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A New Approach on Grain Size Estimation from Airborne Hyperspectral Data

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Abstract: - The Bay of Santander is a very important environmental element, located in the north of Spain (Cantabria). Human spills to convert sea into land started about 1850 and gradually change the tide prism. This produced the Bay to start filling up and consequently, problems for the safety navigation. Whence the navigational channel must be periodically measured and dredged.

Marsh, dunes or estuaries use to be characterized by their high natural values what usually cause them to be subjected to high protection levels that make the activities sought to develop inside. The current work compiles and developed process to estimate the grain size (sand, silt, clay, silty loam, sandy clay loam,…), Pb and Zn contents, and ripples from hyperspectral data.

The data were obtained in June 2005 by the Catalonian Cartographic Institute (ICC). The ICC has an airborne sensor (Compact Airborne Spectrographic Imager-CASI) which let the user setup temporal, radiometric and spatial resolution according to the requirements (36 bands and 4 m. spatial resolution). This makes possible to collect data in the optimum tide level and brightness conditions and so they can be considered as an interesting tool to monitor depths, grain size and ripples.

Results show that accuracy is highly dependent of the radiometric and atmospheric corrections, but it can be used as a practical tool for deriving thematic cartography of grain size and inorganic sediments in coastal environments; cheaper than classical chemical field methods.

Key-Words: - Atmospheric correction, Grain size, Passive optical remote sensing, airborne sensor, spectral rationing, Principal Components Analysis (PCA), Robust Principal Components Analysis.

1 Introduction

Heavy metals are a special interest topic either in the environmental field either in the public health field. The harms that they cause are so severe and, sometimes, so absent of symptoms, that environmental and health authorities from the whole world pay special attention in minimizing the exposure of the population, particularly childish population, to these toxic elements.

Water acquires a variety of many inorganic elements when it contacts with the environment; with the atmosphere (gases), with land (minerals) and with the man-polluted environments

Spills in Santander a mainly due to urban waters from various industrial polygons (industry dedicated to the metal transformation, manufacturing of mechanical equipments and machinery, extraction and transformation of minerals, chemical industry and manufacturing of transport material). Last, the port is an essential element since several tasks as hydrocarbures storage, load and discharge, cleaning of vessels are developed in it.

In this way and due to Bay sediments are traps for all those products that do not remain in the water columns at first instance, these can contain a high degree of pollutants waiting to pass to the trophic chain, returned to the water column or simply be located in a more favourable place for its mobilization.

Parameters such as Total Organic Content, sediment humidity, grain size (sand, clay, silt) and heavy metals (Pb, MnO, and Fe) have been analysed of several sample points in different places (29 points)

2 Problem Formulation

2.1. Study area.

The Bay of Santander (Figure 1) is located in a privileged place within Cantabrian Community (Spain). It is a depression whose ecosystem is very rich both from biological and from the socio-economical point of view. More than 250.000 inhabitants are concentrated in this area, which means more than 50% of the community population. The bay has been conceiving from the Mesozoic and it is very important for a population which develops several activities, all of them creating residually spills.

This ecosystem is very sensitive and with high ecological fragility. It presents sediments such as limes, clays and other particles from Miera River. There are lots of points which collect the municipalities' spills that surround the bay (Santander, Camargo, Astillero, Marina de Cudeyo, Ribamontan al Mar y Villaescusa) and that flow into it, either directly either nearby estuary. Fluvial, fecal and even residual waters

from industries are collected.

Fig. 1. Location of Bay of Santander in the Spain context.

Thereby and given that sediments of the Bay act as a trap for all those products that do not remain in the water column at first instance, these can contain a high degree of pollutants waiting to pass to the trophic chain, be returned to the water column o simply be located in more propitious medium for its mobilization.

It is essentially important to investigate the presence of polluting agents in sediments and their effects in the environment, trying to look for parameters that could inform about the quality of the sediment. It has been already proven that sediments are and important tool to measure the impact of men on the middle.

2.2. Materials

The CASI sensor (Compact Airbone Spectrographic Image) is a pushbroom linear scanner based on a matrix CCD, which allows collection of up to 36 spectral bands in the range of 430 nm to 950 nm and 512 spatial samples.

The sensor was installed on board of the plane "Cessna Citation I" belonging to ICC. The flight was made the 3rd of June and to capture the whole bay, 10 tracks were needed. The imagery was radiometrically and geometrically corrected and then orthorectified.

The spectral configuration of the images was configured by the ICC, with 36 channels and a spatial resolution of 4 x 4 m^2.

The images were recorded in enhanced spectral mode. This mode lets the users obtain a continuous channels configuration between a spectral range from 408 nm to 953 nm and minimum spectral width of up to 1.8 nm. The designed configuration has consisted in 15nm width per channels, and 36 spectral channels.

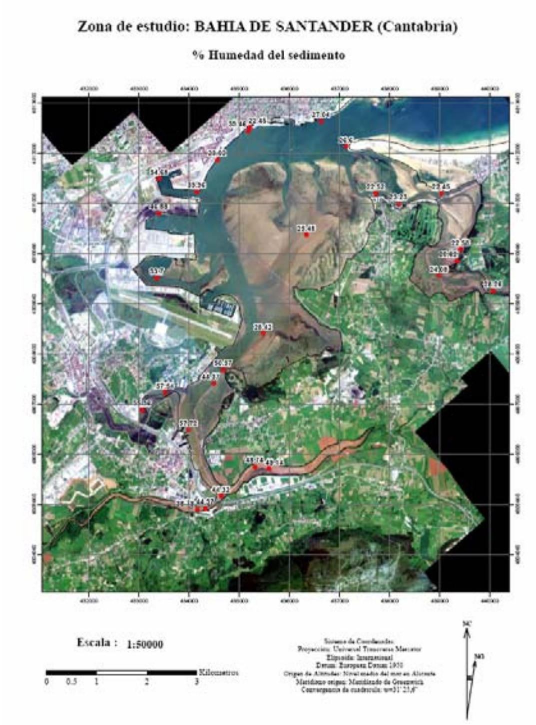

Fig. 2. Field samples location.

The Chemical Engineering group of E.T.S.I. Industriales y Telecomunicaciones of University of Cantabria where responsible of sampling the area, measuring the sediment concentrations between 0 and 20 cm. The analysed parameters were: humidity, Lost of ignition (L.O.I.), total organic content (T.O.C.) grain size distributions, concentration of plumbum, zinc, iron and Manganese oxide.

To develop a correct and precise analysis of the spectral data, it is necessary to dispose of an accurate correction for the atmospheric, geometric and radiometric effects on the imagery.[1,2,3,4]

Lack of corrections insert noise within data registered by CASI in each of the interest parameters. In the following points, the most used classical methods in multispectral remote sensing, as well as some advances that can be very useful when an analysis with the highest precision is made.

The atmospheric correction made by the Catalonian Cartographic Institute was based on applying the 6S algorithm (*Second Simulation of the Satellite Signal in the Solar Spectrum*) [5], so it was necessary to sample points on site with the ASD-FR spectro-radiometer(Figure 3), property of the Hydrographic Studies Center of Spain (CEDEX). Two different measurement methodologies were developed depending if the working area was either water either soil. Spectral signatures for different types of surface were obtained (dry sand, pavement, bare soil, dense grass, etc)

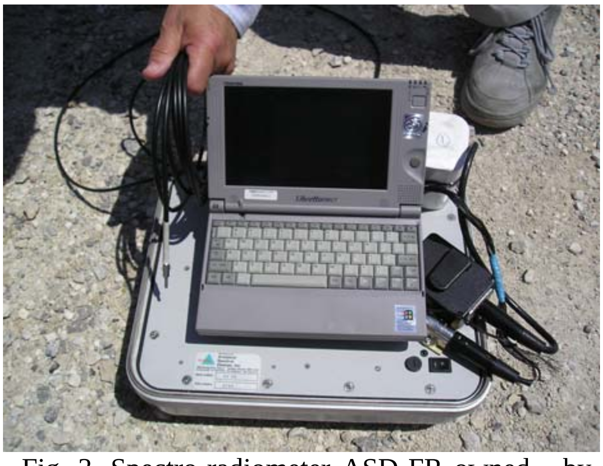

Fig. 3. Spectro-radiometer ASD-FR owned by CEDEX.

3 Problem Solution

The analysed methods include different complexity methods such as single bands, spectral rationing and classical and robust Principal Components Analysis.

It is necessary taking into account that a double study has been done, that is to say on one hand the intertidal area, whose spectral response is similar to a soil with different degree of humidity, has been analysed and on the other hand the subtidal area, completely afloat of water. Imagery was taken one hour after low tide.

Single band analysis is the oldest method of the ones that are going to be analysed y It is based in the existing relation between the analysed parameter (% sand, Pb, Zn, MnO concentration, etc.) and the obtained spectral response in each of the bands of the CASI sensor. Those bands whose correlations with data are the highest will provide the better final result and on this way the error between the observed and the estimated value is minimized.

The spectral rationing between two bands or combinations of them let decrease the radiometric differences produced when atmospheric corrections are performed. It is very difficult to apply an atmospheric model which took into account all the atmospheric elements that influence imagery. This type of methods increases, at the same time, the spectral differences due to the presence of a determinated parameter or sediment.

Therefore, the objective of this type of methodology is to determine la band or bands in which this parameter o f interest has the maximum reflectance and, at the same time, those bands in which the signal received is minimum. Rationing between bands or band combinations evidences the presence of such element letting discriminate the parameter easily.

Classical Principal Components Analysis (Classical PCA) is a very common statistical process in multispectral remote sensing that was proposed by Pearson in 1901. Original data is transformed into a new set of uncorrelated bands (orthogonal principal components) sorted by the amount of variance that any of them explains.

Robust Principal components Analysis (Robust PCA) has the objective of “robusting” the classical data obtained in the multivariate analysis detecting the presence of anomalous data. To be able to do this It is necessary to robust the covariance matrix since the most of results are based on it.

The first stage is based on knowing to which band corresponds the observed spectral response on each of the evaluated methods; it consists on studying the correlation between each one of the parameters. (Table 1)

It is observed that the degree of humidity of the sediment is directly related to the grain size (sand, limes or clays) obtaining a really high correlation index.

The work has consisted in two phases; the first one deals with calibrating the different methods with the on-site samples and the second one has consisted in validating the results

	humidity	gravel	sand	Silt/clay	Pb	Zn	MnO	TOC	pH	LOI
humidity	1.000	-0.099	-0.887	0.887	0.648	0.796	0.686	0.588	-0.268	0.746
gravel	-0.099	1.000	0.068	-0.094	-0.036	-0.114	-0.167	0.065	-0.124	0.100
sand	-0.887	0.068	1.000	-1.000	-0.617	-0.694	-0.610	-0.582	0.405	-0.732
Silt/clay	0.887	-0.094	-1.000	1.000	0.617	0.695	0.613	0.579	-0.401	0.728
Pb	0.648	-0.036	-0.617	0.617	1.000	0.904	0.455	0.552	-0.211	0.736
Zn	0.796	-0.114	-0.694	0.695	0.904	1.000	0.611	0.604	-0.187	0.668
MnO	0.686	-0.167	-0.610	0.613	0.455	0.611	1.000	0.141	-0.471	0.504
TOC	0.588	0.065	-0.582	0.579	0.552	0.604	0.141	1.000	-0.007	0.561
pH	-0.268	-0.124	0.405	-0.401	-0.211	-0.187	-0.471	-0.007	1.000	-0.291
LOI	0.746	0.100	-0.732	0.728	0.736	0.668	0.504	0.561	-0.291	1.000

Table 1.- Analysed correlation parameters

On the other side, plumbum and zinc obtain a correlation index of 0.9, so we can say that they have similar spectral signatures.

Isoline planes were generated for each one of the interest parameters aimed to assess in a general way the distribution the parameter in the Bay (Figure 4). The methods used to calculate the surface were 2nd degree polynomial, Inverse Distance Weighting and ordinary kriging.

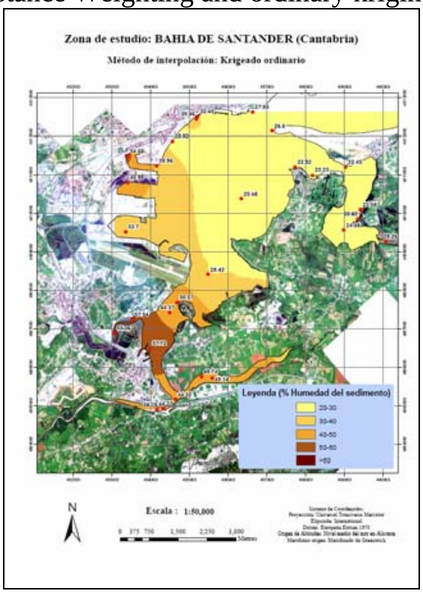

Fig. 4. Plane of isolines
(Humidity within the sediment)

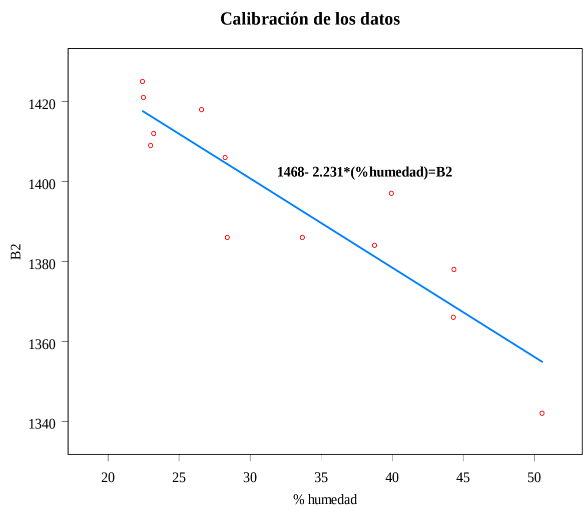

Fig. 5. Data calibration (subtidal area). Robust Adjust

The calibration phase has been developed in the SPLUS software and different classical and robust algorithms methods (linear regression model, Least Median of Squares Robust Regression, Least Trimmed Squares Robust Regression, M-Estimates of Regression, Linear Least-Squares, Minimum Absolute Residual Regression, High Breakdown and High Efficiency Robust Regression) have been applied obtaining adjust functions as it can be appreciated in Figure 5.

Once the adjust equation is obtained, it is inverted and the image corresponding to the sediment humidity for the study area calculated (Figure 6)

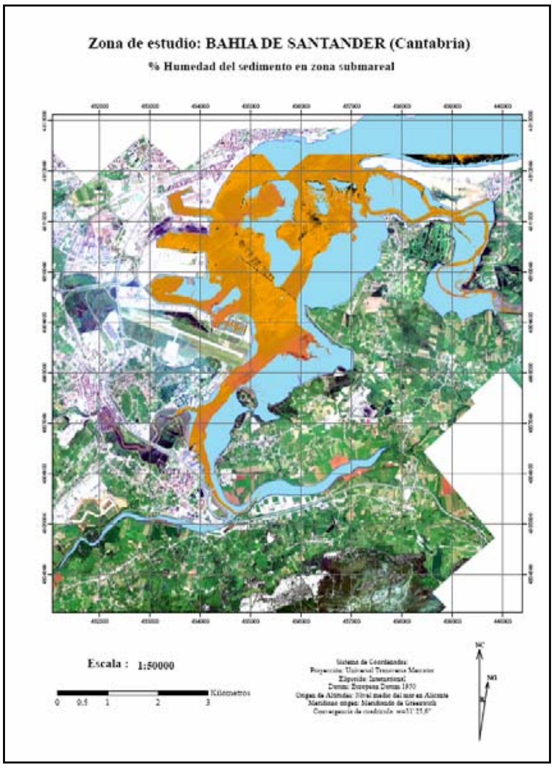

Figure 6.- Result of the B2 adjust and % humidity in the subtidal area.

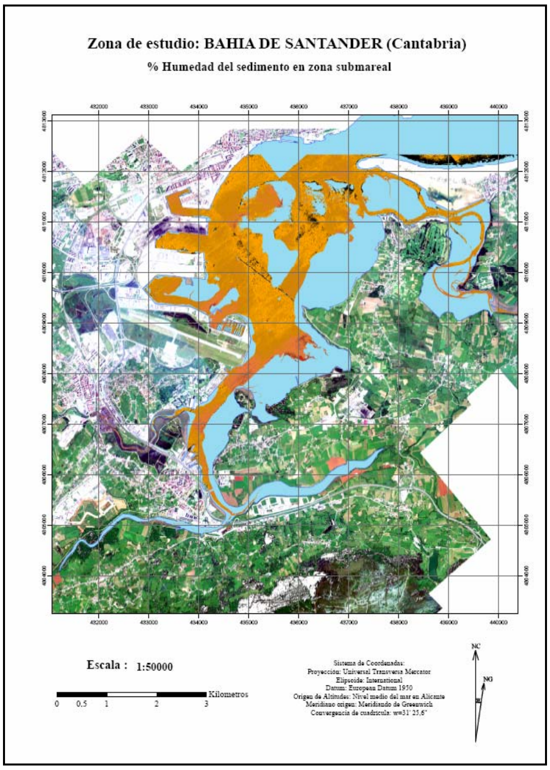

Figure 7.- Result of the B36 adjust and % humidity in the intertidal area.

The intertidal area is adjusted in the same way than the subtidal area for whom a different expression will be obtained and whose result is shown in figure 7.

The spectral responses on each one of the previous cases are shown in figure 8 in the way that different maximums are observed. In later analysis phases it has been checked that they correspond to the signal corresponding to each one of the interest parameters.

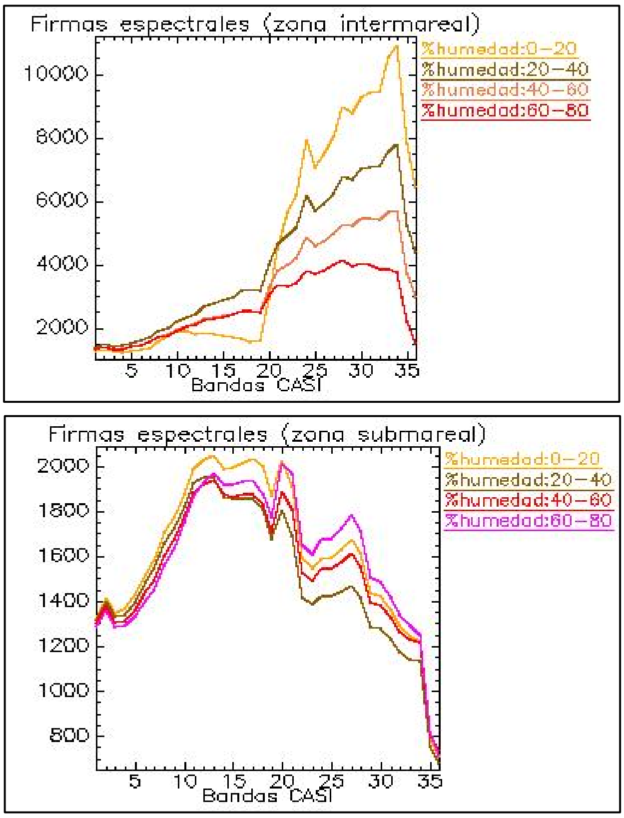

Figure 8.- Spectral signatures obtained when the intertidal area is adjusted.

Both proceedings have been applied to CASI imagery by using the Program “R: A Language and Environment for Statistical Computing” v. 2.0.0 and a robust statistics module implemented by Professor Alfonso García Pérez (UNED). All the routines needed to convert imagery into matrices and undo such process. This procedure has been implemented in IDL 6.0. The minimum volume ellipsoid estimator has been used as a covariance matrix. This estimator reaches a breaking point close to 0.5, since it has less efficacy than the one of least determinant of the covariance matrix but it has higher breaking point.

Last the validation phase for the results has been made by using a new validation data set so new chemical analysis of each of the parameters are needed.

4 Conclusion

Robust techniques have performed better results both in the calibration and validation phases than the classical methods.

To be able to develop these types of studies, a coordinated multi-disciplinary work of all the interested parts is needed, since field spectro-radiometer and the chemical group must be sampling the study area while the airborne sensor is flying to capture imagery.

Obtained results conclude that spectral analysis of imagery ease by this sensor is an effective and viable alternative that cheapen the sampling, analysis and interpolation processes; being able to extend the results to the whole study area providing at the same time more precise results.

5 Future Work

Once the results have been analysed, different lines of work pretty interesting arise. The first one consists of applying a new atmospheric correction algorithm to tune imagery even more.

Future experiences will integrate Incident Lightness Sensor (ILS) data, field-spectrometer measurements, modelling of the atmospheric effects when flight will be made and the Inherent Optical properties [16] of water.

New robust techniques as bootstrap and new correlation techniques as Huber, least squares and winsorized methods.

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