a relation for a homogeneous sample. However, shifts in the band values due to markedly different cover types also influence the correlations and particularly the variances.

V. STUDY AREA AND SATELLITE DATA

The study area is the Romanian North-Western Black Sea coast, delimited by the Southern border line with Bulgaria up to the Northern border with the Ukraine. It is bounded by latitudes 43.6 °N and 45.40 °N and longitudes 28.5 °E and 29.8 ° E . The Romanian Black Sea shelf is a region of active biogeochemical interactions between land and the deep, interior basin. The North-Western part of the Black Sea is a lacustrine coast. One of the most important areas on Romanian Black Sea coastal zone is the town of Constantza. The 247 km length of Romanian North-Western Black Sea coast is representative of sandy coastal environments with long linear beaches bordering a large continental shelf, being divided in two main sectors: a Northern one delimited by Danube River's Chilia branch and Cap Midia and a Southern one delimited by Cap Midia and Vama Veche. The Danube River Delta is placed in the North Western part of Romanian Black Sea coastal zone. The Danube River runs through 2850 kilometers of Central Europe, then splits up into three channels (Chilia, Sulina and Saint-Gheorghe) which empty into the Black Sea. The delta (5500 km^2), crossed by drainage canals is covered with large areas of reed, agricultural fields, and an exotic forest raised on sandy dunes soil. The study was done based on satellite images from Landsat MSS 24/07/1975, Landsat MSS 7/08/1981, Landsat TM 20/08/1989, Landsat TM 28/08/1992, Landsat TM 20/08/1993, Landsat TM 24/07/1998, Landsat ETM 16/08/2004, IKONOS 25/07/2005 and ERS-1 SAR data of 27/04/1993, 6/07/1993 and 11/09/1993, MODIS data of 3/08/2001, 16/09/2002 , 12/06/2003, 12/08/2003, 20/09/2003 and SPOT XS (21/07/1998), ASTER data 31/05/2003. Also used were radiometric measurements as ground truth profiles and topographic maps (1: 50000 and 100000 scales) over the selected areas as well as in situ measurements.

VI. RESULTS

As an indicator of land use/cover change, the extension of the road network and the urban areas over Romanian Black Sea coastal zone is compared over the period 1975 and 2005. Also the change in the position of the coastline is examined and linked to the urban expansion in order to determine if the changes are natural or anthropogenic. A distinction is made between landfill/sedimentation processes on the one hand and dredging/erosion processes on the other. Waves play an important role for shoreline configuration. Wave pattern could induce erosion and sedimentation. A quasi-linear model was used to model the rate of shoreline change. The vectors of shoreline were used to compare with wave spectra model in order to examine the accuracy of the coastal erosion model [10]. The shoreline rate modeled from vectors data of SAR ERS-1 has a good correlation with a quasi-linear model. Wave refraction patterns are a good index for shoreline erosion. A coast-parallel wind drives the surface layer of water almost directly offshore. Removing the surface layer causes deeper water, with different characteristics (e.g. colder and with higher salinity), to upwell along the coast. The upwelling signal is strong influenced by the seasonal cycle, the upwelling effects have strong influence on the marine ecosystems, which are all localized in the first 100-200 m. Below this layer there are no conditions for life.Also a land cover classification and subsequent environmental quality analysis for change detection was done based on satellite images. Spectral signatures of different terrain features were used to separate and classify surface units of coastal zone and sub-coastal zone area .Figure 4 illustrates coastal zone retraction as well as harbor developments and PCA analysis of landcover/landuse in Constantza area , placed on Romanian coastal zone of North-Western Black Sea. Erosion has an almost irreversible environmental and economic impact on the Romanian Black Sea coast. Ii is an urgent task to assess the most efficient actions to minimize coastal erosion by considering the real value of land and property loss over time, the negative impact on the economy in the coastal zone (tourism, transportation, harbors, industry, agriculture); the total costs of building defensive structures; and the secondary costs associated with implementing of sea defense structures and the costs for restoring the beaches and the coastal zone.

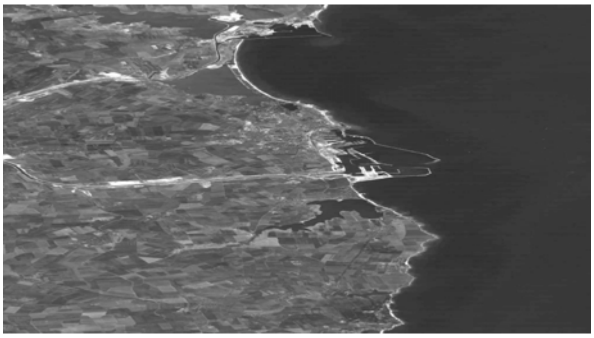

Fig.4. Black Sea coastal zone PCA 3/5/1 on Landsat ETM 16/08/2004

The results can be utilized as a temporal land-use change model for coastal zone regions to quantify the extent and nature of change, and aid future prediction studies, which helps environmental agencies to develop sustainable land-use practices. The change in the position of the coastline in the Constantza area is examined and linked to urban expansion in order to determine if the changes are mainly human induced or natural.

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