FHyl: Field Spectral Libraries, Airborne Hyperspectral Images and Topographic and Bathymetric Lidar Data for Complex Coastal Mapping

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Abstract

Remote sensing of coastal ecosystems provides fundamental information for the effective assessment of valuable natural habitat. A synoptic view of the shallow submerged and emerged coastal landscape can offer the quantitative ability to obtain spatially explicit data over large and complex areas, where the heterogeneity of habitat is mixed by vegetation and sediment/soil interactions at the interface with water and atmosphere. In the present paper, by combining field radiometry with contemporary airborne hyperspectral imagery and topographic and bathymetric LiDAR data, an innovative approach with the application of Spectral Mixture Analysis (SMA) and Multiple Linear Regression models is proposed in order to define shallow coastal seabed, beach and dune habitat at the finest scale. The implemented FHyl (Field spectral libraries, airborne Hyperspectral imagery and LiDAR altimetry) processing chain leads to an innovative mapping results obtained by an integration of multisensory data. Presence and typology of vegetated and unvegetated beach is represented as the abundance of each physical response within the hyperspectral reflectance by building multisensory and multidimensional hyperspectral - LiDAR mixture space. Mineralogical and sedimentological properties of the beach sediment was estimated by using field and airborne spectral libraries combined with sediment sampling in a multiple linear regression statistical model.

Therefore, FHyl represents the multisensory data fusion process to classify and map vegetation presence and distribution, as well as sediment properties and geomorphology of complex coastal seabed, and beaches dunes systems. The present research is a novel input for multilayered analysis in biophysical studies and its application on multi temporal dataset modeling of coast evolution.

Index Terms— FHyl, Lidar, Hyperspectral, Coastal mapping

1. Introduction

Coasts are dynamic systems naturally subject to morphological and ecological changes due to factors external to the system. In the studied area, erosion is caused by a large number of factors such as coastal anthropization, changes of winds and coastal current regimes that increase energy of incident waves [1]. The impact of human activities, that involves the loss of coastal wetlands and deforestation; the construction of dams along the rivers and their discharge control, the construction of jetties at sea and other infrastructures, is altering the natural equilibrium of coastal areas and consequently affect the distribution of renovated surface and ground water, sediments and nutrients in coastal habitats and beaches. The compromise of the delicate equilibrium governing the coastal habitats creates a major impact on all living habitats associated with this complex ecosystem. Understanding of conservation status and coast dynamics is essential not only for the protection of habitats, but also for proper management of all components of the coast [2]. Submerged beach, backshore and dune area are three separate interdependent elements of the same system. For that, we plausibly expect that changes affecting one of these three components have direct or indirect influence on the state of the other two [3]. For the purposes of proper management and planning, and in accordance with the principles of Integrated Coastal Zone Management (ICZM) the coastal system must be studied and analyzed in its three components, in terms of both morphological and ecological-environmental approach [4]. The techniques that actually the Geomatics provides the scientific community are particularly suitable for collecting morphological and ecological information in order to identify and quantify the relative indicators. Among these, morphometric parameters related to ecological parameters (such as vegetation presence/absence and structure) are generally important and are of particular relevance in the dunes system coastal context [5]. A great effort has been spent to discover patterns and relationships within dunes system areas, in order to reach a successful management and monitoring of these transitional environments [6]. An innovative approach recently used is the combination of two innovative remote sensing techniques that can be used to study the sediment dynamics and the vegetation patterns (both emerged and
submerged), and hence the morphodynamics, along sandy shorelines [7] [8]. Remote sensing in general is a very powerful tool for beach monitoring and investigation, since it allows collection of spatially continuous information over a vast area in a short time frame [9]. Airborne remote sensing allows a mission to be planned carefully, taking into account all possible constraints. In recent years for the construction of DSM and DTM, on a wide scale range regardless of the site characteristics, laser altimetry technology is spreading through the use of LIDAR bathymetric airborne. This approach measurements provide 3D digital representations (3D clouds) of extremely wide surfaces (from squared km to hundreds of squared km), with high density of points/m² and high accuracy both on horizontal (cm) and vertical (cm-dm) component, solving large part of the above critical states for direct in situ measurement. LIDAR acquisition, including integrated GPS, is the most suitable techniques to measure morphometric status and to establish the baseline reference for accurate future assessment of evolutionary trend in coastal areas.

2. METHODOLOGY

Two airborne surveys with MIVIS hyperspectral and LiDAR Hawkeye II sensors, during the spring 2009 and 2010 provided the hyperspectral, topographic and bathymetric airborne. Several field surveys were carried out during the airborne acquisitions providing spectral data for enhancement and validation of remote records. A modular approach has been used to develop the FHyL processing chain (Fig. 1) [10]. FHyL consists of four main modules and two preprocessing steps: each module differs for the analyzed environment (emerged and submerged) and for the approach in the sensors integration (Hyperspectral, LiDAR and Field); in the two preprocessing steps, one for each sensor, the data is prepared for main analysis.

2.1. Preprocessing steps

The geometrically calibrated hyperspectral dataset was corrected for atmospheric influence using ATCOR4, based on the radiometric transfer model MODTRAN4 [10] and is designed for the atmospheric correction of remotely sensed data acquired from aerial platform that suffer from distortions. All the analyses started with the definition of the Region of Interests (ROIs). Baseline MIVIS imagery required the gradual generation of masks to reduce the extent of image itself and to define the best subsets for the final habitat processing (seabed and dunes). Picking MIVIS thermal bands it was possible to define a threshold temperature value, to mask emerged and submerged areas on an empirical basis supported by field validation measurements. MIVIS and LiDAR were coupled by interpolating the filtered LiDAR point cloud on a raster with the same extent of the MIVIS one (with 3x3 m cells) and layer stacked as a new band. Field Spectral Libraries were resampled on MIVIS bands spectral resolution so that the data were comparable. For collected sediment samples, the results of mineralogical and grain size analysis, the resampled field spectral measures and MIVIS spectral measures were linked by means of spatial coordinate [11].

2.2. Processing

2.2.1. Module 1 – LiDAR-MIVIS Emerged

The analysis of the LiDAR elevation data allowed a complete morphological characterization of the emerged beach and dune environments and leads to obtain results such as accurate shoreline position, DSM, dune amplitude and elevation, slope, dune foot and the inner edge. In this case the evaluation of vegetation indexes was used to get a synoptic view of biomass distribution of vegetation on coastal dunes that supported accurate foot and inner edges extraction and the discussion of the preliminary definition of beach-dunes polygons.

2.2.2. Module 2 – LiDAR-MIVIS Submerged

Standard deviation of the LiDAR point cloud was calculated on a 4x4 m grid in order to observe and classify: (1) seafloor topography, (2) rugosity and (3) consolidated and unconsolidated seabed on the base of an accurate interpretation. By the application of morphometric slope and curvature parameters the sand bars and complex sedimentary structure were analyzed. Size, orientation and asymmetry of several bedforms observed in shallow water were described and correlated to longshore current, waves and wind regime to better understand their formation and evolutionary trend. Then, selecting the hyperspectral subset for submerged environment the analysis of sandy bars and the definition of different sectors along the coastal stretch was enhanced by introducing combined indexes of spectral bands or band ratios and parameters such as sandy bar order, extent and their relation to emerged landscape.

2.2.3. Module 3 – MIVIS-LiDAR Emerged

Beach and dune polygons, obtained on the base of module 1 were used to define two sets of ROI, one for the dune cords and one for the emerged beach. For dune cords multisensory mixing space has been generated on the base of PC rotation scatterplots (0.43 - 1.55 µm). The PCA multidimensional space identified for each dune polygon quotes of the scatter plots on the base of the first two or more dimensions as pure pixels. Two, three and four pure pixels were selected for vegetation, sands and eventually atrophic structures (EM) and used as training sets for running the maximum likelihood classification for vegetation presence and absence. Dune geomorphology and the field spectral profiles were considered to enhanced the habitat classification (trees, shrub and grasses).

On the beach subset, a multitemporal and distributed sediment sampling were collected during the first MIVIS acquisition. Then, an algorithm to find and test all
the possible multiple linear regression models between sedimentological characteristics and spectral properties was implemented [12]. Two multiple linear regression model were developed for the mean phi and for each of the principal mineralogical phases present on the beach (quartz, calcite, albite, sanidine and pyroxene) [13] [14]. One using the band values extracted from the MIVIS (using just the range 0.46 - 2.5 μm), and one using the band values obtained by the field spectral measurements and resample on the MIVIS’s ones. The first method doesn’t need field spectral data, but is applicable only if sampling is contemporary with MIVIS acquisition, the second one permits to use not contemporary sampling for the model calibration.

2.2.4. Module 4 – MIVIS-LiDAR Submerged

A high-resolution airborne sensor spectral data in combination with innovative assimilation from field radiometric observation and from LiDAR bathymetry develops a multidimensional and multisensory mixture space. The processing chain starts by integrating morphologies into the hyperspectral mixing space (0.43 – 0.72 μm) and then the EM collection from image is used to achieve an image based linear mixture model of fraction that describes the composition of each mixed pixel [15]. With a spectral resampling of Field Spectral Library on MIVIS hyperspectral bands, single and multiple spectral signal enhanced the image based EM collection in order to obtain different mixing of fraction maps. The endmembers were evaluated against the consistency in the topology of the multisensory mixture space. The spectral separation between cover typologies and water absorption was observed and analyzed.

All the four modules were validated by field surveys, laboratory analysis and videoshots.

3. RESULTS

Biophysical maps are obtained with 3x3 m resolution. Vegetation composition and distribution is grouped in different classes, 2 for seabed (down to -6 m of depth) and 4 for dunes (up to 30 m of height). For the emerged area, an accurate grain size and mineralogical sediment features estimation permitted to appreciate variation occurring at both large scale (along the entire stretch of coast) and micro scale (few meters). The spectral library introduced in the linear mixture model for SMA both lowered the reflectance and enhanced the variety of vegetated and not vegetated seabed leading to a magnification of results. Meanwhile, in the emerged AOIs the spectral library introduced in the linear mixture model allowed to clearly distinguish spectral properties of vegetation communities and part of the moisture contribution within the beach areas. The present research suggest that morphology is the driving factor for: (1) vegetated habitat classification; (2) hyperspectral image content enhancement; (3) the implemented final maps contributes to the knowledge of relationships between seabed and (4) seawaters mixed absorption as well as between sediment and vegetation interaction. The strategy of combining high and very high resolution spectral measurements in a multisensory and multi resolution analysis includes different way of data fusion to assimilate spectral and spatial variability in complex coastal mapping.

4. CONCLUSION

The new systematic approach through new methodologies such as the combined analysis of remotely sensed data (hyperspectral and LiDAR) for the quantitative estimation of different morphometric index is useful for geomorpho-ecological analysis. The new approach shows the impressive results of physical characterization and environmental impact of coastal ecosystems based on integrated use of remote sensing data type LiDAR and hyperspectral MIVIS. The synergy between the two sensors has allowed on one hand to evaluate the morphological characteristics of the surface and on the other hand to investigate the physical nature of the targets, in order to correlate the performance and the morphotypes of the territory with the presence and distribution of some ecological matrices. For example, the integrated use of two datasets, the LiDAR (morphological and quantitative) and the MIVIS (environmental), offered the chance to explore the vast territory from areas, emerged and submerged, by providing high quality information related forms (morphotypes) and the development of the territory but also the distribution and characteristics (structural and physico-ecological) of the region. In particular, the use of the MIVIS data, provided information on the physical nature of landforms. The integration of information derived from LiDAR data and the data MIVIS has enabled us to carry out inspections and quantitative characterization of the coastal ecosystem of environmental matrices such as sediment and vegetation cover, large scale bed forms (both above and below msl)
allowing for the first time ever to recognize complex conceptual models of land form. The results obtained have enabled us to produce cartographic thematic summaries that describe the feedback between habitats and morphodynamics even at the scale of retail. The results evidenced most from this stage of work is that the integrated LiDAR data with hyperspectral MIVIS data has resulted in better delineation of the system emerged-submerged present in the study area and a better characterization of the morphological and environmental discontinuities. Within a context of Ecology and biological resources management, airborne and field techniques has revealed interesting options in monitoring coastal nearshore zones. Airborne multisensory acquisition has been an important cost of this research (~1600€/km²), mostly because of the mobilization and demobilization of sensors and airplanes. Field data collection, laboratory analysis and data processing were about 2/3 more per kilometer. In this monitoring test, the first in Italy in its own characteristics, the highest effort has been certainly processing and post-processing effort because of the unavailability of already implemented procedures for coastal integrated analysis and because of the groundtruth effort required with new remote sensing technologies implementation. With this work and the overall results of these research standards for data and processing tools have been developed hoping this will determines also a reduction of processing and post-processing effort. If the remote sensing data and the information they store in, would be free of charge, the users will have the ability to create value added products and foster the creation of new insight into environmental analysis and management.

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6. REFERENCES